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Exploring the Dynamic and Spillover Effects of Renewable Energy, Energy Consumption, and Financial Growth on SDG 13: Evidence from India and China

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ABSTRACT

Climate change represents a critical global challenge, propelled by increasing greenhouse gas emissions, industrial growth, and reliance on fossil fuels. The United Nations' Sustainable Development Goal (SDG) 13 underscores the imperative for immediate climate action and sustainable energy policies. This study seeks to analyze the influence of energy consumption, renewable energy transition, and financial development in India and China on climate change mitigation, in accordance with Sustainable Development Goal (SDG) 13. The energy policies and financial mechanisms of the two largest emerging economies and carbon emitters are pivotal to global sustainability. The primary research question of this study is, how do India's and China's energy sectors and financial development influence climate change mitigation efforts? The findings reveal that despite advancements in renewable energy, both nations continue to struggle with high carbon emissions and environmental degradation. China's substantial investments in clean energy and financial instruments, including green bonds, have facilitated emission reductions, while India encounters infrastructural and financial limitations despite its ambitious sustainability objectives. The study underscores the necessity of integrating financial development with sustainable energy initiatives to reduce environmental harm. By evaluating the environmental consequences of energy policies, this research contributes to the broader discourse on sustainability and the role of major economies in global climate mitigation efforts.

Keywords: Climate Change Mitigation, Renewable Energy Transition, Financial Development, Sustainable Development Goal 13, China, India
JEL Classifications: Q56, O13, F65, Q01

1. INTRODUCTION

Climate change and global warming have turned out to be our era's most prominent environmental concern. Increasing emissions of greenhouse gases, reliance on fossil fuels, industrialization, and urbanization have intensified the climate crisis. Along these lines, the United Nations' Sustainable Development Goal (SDG) 13, "Climate Action," calls for states to take practical steps against climate change and devise sustainable energy policies. High-consumption energy nations with rapidly expanding economies have a fundamental role in slowing worldwide carbon emissions. This study aims to analyze how the energy sectors of India and China, along with their stages of financial development, influence efforts to counteract climate change in accordance with SDG 13.

India and China are two of the world's largest energy consumers and carbon producers. Industrial production, economic growth, and population have exponentially fueled the energy demand of both nations. Though fossil fuel-based energy systems remain the dominant source of carbon emissions, transitioning to renewable energy is essential for sustainable development and environmental protection. In this case, India's and China's renewable energy policy, energy investment, and degree of financial development are key to determining their success in curbing climate change. China controls 14.84% of the global economy. It is the largest emitter of CO_2 and, particularly in terms of fossil fuels, the largest importer of energy, consuming approximately 37% of the world's energy (Khan et al., 2020; IRENA, 2021). India is the third-largest producer of greenhouse gases globally. India's total CO_2 emissions increased by 3.9% from 1.6 Gt in 2009 to 2.6 Gt in 2019 (Andrew, 2020). By 2030, India's CO_2 emissions will reach as high as 4,766,584 kt. In 2025, it is anticipated that India's annual total CO_2 emissions will be approximately 3.89 million kt. India plans to reduce emissions by 33-35% below 2005 levels by 2030 (Ali et al., 2023).

Table 1 outlines the national and international initiatives and collaborations that China and India have implemented or aimed for in the post-2000 period regarding climate change. The content of this table is crucial for the empirical tests to be conducted in this study. The trend analysis of the relationships among the variables provides insights into the future. Upon our return to the discussion, it is observed that China and India have made positive efforts regarding climate change over the previous two decades. Nevertheless, due to the larger scale and impact of the Chinese economy compared to India, it appears that while China causes more environmental damage to support its economic growth, it also has a greater ability to invest in new technologies and reduce its negative contribution to climate change alongside its developing economy.

In the literature, the examination of the link between financial development and energy consumption started with a macroeconomic emphasis and then moved to their subcategories. The emphasis has transitioned from economic growth to demand and the influence of financial development on demand. This alteration in the structural thinking is evidenced by empirical studies. The influence of financial development on economic agents is examined via various avenues. Cheap credit's availability has increased demand and caused stock markets to grow and mature, lowered investment costs, more investments, a shift in the business sector toward energy-intensive investments, and an improvement of the trust environment. Financial development that supports effective energy generation also allows a reduction in energy consumption. Numerous empirical studies on the one-way and two-way relationships between financial development and energy consumption clearly demonstrate this correlation (Xulan et al., 2022). Financial development is essential in guiding energy investments, financing renewable energy projects, and creating green financing instruments. India and China's financial development levels regarding green bonds, sustainable banking, and financial policies for a low-carbon economy transition are measured. In well-developed financial systems, investing more in clean energy projects and encouraging environmentally friendly investments is possible. At this point, the role of financial development in addressing climate change and its influence on sustainable energy policies constitutes one of the main research topics of the study.

This study examines the role of India's and China's energy use, renewable energy transformation, and degrees of financial development in climate change mitigation via SDG 13. By reviewing the policies we have implemented in their energy and economic sectors, this research hopes to contribute to the knowledge of sustainable energy transformation. Therefore, it will be significant to comprehend the role of major economies like India and China in climate change mitigation within global sustainability policies.

2. LITERATURE REVIEW

The role of green energy distribution in improving energy efficiency and reducing emissions has become an important research focus in the literature. Various studies have recently evaluated the relationship between renewable energy and CO_2 emissions. While some studies have found a positive relationship between renewable energy and carbon emissions, the consensus in the literature suggests a negative relationship between renewable energy and carbon emissions (Koengkan, 2018; Balsalobre-Lorente et al., 2018; Asongu et al., 2019; Bekun et al., 2019; Kahia et al., 2021; Busu and Nedelcu, 2021; Hawitibo and Tenaw, 2022). Prevalent research has inadequately examined the combined impacts of energy efficiency and renewable energy on emission reductions in relation to the Sustainable Development Goals. To address this gap, our study examines the impact of energy consumption, the shift to renewable energy, and financial development on SDG 13 (Climate Action) in the cases of India and China. While existing research generally addresses the relationship between energy consumption, financial growth, and CO_2 emissions, a limited number of studies specifically analyze how these variables interact within the context of SDG 13 (Ali et al., 2023; Song et al., 2025; He et al., 2025; Chen et al., 2025; Tenaw, 2025; Cao et al., 2025).

Ali et al. (2023) employed advanced panel methodologies to investigate the heterogeneous effects of energy resources and financial development on environmental sustainability in E7 countries from 2000 to 2020. The study's findings suggest that high financial development, rapid economic growth, and the expanding use of non-renewable energy sources necessitate a policy framework aligned with the Sustainable Development Goals (SDGs). Song et al. (2025) analyzed China's provincial-level SDG performance from 2006 to 2021. Although China had made progress in SDG implementation by 2015, regressions were observed in SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water), and SDG 15 (life on land), highlighting the need to strengthen regional sustainability policies. He et al. (2025) analyze the linkages between climate change mitigation pathways and the Sustainable Development Goals (SDGs) using the IPAC model, which assesses China's energy and environmental policies, demonstrating that fossil fuel consumption will decrease by 65% by 2060, while renewable and nuclear energy will increase rapidly. Chen et al. (2025) examined the impact of Chinese firms' contributions to the UN Sustainable Development Goals (SDGs) on stock returns. It was found that firms with high SDG performance experienced adverse effects on excess returns and, despite alleviating financial constraints, did not significantly increase their market value. Tenaw (2025) examined the combined effects of green energy (SDG-7.2), energy efficiency (SDG-7.3), and economic productivity (SDG-8.2) in reducing energy-driven greenhouse gas emissions using annual data from 161 countries between 1995 and 2019. The study found that green energy and energy efficiency contribute to reducing emissions. At the same time, economic productivity increases emissions, and the synergistic interaction between the SDG-7 targets weakens the emission-increasing effect of SDG-8.2. Cao et al. (2025) examined the impact of public expenditures on R&D related to green energy and technological innovation in G7 countries on renewable energy shares and greenhouse gas emissions. The study emphasizes the importance of government intervention in green energy, innovation, and global trade in increasing renewable energy supply and reducing emissions in the long term. These findings contribute to formulating policies that will help G7 countries achieve SDG-7 (ecological sustainability) and SDG-13 (renewable energy transition).

In recent years, with the growing significance of the Sustainable Development Goals (SDGs), scholars have increasingly investigated how uncertainty factors such as economic, political, and geopolitical risks affect development targets. Nevertheless, the literature reveals that the specific impacts of climate policy uncertainty (CPU), economic policy uncertainty (EPU), and energy uncertainty ındex (EUI) on the SDGs have received relatively little attention (Nguyen et al., 2023; Ahmad et al., 2024; Bakhsh et al., 2024; Demirkale and Duran, 2024; Demirkale and Ojaghlou, 2025). Recent empirical studies underline the growing academic interest in the intersection of uncertainty indicators and sustainable development goals. Collectively, these studies suggest that while financial development and green finance policies tend to support SDG progress, rising geopolitical risks can undermine sustainability efforts particularly in areas such as clean energy (SDG 7) and climate action (SDG 13). The literature emphasizes that managing uncertainty especially geopolitical and climate-related risks has become crucial for achieving long-term sustainability objectives across various country groups, including OECD and developing nations.

This study aims to fill a significant lacuna in the literature by examining the impact of energy consumption, the shift toward renewable energy, and financial development on SDG 13 (Climate Action) for India and China. While numerous research studies have examined the relationship between energy consumption, financial development, and CO_2 emissions, very little research has focused on analyzing these variables in relation to SDG 13 for these two countries. In particular, empirical research that simultaneously quantifies the role of financial development in influencing investments in renewable energy and emission reductions and the role of renewable consumption in contributing to SDG 13 targets is limited. Such variables are addressed in most studies in a one-dimensional way. In contrast, first and foremost, the present work utilizes a holistic framework based on ARDL and BEKK models to investigate both short- and long-term dynamics. This approach facilitates a comprehensive analysis of the interactions among variables over various time horizons. By integrating both models, the study seeks to provide deeper insights into the fundamental relationships and their implications for policy and decision-making. Second, the comparative study of two rapidly emerging economies, China and India, regarding their progress toward sustainable development goals, represents an area that is not well-developed in current research. This study seeks to provide significant policy guidance to policymakers and scholars by evaluating the impacts of energy and financial development strategies on SDG 13. The discussion will not only highlight the successes and challenges faced by each country but will also offer insights into best practices that can be adopted or adapted by other nations striving to achieve similar sustainability targets. Ultimately, the findings of this research could help bridge the gap in understanding how various economic models might effectively contribute to global climate action.

In particular, we seek to answer the following research questions: (1) How does the consumption of renewable energy, aggregate energy consumption, CO_2 emissions, and financial development influence the SDG 13 (Climate Action) targets in India and China? (2) How does renewable energy consumption contribute to achieving SDG 13 targets in India and China? (3) What is the dynamic link between aggregate energy consumption and SDG 13 in India and China? (4) How do CO_2 emissions influence achieving SDG 13 targets? (5) What is the link between the financial development ındex and SDG 13 in India and China? (6) Using ARDL and BEKK methods, what are the short-run and long-run relationships among renewable energy consumption, total energy consumption, CO_2 emissions, financial development, and SDG 13 in India and China?

The hypotheses that can be developed in the context of this study can be formulated as follows:

H_1: Renewable energy consumption positively contributes to SDG 13 in India and China.

H_2: Total energy consumption negatively contributes to SDG 13 in India and China.

H_3: CO_2 emissions are a barrier to the achievement of SDG 13 targets in India and China.

H_4: The Financial Development Index is an enabler of the achievement of SDG 13 in India and China.

H_5: ARDL and BEKK models statistically and significantly reveal the short-run and long-run relationships between renewable energy consumption, total energy consumption, CO_2 emissions, financial development, and SDG 13 in India and China.

Moreover, by analyzing these relationships, we can identify effective strategies that promote sustainable energy practices while fostering financial development. This insight will be vital for both countries as they strive to meet global climate commitments and enhance their energy security. As they navigate this complex landscape, collaboration between governments, businesses, and communities will be essential.

3. MODEL SPECIFICATIONS AND DATA

The ARDL model, introduced by Pesaran et al. (1996), Pesaran and Shin (1999), and Pesaran et al. (2001), is designed to examine the cointegration relationship among variables in datasets with limited observations. Unlike traditional cointegration tests, such as those proposed by Engle and Granger (1987), Johansen (1988), and Johansen and Juselius (1990), which necessitate that variables be integrated of the same order, the ARDL bounds test can be applied regardless of the integration levels of the variables. The ARDL methodology is also noted for its robustness in small sample sizes (Narayan and Smyth, 2005). The hypotheses for the ARDL bounds test should be formulated as follows (Pesaran et al., 2001);

H_0: $\pi_{yy} = 0$, $\pi_{yxx} = 0$ (There is no cointegration)

H_1: $\pi_{yy} \neq 0$, $\pi_{yxx} \neq 0$ (There is cointegration)

The adapted forms of the models used in the study according to ARDL are shown as Equal 1 and Equal 2:

$$IndiaSDG13_t = \alpha_0 + \beta_1 LCO2_1 + \beta_2 LFDI_2 + \beta_3 LREC_3 + \beta_4 LTEC_4 + \varepsilon_t \quad (1)$$

$$ChinaSDG13_t = \alpha_0 + \beta_1 LCO2_1 + \beta_2 LFDI_2 + \beta_3 LREC_3 + \beta_4 LTEC_4 + \varepsilon_t \quad (2)$$

The BEKK model was proposed by Engle and Kroner (1995) and is an extension of the GARCH model used to model the time-varying variance-covariance matrix. This model is widely used, particularly for analyzing volatility spillovers between financial assets. First, the results obtained with the traditional BEKK model proposed by Engle and Kroner (1995) were compared. The average equation is expressed as follows:

$$H_t = CC' + A'u_{t-1}u'_{t-1}A + B'H_{t-1}B \quad (3)$$

Where C, the A' s and the B' s matrices are of dimension while C is upper triangular.

The bivariate BEKK-GARCH (1,1) system is defined as:

$$\begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,2} \end{bmatrix} = \begin{bmatrix} C_{11,t} & C_{12,t} \\ C_{21,t} & C_{22,2} \end{bmatrix}' \begin{bmatrix} C_{11,t} & C_{12,t} \\ C_{21,t} & C_{22,t} \end{bmatrix} +$$

$$\begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix}' \begin{bmatrix} \varepsilon^2_{1,t-1} & \varepsilon_{1,t-1},\varepsilon_{2,t-1} \\ \varepsilon_{2,t-1},\varepsilon_{1,t-1} & \varepsilon^2_{2,t-1} \end{bmatrix} \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix} +$$

$$\begin{bmatrix} \beta_{11,t} & \beta_{12,t} \\ \beta_{21,t} & \beta_{22,t} \end{bmatrix}' \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} \beta_{11,t} & \beta_{12,t} \\ \beta_{21,t} & \beta_{22,t} \end{bmatrix}$$

Where $h_{11,t}$ = variance of the change rate returns,
$h_{12,t}$ and $h_{21,t}$ = the covariance of two returns.
$h_{22,t}$ = variance of return.
C= a positive definite H matrix can be obtained by multiplying the upper triangular matrix C, which contains constants.
A = historical squared errors (*healthcare professionals*$_{t-1}$) affects the H_t.
B = impact of past conditional variance (covariances) (H_{t-1}) on current H_t and it shows spillover effect.
α and β are elements of matrices A and B, respectively.

The study explores the impact of the energy sector and financial development on Sustainable Development Goal (SDG) 13: Climate Action in India and China. By examining the relationships between energy consumption, the shift to renewable energy, and the level of financial development in the two countries, this study aims to assess their contributions to climate change mitigation and inform the development of sustainable energy policies. The ARDL and BEKK analyses will also reveal the long-run and dynamic relationships among the variables, which will assist in identifying the most appropriate policy instruments for addressing climate change.

The use of renewable energy is a vital element in promoting sustainable development by reducing carbon emissions. For countries with rapidly increasing energy demands, such as China and India, greater investment in renewable energy is essential to mitigate climate change. It is crucial to acknowledge the impact of this variable on SDG 13 when measuring the transition toward low-carbon economies in these nations. While energy consumption is a key driver of economic development, the manner in which energy resources are utilized significantly influences climate change. Fossil fuel-based energy consumption produces higher carbon emissions, whereas a renewable energy-based system can effectively minimize them. Consequently, the relationship between total energy use and SDG 13 is instrumental in evaluating energy policies from a sustainability perspective. Carbon emissions are among the major contributors to climate change, and two of the largest emitters, India and China, play a critical role in shaping global climate policy. Emission trends in these countries are vital for understanding and formulating effective climate policies. In this study, the interaction between energy consumption and financial development in relation to CO_2 emissions is analyzed and assessed against their contribution to SDG 13. Financial development would promote sustainability in the environmental dimension through increased investments in projects focused on sustainable energy. Well-developed financial markets and resilient financial institutions will facilitate investments in renewable energy, thereby accelerating the transition to a low-carbon economy. An analysis of financial development's role in achieving SDG 13 in large emerging market economies such as India and China would provide valuable insights for policy-makers. The study's time frame spans from 2000 to 2021, utilizing annual data, as the dataset for the Financial Development Index (FDI) is available only up to 2021. Table 2 presents descriptive information about the variables used in the analysis.

4. ECONOMETRIC FINDINGS AND DISCUSSION

4.1. India

The results of the unit root tests are presented in Table 3. As shown in Table 3, the series are stationary at level except for the LREC variable, and none of the series exhibit stationarity at the I(2) level. This allows for the application of ARDL and BEKK models.

Table 1: China and India's climate actions chronology

China's climate actions chronology			
Year	**National**	**Year**	**International**
2006	11th 5-year plan targets 20% energy intensity reduction.	2002	Joined UNFCCC
2007	First national climate change program published.	2005	Ratified Kyoto Protocol
2009	Copenhagen Climate Summit commits to 40-45% carbon intensity reduction by 2020.	2009	At COP15 Committed to reducing carbon intensity by 40-45% by 2020.
2011	Prioritized low-carbon development in the 12th 5-Year Plan.	2015	Joined the Paris Agreement in 2015, aiming for peak carbon emissions by 2030.
2013	Launched pilot emission trading systems	2016	Ratified the Paris Agreement at the G20 Summit in 2016.
2015	Committed to peak carbon emissions by 2030.	2017	Joined the International Solar Alliance, supporting renewable energy access for developing countries.
2017	Launched National Emission Trading System	2018	Supported Global Carbon Markets at COP24, pledged to develop Emission Trading System.
2018	Becomes world's largest renewable energy investor	2019	Increased green finance projects under the Belt and Road Initiative
2020	Defined by Xi Jinping as the net greenhouse gas emissions by 2060.	2020	President Xi Jinping announces net-zero emissions target by 2060.
2021	Adopted policies to limit use of fossil fuels in the 14th 5-year Plan.	2021	China stops financing coal-based energy projects at COP26.
2022	Achieved 40% reduction in global carbon emissions	2022	Committed to increasing green development funds for developing countries at COP27.
2023	Led 68 million dollars in clean energy investment, focusing on electric energy production.	2023	Expanded green bond market with World Bank and Global Green Finance Initiative.
2025	Aimed to reduce carbon emissions by 2025.	2024	Expected peak carbon emissions in 2025, leading Paris Agreement targets.
India's climate actions chronology			
Year	**National**	**Year**	**International**
2003	Implementation of electricity act 2003 prioritizing renewable energy.	2002	Ratification of UNFCCC
2008	Announcement of national action plan on climate change (NAPCC)	2009	Committed to developing low-carbon growth strategy at COP 15
2010	Implementation of state action plans on climate change (SAPCCs)	2009	Actively participated in clean development mechanism projects.
2012	Incentives for renewable energy under national electricity plan 2012.	2012	Called for climate financing for developing countries at COP17.
2015	Setting renewable energy targets for India: 175 GW by 2022.	2015	Accepted the Paris climate agreement and committed to reducing emission intensity by 33-35% by 2030.
2016	Bureau of energy efficiency (BEE) issued regulations promoting energy savings in industry and buildings	2015	India and France founded the International Solar Alliance to promote solar energy.
2017	Inauguration of Kurnool Solar Park, world's largest.	2017	Joined the Zero Emission Vehicle Initiative.
2019	Announcement of Single-Use Plastic Ban	2019	Announced goals to increase renewable energy capacity and green financing at the UN Climate Action Summit.
2022	Launched National Hydrogen Mission with incentives for green hydrogen production.	2021	Announced to achieve net zero emissions by 2070 at COP26 Summit.
2023	Reached 68 billion dollars in clean energy investments	2022	India and the USA launched the Clean Energy Partnership.
		2023	Highlighted the agenda of "Green Development, Climate Finance, and Climate Justice for the Global South."

Source: Compiled by the authors

According to the ARDL (2, 0, 2, 1, 2) model established for Equation 1, the calculated F-statistic value (6.53) exceeds the upper bound critical value at the 1% significance level. Therefore, the H_1 hypothesis is accepted, indicating the presence of cointegration among the variables. This result signifies a significant long-term relationship among the variables in the model (Table 11).

ECM coefficient of Eq.1 is −1.51. Within the scope of the error correction model (ECM), the ECM coefficient of −1.51[1] indicate the existence of long-term equilibrium and that the model can return to this equilibrium. In the bounds test results, the F-Bounds test statistic was determined as 6.53, which exceeded the critical values of I(0) and I(1) at both asymptotic and finite sample levels. This demonstrates a strong long-term relationship between the dependent and independent variables. In accordance with these findings, the long-term effects of renewable energy consumption, total energy consumption, CO_2 emissions, and financial development on sustainable development goals can be understood. Specifically, policymakers should take into account the supportive role of financial development in climate action.

ARDL bounds test results evaluate the long-run relationship between the dependent variable of "Sustainable Development

1 In the simple case of an ARDL(1,1) model: $Y = \alpha+\beta Yt-1)+\gamma X+\delta Xt-1$ the coefficient of the ECM term in the error correction representation is given by $-(1-\beta)$. In this case If $\beta < 0$, then $-(1-\beta)$ can be less than −1 but not <−2. If $\beta > 0$, the coefficient cannot go below −1. For further details, refer to the derivation from equation (21.168) in the Microfit 5 manual, authored by Bahram Pesaran and M. Hashem Pesaran.

Goal 13: Climate Action" (SDG13) and independent variables, including renewable energy consumption (REC), total energy consumption (TEC), CO2 emissions (CO_2), and financial development (FDI). According to the long-run coefficients, the coefficient of FDI is −2.57, which is both negative and significant (P: 0.0405), suggesting that financial development can align with climate action.

Table 2: Definitions, codes, and sources of variables

Variable	Symbol	Source
Sustainable Development Goals 13: Climate Action	SDG13	Sachs et al., 2024.
Renewable Energy Consumption	REC	World Bank
Total energy consumption	TEC	World Bank
CO_2 Emissions	CO_2	World Bank
Financial Development Index	FDI	IMF

Table 3: Unit root test[2]

Variables	ADF[3]		PP[4]	
	Intercept	Intercept and trend	Intercept	Intercept and trend
LSDG13	−3.82	−3.64	−4.78	−4.62
LCO_2	−3.86	−1.79	−3.86	−4.11
LFDI	−4.45	−4.35	−4.45	−4.35
LREC	−5.25	−5.91	−5.19	−5.91
LTEC	−3.78	−3.07	−3.76	−3.97

[2]L shows natural logarithms of all series have been taken.
[3]Based on Schwartz Info Criterion
[4]Based on Bartlett Kernel

Table 4: Bounds test for ARDL model

Test statistic	Value	Signif. (%)	I (0)	I (1)
F-statistic	6.53	10	2.2	3.09
		5	2.56	3.49

Table 5: The hypothesis concerning SDG 13 for India

Variable	Coefficient	t-Statistic	Probability
CO_2	−0.001718	−1.488353	0.1750
FDI	−2.578527	−2.441801	0.0405
REC	−0.005306	−0.534796	0.6073
TEC	−0.001600	−0.527904	0.6119
C	100.8303	142.9935	0.0000
CointEq (−1)*	−1.518775	−7.983378	0.0000
Diagnostic test results			
Breusch-Godfrey LM Test		0.0403	
Heteroskedasticity Test: Breusch-Pagan-Godfrey		0.1799	
Ramsey RESET test		0.8356	
Cusum of squares		Stable	
Cusum of squares		Stable	

*EC=SDG13 − (−0.0017*CO_2_EMISSIONS−2.5785*FDI−0.0053*REC−0.0016*TEC+100.8303)

The result of BEKK model for India are summarised in Table 6;

Table 6 presents the results of the BEKK model for India. The coefficients and standard errors in the mean equation were subjected to statistical significance tests, as indicated by the results. The off-diagonal elements of matrices A and B provide insights into the volatility spillover effect. The statistically significant coefficients were concurrently examined to assess the model's efficacy. Despite certain components of the C, A, and B matrices lacking statistical significance, the model's overall validity was evaluated using the log-likelihood value. The table below displays the statistically significant coefficients of the C matrix.

Table 7 displays the statistically significant coefficients of the C matrix from the BEKK model for India. Although coefficients of the C matrix are not economically significant, the coefficients C(1,1), C(2,1), C(2,2), C(3,1), C(3,2), C(4,2), C(5,1), and C(5,2) are statistically significant ($P < 0.05$). This indicates a substantial contribution to the fixed initial variance in the system.

As mentioned above, the coefficient of diagonals show that each conditional variance is due to its lagged shocks. Meanwhile, the off-diagonal elements of the A matrix reflect past diagonal innovations. Table 8 shows statistically significant coefficients of the A matrix.

Table 8 presents the statistically significant coefficients of the A matrix from the BEKK model for India. The effect of SDG13 on itself A(1,1) is positive and quite strong. The coefficient shows that a one-unit increase in SDG13 will result in approximately a 139.88% increase in SDG13 in the next period. Considering this coefficient's high t-statistic and significance level (much smaller than 0.01), the result is statistically highly significant. This demonstrates the dependence of SDG13 on its past values. The effect of TEC on SDG13 A(1,2) is negative and significant. REC effect on SDG13 A(1,3) is positive and essential. CO_2 effect on SDG13 A(1,5) is negative and enormously important. A one-unit increase in CO_2 creates a decrease of about 92% in SDG13.

The effect of SDG13 on TEC A (2,1) is positive and significant. The REC effect on TEC A(2,3) is positive and significant. CO_2 effect on TEC A(2,5) is negative and strongly significant. A one-unit increase in CO_2 creates a decrease of about 20% in TEC. The effect of SDG13 on REC A(3,1) is positive and significant. TEC effect on REC A(3,2) is negative and significant. CO_2 effect on REC A(3,5) is negative and strongly significant. The effect of SDG13 on FDI A (4,1) is negative and significant. TEC effect on FDI A(4,2) is positive and significant. REC effect on FDI A(4,3) is negative and strongly significant. CO_2 effect on FDI A(4,5) is positive and strongly significant. The effect of TEC on CO_2 A(5,2) is negative and significant. REC effect on CO_2 A(5,3) is positive and significant. This may require more detailed analysis to understand the relationship between uncertainty indices and SDG13. In case of spillover effect (B(İ,İ)), are summarised in Table 9:

The coefficients in matrix B reveal the direct and indirect effects among economic variables, namely "spillover" effects. These effects enhance our understanding of how one variable's spillover or contagion mechanisms influence others. Diagonal Coefficients (B(i, i)) and Autoregressive Dynamics indicate that diagonal coefficients express the relationships of variables with their past values.

Table 6: The results of the BEKK model for India

Variable	Coeff	Standard error	T-statistics	Signif
Mean (SDG13)	96.294852	0.081132	1186.889	0.0000
Mean (TEC)	565.971339	13.099129	43.20679	0.0000
Mean (REC)	41.735789	0.424181	98.39138	0.0000
Mean (FDI)	0.442283	0.000639	692.1661	0.0000
Mean (CO_2_E)	1310.48149	36.75095	35.65844	0.0000
C (1,1)	0.341985	0.025029	13.66347	0.0000
C (2,1)	−53.752767	3.987533	−13.48021	0.0000
C (2,2)	2.499955	0.338018	7.39593	0.0000
C (3,1)	1.763724	0.128939	13.67874	0.0000
C (3,2)	−0.056885	0.01225	−4.64348	0.00000343
C (3,3)	0.00018	0.007206	0.025	0.98005476
C (4,1)	0.000335	0.000335	1.00125	0.3167044
C (4,2)	−0.001009	0.000309	−3.26629	0.00108967
C (4,3)	0.00002	0.000304	0.06465	0.94845169
C (4,4)	0.000006	0.000248	0.02477	0.98023864
C (5,1)	−152.064594	11.289623	−13.46941	0.0000
C (5,2)	9.101068	1.240029	7.3394	0.0000
C (5,3)	−0.076761	0.460472	−0.1667	0.86760528
C (5,4)	0.031382	0.321758	0.09753	0.92230389
C (5,5)	−0.020385	0.348366	−0.05852	0.9533368
A (1,1)	1.398813	0.079413	17.61451	0.0000
A (1,2)	−37.695035	2.677161	−14.08023	0.0000
A (1,3)	1.186685	0.258028	4.59905	0.00000424
A (1,4)	−0.000296	0.006818	−0.0434	0.96538174
A (1,5)	−92.642234	10.107471	−9.16572	0.0000
A (2,1)	0.002493	0.000479	5.207	0.00000019
A (2,2)	0.890169	0.044705	19.91225	0.0000
A (2,3)	0.011364	0.002477	4.58703	0.0000045
A (2,4)	−0.000004	0.000063	−0.06636	0.947088
A (2,5)	−0.201015	0.039578	−5.07892	0.00000038
A (3,1)	0.021186	0.004854	4.36475	0.00001273
A (3,2)	−2.796453	0.811715	−3.44512	0.00057081
A (3,3)	1.413046	0.085025	16.61913	0.0000
A (3,4)	0.000239	0.0008	0.29882	0.76507479
A (3,5)	−10.531499	2.251035	−4.67851	0.00000289
A (4,1)	−3.214849	0.417271	−7.70446	0.0000
A (4,2)	451.816046	67.908231	6.65333	0.0000
A (4,3)	−14.160382	2.234936	−6.33592	0.0000
A (4,4)	1.27866	0.073302	17.44367	0.0000
A (4,5)	1126.798997	199.751132	5.64101	0.00000002
A (5,1)	−0.000058	0.000122	−0.4745	0.63514019
A (5,2)	−0.027503	0.004309	−6.38225	0.0000
A (5,3)	0.001814	0.000523	3.46957	0.00052129
A (5,4)	0.000004	0.000015	0.23156	0.81687634
A (5,5)	0.880526	0.037267	23.6275	0.0000
B (1,1)	−0.089628	0.048816	−1.83604	0.06635176
B (1,2)	46.129818	3.800953	12.13638	0.0000
B (1,3)	−0.663658	0.209394	−3.16942	0.00152746
B (1,4)	−0.025623	0.004219	−6.0726	0.0000
B (1,5)	90.168093	10.274493	8.77592	0.0000
B (2,1)	−0.001547	0.000368	−4.20857	0.0000257
B (2,2)	0.318386	0.030409	10.47003	0.0000
B (2,3)	−0.005084	0.001887	−2.69382	0.00706389
B (2,4)	−0.000292	0.000046	−6.30406	0.0000
B (2,5)	−0.670529	0.061501	−10.90271	0.0000
B (3,1)	0.010857	0.00661	1.64262	0.10046076
B (3,2)	−0.449266	1.042731	−0.43085	0.66657393
B (3,3)	−0.21716	0.045595	−4.7628	0.00000191

(Contd...)

Table 6: *(Continued)*

Variable	Coeff	Standard error	T-statistics	Signif
B (3,4)	0.005934	0.000538	11.02269	0.0000
B (3,5)	−5.008203	2.810458	−1.78198	0.07569074
B (4,1)	1.621057	1.019698	1.58974	0.11189295
B (4,2)	−219.405018	164.922956	−1.33035	0.18340345
B (4,3)	1.750197	5.265702	0.33238	0.73960474
B (4,4)	−0.147323	0.04248	−3.46803	0.00052429
B (4,5)	−371.350768	459.458328	−0.80824	0.41895473
B (5,1)	0.000719	0.000077	9.29817	0.0000
B (5,2)	−0.051228	0.008817	−5.80991	0.00000001
B (5,3)	−0.001102	0.000613	−1.79876	0.07205655
B (5,4)	0.000112	0.000011	9.83007	0.0000
B (5,5)	0.290466	0.031023	9.36301	0.0000

Table 7: Statistically significant coefficient of C matrix of BEKK model for India

Variable	Coeff	Standard error	T-statistics	Signif
C (1,1)	0.341985	0.025029	13.66347	0.0000
C (2,1)	−53.752767	3.987533	−13.48021	0.0000
C (2,2)	2.499955	0.338018	7.39593	0.0000
C (3,1)	1.763724	0.128939	13.67874	0.0000
C (3,2)	−0.056885	0.01225	−4.64348	0.00000343
C (4,2)	−0.001009	0.000309	−3.26629	0.00108967
C (5,1)	−152.064594	11.289623	−13.46941	0.0000
C (5,2)	9.101068	1.240029	7.3394	0.0000

Table 8: Statistically significant coefficient of A matrix of BEKK model for India

Variable	Coeff	Standard error	T-statistics	Signif
A (1,1)	1.398813	0.079413	17.61451	0.0000
A (1,2)	−37.695035	2.677161	−14.08023	0.0000
A (1,3)	1.186685	0.258028	4.59905	0.00000424
A (1,5)	−0.926422	10.107471	−9.16572	0.0000
A (2,1)	0.002493	0.000479	5.207	0.00000019
A (2,2)	0.890169	0.044705	19.91225	0.0000
A (2,3)	0.011364	0.002477	4.58703	0.0000045
A (2,5)	−0.201015	0.039578	−5.07892	0.00000038
A (3,1)	0.021186	0.004854	4.36475	0.00001273
A (3,2)	−2.796453	0.811715	−3.44512	0.00057081
A (3,3)	1.413046	0.085025	16.61913	0.0000
A (3,5)	−10.531499	2.251035	−4.67851	0.00000289
A (4,1)	−3.214849	0.417271	−7.70446	0.0000
A (4,2)	451.816046	67.908231	6.65333	0.0000
A (4,3)	−14.160382	2.234936	−6.33592	0.0000
A (4,4)	1.27866	0.073302	17.44367	0.0000
A (4,5)	1126.798997	199.751132	5.64101	0.00000002
A (5,2)	−0.027503	0.004309	−6.38225	0.0000
A (5,3)	0.001814	0.000523	3.46957	0.00052129
A (5,5)	0.880526	0.037267	23.6275	0.0000

B(1,1) = −0.089628, B(3,3) = −0.21716, and B(4,4) = −0.147323 show that India's SDG13, TEC, and FDI are highly negatively affected by its past values. This indicates that previous values of India's SDG13, TEC, and FDI have a considerable effect on future values, but the effect is detrimental. In other words, past increases in India's SDG13, TEC, and FDI may lead to decreases in their future values. This suggests that the impact of sustainability policies related to SDG13 in India may diminish over time or that

Table 9: Spillover effect (statistically significant coefficient of B Matrix of BEKK Model for India)

Variable	Coeff	Standard error	T-statistics	Signif
B (1,1)	−0.089628	0.048816	−1.83604	0.06635176
B (1,2)	46.129818	3.800953	12.13638	0.0000
B (1,3)	−0.663658	0.209394	−3.16942	0.00152746
B (1,4)	−0.025623	0.004219	−6.0726	0.0000
B (1,5)	90.168093	10.274493	8.77592	0.0000
B (2,1)	−0.001547	0.000368	−4.20857	0.0000257
B (2,2)	0.318386	0.030409	10.47003	0.0000
B (2,3)	−0.005084	0.001887	−2.69382	0.00706389
B (2,4)	−0.000292	0.000046	−6.30406	0.0000
B (2,5)	−0.670529	0.061501	−10.90271	0.0000
B (3,3)	−0.21716	0.045595	−4.7628	0.00000191
B (3,4)	0.005934	0.000538	11.02269	0.0000
B (3,5)	−5.008203	2.810458	−1.78198	0.07569074
B (4,4)	−0.147323	0.04248	−3.46803	0.00052429
B (5,1)	0.000719	0.000077	9.29817	0.0000
B (5,2)	−0.051228	0.008817	−5.80991	0.00000001
B (5,3)	−0.001102	0.000613	−1.79876	0.07205655
B (5,4)	0.000112	0.000011	9.83007	0.0000
B (5,5)	0.290466	0.031023	9.36301	0.0000

past conditions might negatively reflect future outcomes. B(2,2) = 0.318386 and B(5,5) = 0.290466 indicate that total energy consumption (TEC) and CO_2 emissions (CO_2) show moderate dependence on their past performances. The P = 0.0000 for both coefficients suggest that these effects are statistically significant and not due to random chance. Past values of TEC and CO_2 emissions significantly impact their future values. The findings suggest that historical performance is essential for forecasting future energy consumption and carbon emissions, while external factors may also influence these trends.

The coefficients B(1,2) = 46.129818, B(1,5) = 90.168093 (positive), B(1,3) = −0.663658, and B(1,4) = −0.025623 (negative) signify a substantial correlation between SDG 13 and total energy consumption (TEC), renewable energy consumption (REC), financial development index (FDI), and CO_2 emissions (CO_2). The statistically significant findings underscore a robust relationship between SDG 13 and these variables. The positive coefficients B(1,2) = 46.129818 and B(1,5) = 90.168093 suggest a positive relationship between SDG 13 and TEC and CO_2 emissions. This indicates that a rise in SDG 13 is associated with increased total energy consumption and CO_2 emissions. This points to the significant impact of sustainable development goals and environmental factors on energy consumption and carbon emissions. The negative coefficients B(1,3) = −0.663658 and B(1,4) = −0.025623 indicate an inverse link between SDG 13 and REC and FDI. This may imply that increases in SDG 13 could result in a reduction in renewable energy consumption and financial development. This suggests that more sustainable development policies adversely affect energy consumption and financial investments.

B(2,1) = −0.001547: A negative correlation exists between Total Energy Consumption (TEC) and Sustainable Development Goal 13 (SDG 13). B(2,3) = −0.005084: A negative correlation exists between total energy consumption (TEC) and renewable energy consumption (REC). This implies that a rise in total energy consumption may diminish renewable energy consumption, albeit to a minimal extent. B(2,4) = −0.000292: A negative correlation exists between total energy consumption (TEC) and the financial development ındex (FDI). This suggests that fluctuations in overall energy use may exert a negligible influence on financial development, and this effect is rather small. B(2,5) = −0.670529: A significant negative correlation exists between total energy consumption (TEC) and CO_2 emissions. This implies that a rise in energy consumption might substantially lower CO_2 emissions, suggesting that heightened energy use may lead to a large reduction in environmental impacts. This underscores the need of enhanced energy efficiency and modifications that result in reduced emissions. B(2,2) = 0.318386 signifies a favorable correlation between TEC (total energy consumption) and its historical values. This indicates that overall energy use is contingent upon prior levels, implying that historical consumption patterns influence future energy usage. This positive autocorrelation signifies a consistent trend in energy consumption, suggesting that rises in energy usage are likely to persist in the future.

B(3,3) = −0.21716 shows a negative relationship between renewable energy consumption (REC) and its historical values. Historical renewable energy consumption exerts a slight negative influence on future renewable energy consumption. A decline in historical renewable energy consumption may result in a sustained decrease in future consumption, indicating that previous trends impede the utilization of renewable energy. B(3,5) = −5.008203 indicates a stronger negative relationship between REC and CO_2 emissions. An increase in renewable energy consumption is associated with significantly reducing CO_2 emissions. This relationship supports the idea that increased use of renewable energy is linked to reduced environmental pollution and carbon emissions. B(3,4) = 0.005934: This positive value suggests a very weak relationship between renewable energy consumption (REC) and the financial development index (FDI). The small positive coefficient implies that changes in renewable energy consumption might impact financial development. However, this effect is minimal.

B(4,4) = −0.147323: This coefficient shows a negative relationship between Financial Development Index (FDI) and its past values. An increase in FDI may lead to a decrease in future FDI values based on past values. This indicates that sustainable development goals may not always align with past trends, and these trends could negatively affect future performance.

B(5,1) = 0.000719: This coefficient indicates a minimal positive relationship between CO_2 emissions and SDG 13. A slight increase in CO_2 emissions may have a minor impact on SDG 13 goals, but this effect is weak and insignificant. B(5,2) = −0.051228: This negative coefficient suggests a negative relationship between CO_2 emissions and TEC (total energy consumption). This implies that an increase in CO_2 emissions may decrease total energy consumption, though the effect is small and limited. B(5,3) = −0.001102: This coefficient indicates a minimal negative relationship between CO_2 emissions and renewable energy consumption (REC). Changes in CO_2 emissions may slightly affect renewable energy consumption, but the impact is weak. B(5,4) = 0.000112: This minimal positive coefficient suggests a weak positive relationship between CO_2 emissions and the financial development index (FDI). Changes in CO_2 emissions may have a negligible effect on financial development, but this impact is minimal. B(5,5) = 0.290466: This coefficient shows a positive relationship between CO_2 emissions and its past values. Past CO_2 emissions strongly influence future emissions, indicating that environmental effects continue sustainably based on past performance.

4.2. China

The results of the unit root tests are presented in Table 9. As indicated in Table 10, none of the series exhibit stationarity at the I(2) level. The LREC variable has been differenced once. This allows for the application of ARDL and BEKK models.

According to the ARDL (2, 2, 0, 2, 1) model established for Equation 2, the calculated F-statistic value (13.84) exceeds the upper bound critical value at the 1% significance level. Therefore, the H_1 hypothesis is accepted, indicating the presence of cointegration among the variables. This result signifies a significant long-term relationship among the variables in the model (Table 4).

ARDL bounds test results evaluate the long-run relationship between the dependent variable of SDG13 and independent variables such as renewable energy consumption (REC), total energy consumption (TEC), CO_2 emissions, and financial development (FDI) for China. According to the long-run coefficients, the coefficient of REC is −0.082755, which is both negative and significant (P: 0.0872). The CO_2 coefficient is also negative and significant (P: 0.0001), indicating that it can adversely affect sustainable development goals. The FDI coefficient is positively related to SDG13 (P: 0.0004), suggesting that financial development can positively contribute to climate action (Table 5). The TEC coefficient is positively associated with SDG13 (P: 0.59); however, this result is not statistically significant.

The ECM coefficient of Eq.2 is −1.30. Within the scope of the error correction model (ECM); the ECM coefficient indicates the existence of long-term equilibrium and that the model can return to equilibrium. In the bounds test results, the F-Bounds test statistic was determined to be 13.84, and this value exceeded the critical values of I(0) and I(1) at both asymptotic and finite sample levels. This supports a strong long-term relationship between the dependent and independent variables. In line with these findings, the long-term effects of financial development, renewable energy consumption and CO_2 emissions on sustainable development goals can be explained. In accordance with these findings, the long-term effects of renewable energy consumption, CO_2 emissions, and financial development on sustainable development goals can be understood (Table 12).

The result of BEKK model for China are summarised in Table 13;

Although coefficients of C matrix are not economically important, The coefficient C(1,1), C(2,1), C(3,1), C(3,3), C(4,1), C(4,2), C(4,3), C(4,4), C(5,1), C(5,2) and C(5,4), are statistically significant ($P < 0.05$). This provides a significant contribution to the fixed initial variance in the system.

As mentioned above, the coefficients of A(i,i) diagonals show that each conditional variance is due to its lagged shocks, while the off-diagonal elements of the A matrix reflect past diagonal innovations. Table 15 shows statistically significant coefficients of the A matrix.

A(1,1) = 0.224027: The effect of SDG 13 on itself is positive, indicating that SDG 13's future value will increase by approximately 22.4% relative to its current value. This suggests that China's ongoing focus on SDG 13 (Climate Action) will likely have a growing impact over time. A(2,2) = 0.239419: The positive relationship between Total Energy Consumption (TEC) and its past values indicates a substantial dependency. This means that energy consumption in China has been increasing consistently, with a growth rate of around 23.9%. A(3,2) = 3.47869: This positive coefficient between total energy consumption (TEC) and renewable energy consumption (REC) suggests that a unit increase in total energy consumption leads to a significant increase in renewable energy consumption. This highlights China's potential for further investment in renewable energy and its transformation toward more sustainable energy practices. A(3,3) = 0.291646: The positive relationship between REC and its past values indicates that the renewable energy sector's growth is influenced by its past performance, with a 29.2% effect on future consumption. This suggests that the renewable energy sector in

Table 10: Unit root test[2]

Variables	*ADF*[3]		*PP*[4]	
	Intercept	Intercept and trend	Intercept	Intercept and trend
LSDG13	−4.94	−4.65	−4.99	−4.65
LCO_2	−3.58	−3.38	−3.52	−3.28
LFDI	−6.72	−5.08	−6.86	−9.01
LREC	−4.08	−3.90	−4.05	−3.85
LTEC	−3.58	−3.97	−3.41	−4.18

[2]L shows natural logarithms of all series have been taken
[3]Based on Schwartz info criterion
[4]Based on Bartlett Kernel

Table 11: Bounds test for ARDL model

Test statistic	Value	Signif. (%)	I (0)	I (1)
F-statistic	13.84337	10	2.2	3.09
		5	2.56	3.49

Table 12: The hypothesis concerning SDG 13 for China

Variable	Coefficient	t-Statistic	Probability
CO_2	−0.002986	−7.422011	0.0001
FDI	1.178623	5.713547	0.0004
REC	−0.082755	−1.948281	0.0872
TEC	0.000547	0.550726	0.5969
C	98.37748	51.60359	0.0000
CointEq (−1)**	−1.308064	−11.61778	0.0000
Diagnostic test results			
Breusch-Godfrey LM Test		0.4773	
Heteroskedasticity Test: Breusch-Pagan-Godfrey		0.7660	
Ramsey RESET Test		0.2127	
Cusum of squares		Stable	
Cusum of squares		Stable	

**EC=SDG13−(−0.0030*CO_2_EMISSIONS+11.7862*FDI−0.0828*REC+0.0005*TEC+98.3775)

Table 13: The results of the BEKK model for China

Variable	Coefficient	Standard error	t-Statistic	P-value
Mean (SDG13)	82.866887	0.040963	2022.992	0.000000
Mean (TEC)	2430.992262	7.672503	316.8448	0.000000
Mean (REC)	15.637191	0.203453	76.859	0.000000
Mean (FDI)	0.532229	0.002812	189.2509	0.000000
Mean (CO_2_E)	7359.944721	11.93121	616.865	0.000000
C (1,1)	3.505494	0.026784	130.8786	0.000000
C (2,1)	−508.104307	6.329321	−80.2779	0.000000
C (2,2)	25.399229	5.940407	4.27567	1.91E-05
C (3,1)	3.026876	0.147853	20.47214	0.000000
C (3,2)	0.833221	0.159243	5.2324	1.7E-07
C (3,3)	0.485512	0.156162	3.10903	0.001877
C (4,1)	−0.071322	0.002127	−33.5384	0.000000
C (4,2)	0.014523	0.002153	6.74502	0.000000
C (4,3)	−0.00405	0.002239	−1.80893	0.070461
C (4,4)	0.004036	0.001677	2.40739	0.016067
C (5,1)	−1586.44864	8.23938	−192.545	0.000000
C (5,2)	20.943016	7.966742	2.62881	0.008569
C (5,3)	−39.156866	9.972142	−3.92663	8.62E-05
C (5,4)	−20.850232	8.341935	−2.49945	0.012439
C (5,5)	−5.383812	6.957244	−0.77384	0.439024
A (1,1)	0.224027	0.003408	65.73309	0.000000
A (1,2)	1.34773	1.04757	1.28653	0.198258
A (1,3)	−0.035593	0.023118	−1.53964	0.123648
A (1,4)	−0.000042	0.000223	−0.18991	0.849376
A (1,5)	−1.142665	1.076088	−1.06187	0.288295
A (2,1)	0.000019	0.000022	0.87644	0.380789
A (2,2)	0.239419	0.006597	36.2908	0.000000
A (2,3)	0.00012	0.000153	0.78473	0.432615
A (2,4)	0.000001	0.000003	0.29571	0.767453
A (2,5)	0.003773	0.007157	0.52726	0.598015
A (3,1)	−0.000339	0.002987	−0.11359	0.909566
A (3,2)	3.47869	1.06287	3.27292	0.001064
A (3,3)	0.291646	0.02044	14.26866	0.000000
A (3,4)	−0.000532	0.000229	−2.32577	0.020031
A (3,5)	−0.391036	0.896191	−0.43633	0.662596
A (4,1)	0.165792	0.182058	0.91065	0.362479
A (4,2)	214.433731	56.02226	3.82765	0.000129
A (4,3)	−2.0994	1.196344	−1.75485	0.079286
A (4,4)	0.259847	0.012191	21.31398	0.000000
A (4,5)	−60.570255	60.37693	−1.0032	0.315763
A (5,1)	0.000002	0.000007	0.33794	0.735409
A (5,2)	−0.001201	0.002278	−0.52699	0.598198
A (5,3)	0.000046	0.000049	0.94912	0.342559
A (5,4)	−0.000004	0.000001	−2.53314	0.011305
A (5,5)	0.226531	0.002334	97.06341	0.000000
B (1,1)	0.67057	0.004457	150.4434	0.000000
B (1,2)	0.893931	1.158579	0.77157	0.440366
B (1,3)	−0.025302	0.02569	−0.98488	0.324682
B (1,4)	−0.000179	0.000335	−0.53401	0.593336
B (1,5)	0.264923	1.408676	0.18807	0.850825
B (2,1)	−0.000014	0.000029	−0.49335	0.621765
B (2,2)	0.662512	0.007298	90.78448	0.000000
B (2,3)	0.000101	0.000174	0.5805	0.561577
B (2,4)	0	0.000002	−0.07197	0.942627
B (2,5)	−0.00335	0.009271	−0.36138	0.717817
B (3,1)	−0.000199	0.004334	−0.04599	0.963317
B (3,2)	−1.752809	1.293287	−1.35531	0.175318
B (3,3)	0.625133	0.022393	3.89538	0.000106
B (3,4)	−0.000063	0.000257	−0.24506	0.806349
B (3,5)	0.853948	1.276588	−0.13976	0.889054
B (4,1)	−0.209798	0.239365	−0.87648	0.807708
B (4,2)	64.650129	57.38406	1.12662	0.259902
B (4,3)	−1.493235	1.448191	−1.0311	0.302492
B (4,4)	0.663634	0.017284	38.39642	0.000000

(contd...)

Table 13: ***(Continued)***

Variable	Coefficient	Standard error	t-Statistic	P-value
B (4,5)	−118.409024	75.56839	−1.56691	0.117135
B (5,1)	−0.000007	0.00001	−0.69139	0.489322
B (5,2)	−0.000503	0.002529	−0.19889	0.842349
B (5,3)	0.000026	0.000056	0.45863	0.646497
B (5,4)	−0.000002	0.000001	−2.10017	0.035557
B (5,5)	0.66842	0.003059	218.2003	0.000000

Table 14: Statistically significant coefficient of C matrix of BEKK model for China

Variable	Coeff	Std Error	T-Stat	Signif
C (1,1)	3.505494	0.026784	130.8786	0.000000
C (2,1)	−508.104307	6.329321	−80.2779	0.000000
C (3,1)	3.026876	0.147853	20.47214	0.000000
C (3,3)	0.485512	0.156162	3.10903	0.001877
C (4,1)	−0.071322	0.002127	−33.5384	0.000000
C (4,2)	0.014523	0.002153	6.74502	0.000000
C (4,3)	−0.00405	0.002239	−1.80893	0.070461
C (4,4)	0.004036	0.001677	2.40739	0.016067
C (5,1)	−1586.44864	8.23938	−192.545	0.000000
C (5,2)	20.943016	7.966742	2.62881	0.008569
C (5,4)	−20.850232	8.341935	−2.49945	0.012439

Table 15: Statistically significant coefficient of A matrix of BEKK model for China

Variable	Coeff	Std Error	T-Stat	Signif
A (1,1)	0.224027	0.003408	65.73309	0.000000
A (2,2)	0.239419	0.006597	36.2908	0.000000
A (3,2)	3.47869	1.06287	3.27292	0.001064
A (3,3)	0.291646	0.02044	14.26866	0.000000
A (3,4)	−0.000532	0.000229	−2.32577	0.020031
A (4,2)	214.433731	56.02226	3.82765	0.000129
A (4,3)	−2.0994	1.196344	−1.75485	0.079286
A (4,4)	0.259847	0.012191	21.31398	0.000000
A (5,4)	−0.000004	0.000001	−2.53314	0.011305
A (5,5)	0.226531	0.002334	97.06341	0.000000

China is expanding, and past trends have a considerable impact on future energy consumption patterns. A(4,2) = 214.433731: The relationship between financial development ındex (FDI) and Total Energy Consumption (TEC) is powerful, indicating that changes in energy consumption are significantly linked to financial development. This coefficient suggests that large increases in energy consumption could drive significant financial development in China. A(4,4) = 0.259847: The positive effect of FDI on itself indicates that financial development in China is positively influenced by its past performance, with a 25.98% increase projected. This shows a strong potential for continued growth in China's financial sector. A(5,5) = 0.226531: The positive correlation between CO_2 emissions and their historical values indicates that China's CO_2 emissions are likely to continue rising. This underscores the persistent necessity for strategies aimed at reducing emissions and mitigating environmental impacts. A(4,3) = −2.0994: The negative relationship between REC and FDI indicates that increases in renewable energy consumption might have a slight negative effect on financial development,

Table 16: Spillover effect (statistically significant coefficient of B matrix of BEKK model for China)

Variable	Coeff	Std Error	T-Stat	Signif
B (1,1)	0.67057	0.004457	150.4434	0.000000
B (2,2)	0.662512	0.007298	90.78448	0.000000
B (3,3)	0.625133	0.022393	3.89538	0.000106
B (4,4)	0.663634	0.017284	38.39642	0.000000
B (5,4)	−0.000002	0.000001	−2.10017	0.035557
B (5,5)	0.66842	0.003059	218.2003	0.000000

but this impact is relatively small. This suggests that China's financial development may not fully align with renewable energy consumption, possibly due to investment shifts or policy focus. The coefficient A(5,4) = −0.000004 indicates a minimal negative relationship between CO_2 emissions (CO_2) and the Financial Development Index (FDI). This suggests that a slight increase in financial development (FDI) might lead to a minor reduction in CO_2 emissions, but the effect is minimal. Spillover effect, (B(İ,İ)) is summarised in Table 16;

B(1,1) = 0.67057: This coefficient indicates a strong positive relationship between Sustainable Development Goal 13 (SDG 13) and its lagged values. Specifically, a 1% increase in SDG 13 in the previous period is associated with an approximate 0.67% increase in the current period. This finding highlights the significant path-dependence of SDG 13, suggesting that its progress is relatively stable and persistently influenced by past performance. B(2,2) = 0.662512: This coefficient reflects a strong positive association between Total Energy Consumption (TEC) and its historical values. A 1% increase in TEC during the prior period results in an approximate 0.66% increase in the current period, indicating a consistent and enduring growth trajectory in energy consumption over time. B(3,3) = 0.625133: This coefficient demonstrates a robust positive relationship between renewable energy consumption (REC) and its past values. A 1% increase in REC in the preceding period leads to an estimated 0.63% increase in the current period, signifying a sustained and steady upward trend in the utilization of renewable energy sources. B(4,4) = 0.663634: This coefficient suggests a strong positive linkage between the financial development ındex (FDI) and its previous values. A 1% increase in FDI in the prior period corresponds to a 0.66% rise in the current period, indicating a stable and progressive trajectory in financial development driven by historical performance. B(5,4) = −0.000002: This coefficient signifies a negligible negative relationship between CO_2 emissions and the Financial Development Index. The extremely small magnitude of the coefficient implies that variations in CO_2 emissions exert an almost nonexistent impact on financial development, denoting a statistically and economically insignificant association. B(5,5) = 0.66842: This coefficient represents a strong positive relationship between CO_2 emissions and their own past values. A 1% increase in CO_2 emissions in the previous period is associated with approximately a 0.67% increase in the current period. This indicates a persistent and self-reinforcing pattern in emission levels, emphasizing the long-term and cumulative nature of environmental degradation.

5. CONCLUSION AND IMPLICATIONS

The economies of China and India have both demonstrated remarkable growth since the early 2000s, albeit with distinct trajectories and challenges. China's economy has expanded nearly 15-fold since 2000, increasing its share of the global economy from 3.6% to 17% by 2024. This growth has positioned China as a leading force in clean energy, responsible for one-third of global investments in this sector, while also making it a key player in emerging manufacturing fields like solar energy and electric vehicles. However, China's ambitious dual carbon targets for 2030 and 2060 are complicated by its ongoing reliance on fossil fuels, particularly coal.

India's economy, meanwhile, has expanded approximately eightfold and is projected to become the third-largest economy by 2030. Despite setbacks from the 2008 global financial crisis and various structural challenges, India has implemented long-term reforms especially in digitalization and taxation to sustain growth. However, poverty, unemployment, and infrastructural deficiencies persist. With energy demand expected to peak globally by 2050, India faces a pressing need to diversify energy sources. In pursuit of its 2070 net-zero target, India has significantly increased clean energy investments, promoted domestic production, and actively engaged in green finance (Planning Commission, Government of India, 2013).

Recent developments in the economies of China and India have positioned these two countries as focal points in contemporary discussions as global actors. In this study, we aimed to conduct research that could guide the resolution of current issues. Given the information provided above, it becomes evident how critical the roles of the Chinese and Indian economies will be in shaping sustainability and climate change policies in the near future. Therefore, the findings obtained from the study are expected to enhance our understanding of China's and India's strategies concerning energy and carbon emissions, as well as to facilitate the development of new roadmaps. Indeed, the main objective of the study was to predict the long-term relationship between energy consumption, renewable energy consumption, carbon emissions, and financial development within the economies of China and India, particularly in relation to Climate Action, which is the 13th Sustainable Development Goal. Upon examining the acquired findings, first the relationship between SDG 13 and its past performance B(1,1) = 0.224027 is positively correlated in India. This indicates that future progress in India towards climate action goals relies strongly on past performance**.** On the other hand, for China, relationship between SDG 13 and its past performance B(1,1) = 0.67057 is much stronger. This indicates that China's climate action goals are more explicitly referenced to its historical performance, and future achievements will be more oriented toward past accomplishments. China is moving ahead with climate action more than India. When evaluating the chronological table in the introduction part, it can be seen that India and China have made significant moves and progress in both national and international arenas to address climate change and reduce carbon emissions. When interpreted according to the empirical study, it is evident that a similar effort will be made in the medium to long term. However, the main question is whether these efforts are sufficient and what are the main challenges both countries face in reducing carbon emissions and addressing the effects of climate change?

In India, there has been an increasing awareness of policy initiatives across all institutions and regions since 2007. Climate change policies are being prioritized in development plans, including the 12th 5-year Plan, and through newly established entities such as the national action plan on climate change (NAPCC), the national steering committee on climate change (MoEFCC), and the National Institution for Transforming Urban India (NITI Aayog). Nonetheless, a limitation is that these plans are more incorporated into India›s development objectives, while giving insufficient consideration to regional research. The primary challenges India is expected to encounter in the near future will be related to urbanization. Issues arising from irregular urbanization should be regarded as primary indications for formulating responses to climate change. When the same question is considered in the context of China, as reflected in empirical studies, it can be argued that the implementation of a clearer and faster action plan in the past makes China's outlook more promising compared to India. Data from the report prepared by China's Ministry of Ecology and Environment in 2024 clearly supports this assessment. Over the past twenty years, China, which had previously adopted an aggressive stance toward economic growth and development, has recently shifted toward a more environmentally focused discourse. This is evident in the emphasis placed on concepts such as "Beautiful China" and "Eco-civilization," and in the adoption of a development model based on these goals. Looking at the recent past, in the last decade the share of coal in China's energy consumption dropped from 67% to 55%, while the share of non-fossil fuels increased from around 10% to approximately 18%. Similar positive developments have also been observed in sectors such as transportation, new production areas that rely on clean energy and require energy efficiency (e.g., electric vehicles, lithium-ion batteries, and photovoltaic products), all coordinated with carbon emission reduction policies in a holistic approach. On the other hand, it is important not to overlook the internal and external driving forces that have triggered the implementation of these policies. Rapid urbanization, industrialization, and population growth resulting from China's fast-paced development have led to numerous environmental challenges. Pollution of rivers has increased the demand for clean water, while air pollution reaching levels that threaten public health has necessitated measures to safeguard public well-being. Since 2018, trade wars between the United States and China have slowed down the Chinese economy, resulting in lower energy consumption. Additionally, measures by the European Union another major trade partner of China such as carbon taxes and other trade restrictions aimed at reducing global carbon emissions, can also be considered among the external pressures. In conclusion, this transformation reflects China's efforts to reduce carbon emissions, improve air quality, and achieve its climate goals. However, it should not be assumed that these efforts are yet sufficient (Ministry of Ecology and Environment of the People's Republic of China, 2025).

Second notable finding is the divergent relationship between total energy consumption (TEC) and renewable energy consumption (REC) in the two nations. The weak and negative correlation in India (B(2,3) = −0.005084) indicates that increases in overall energy consumption have not been accompanied by a shift toward renewables. This could point to structural constraints in India's energy policy or investment landscape, where renewable sources remain peripheral despite rising energy demands. Also raises apprehensions over the long-term viability of India's energy infrastructure, particularly in the context of global decarbonization objectives. Conversely, China has a robust and favorable correlation between TEC and REC (B(3,3) = 0.625133), signifying that renewable energy is progressively being harnessed to satisfy escalating demand. In 2024, with the Guiding Opinions on Vigorously Implementing the Renewable Energy Substitution Initiative, China has announced a new renewable energy strategy, targeting an annual renewable energy consumption of 1 billion tons of conventional coal equivalent by 2025 and 5 billion tons by 2030. This strategic transition emphasizes enhancing infrastructure, electrifying sectors, and advancing sustainable technology. The plan outlines prospects in grid modernization, industrial electrification, green hydrogen production, and the emerging electric vehicle and sustainable aviation industries. Additionally, China is not only planning to increase its use of green energy within its domestic economy but also in other countries. By leveraging the Belt and Road Initiative for large-scale green energy infrastructure investments, it aims to export these products and create opportunities for their implementation abroad. As previously mentioned, the advancements it has made in "new three" industries can be viewed not only as fulfilling the needs of the domestic economy but also as a strategy to address global demand.

The third significant poin, the link between financial development and energy consumption in India and China reflects nuanced dynamics that necessitate further analysis. In India, the coefficient between the financial development index (FDI) and total energy consumption (TEC) is notably weak and negative (B(2,4) = −0.000292). This suggests that now, energy consumption is not a significant catalyst for financial progress. This observation yields multiple potential interpretations. Firstly, India's financial sector may remain inadequately connected with its energy sector, particularly with the financing of infrastructure for power generation, renewable energy, and energy efficiency. The restricted use of green finance instruments, immature financial markets for clean energy initiatives, and regulatory delays may serve as impediments, leading to a decoupling of energy and finance. This indicates that, at present, energy consumption does not serve as a strong driver of financial development. Several possible interpretations arise from this observation. India's financial sector may still be insufficiently integrated with its energy sector, especially in terms of financing infrastructure for power generation, renewable energy, and energy efficiency. The limited penetration of green finance instruments, underdeveloped capital markets for clean energy projects, and bureaucratic delays may act as constraints, resulting in an energy-finance decoupling. Furthermore, India's financial development in recent years has been predominantly powered by the service sector, digital finance, and innovations in retail banking, rather than by industrial growth or energy-intensive industries. This structural composition might clarify why rising energy consumption frequently associated with manufacturing or extractive sectors does not automatically result in measurable gains in financial development indicators. In contrast, the stronger positive correlation observed in China (B(4,4) = 0.663634) suggests that financial development and energy consumption are more tightly interlinked. This is likely due to China's growth model after the 2000s, which has historically relied on state-led infrastructure investments, large-scale industrialization, and export-oriented manufacturing all of which are energy-intensive and heavily supported by financial institutions. China's financial reforms, which began after 2003, aimed to achieve financial deepening, digitalization, risk management, and globalization through restructuring, while also improving sustainability and transparency. The effects of these aims may be seen in the almost 12-fold increase in total bank assets from 2003 to 2023, the stock markets achieving a valuation of 11 trillion dollars, international investor participation increasing to 3.5%, and the green bond market ranking second globally with 111 billion USD. Ultimately, the reform process led to the development of new products and market systems. These pertained directly to mechanisms such as the issue of green bonds to facilitate green funding, adaptable interest rate policies, augmented incentives for green initiatives, and enhanced environmental transparency in corporate disclosures. Consequently, alongside the quantitative advancement of the financial industry, the enhancement of quality and diversity has emerged as a dynamic that sustains and accelerates the energy sector. Upon analyzing the correlation between financial development and the energy sector, disparities in institutional architecture and governance between the two nations are evident. The primary issue can be seen as the lack of coordination inherent in India's state system, in contrast to the synergy fostered by China's central planning. Importantly, these findings suggest that financial development can serve as both a catalyst and a reflection of energy transition efforts but only when policy, institutional alignment, and targeted investments are present. The implication is clear: for India to accelerate its energy transition and achieve low-carbon growth, it will need to strengthen the synergy between its financial system and the energy sector, potentially through regulatory reform, incentivization of green finance, and de-risking mechanisms for clean energy investments.

Finally, and perhaps most critically, the contrasting results regarding CO_2 emissions and energy consumption address the core of the sustainability debate. India's negative coefficient (B(2,5) = −0.670529) may reflect the effects of policy interventions aimed at decoupling emissions from energy use; however, the relatively minor scale of this effect merits further investigation. Conversely, China's favorable correlation (B(5,5) = 0.66842) underscores the persistent difficulties the nation faces in reconciling swift industrial expansion with environmental obligations. Despite China's considerable investment in renewable energy, its carbon intensity remains a critical concern, potentially exacerbated by the structural inertia of coal-dependent industries and the remnants of fast industrialization.

For the sustainable development goal of India and China's economies, there are some fundamental issues within the subheadings of Sustainable Developmment Goals; Climate Action 13. Increasing resilience and adaptive capacity, integrating climate change measures into national policies, raising awareness about climate change mitigation and adaptation, and benefiting from financial instruments are the subheadings listed that should be expressed more clearly in terms of the strategies and policies that developing countries will implement. In countries like India and China, which have development priorities but face dilemmas, it is essential to create good examples of increasing adaptation capacity and integrating it into national policies, and to involve key actors in the process.

Taken together, these results highlight the importance of context in understanding energy transitions. China's trajectory appears more coherent and policy-driven, albeit still facing environmental headwinds. India, meanwhile, shows signs of fragmentation with energy, finance, and environmental goals not yet fully aligned. These observations underscore the necessity for tailored, country-specific energy policies that include institutional capacity, developmental stage, and socio-economic factors. Furthermore, the empirical basis of this analysis utilizing historical data to evaluate contemporary relationships highlights the importance of long-term trend assessment in informing future energy and climate plans.

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