

Assessing the Impact of Renewable Energy Transition on the Environmental Sustainability and Carbon Neutrality in China: Composite Index Approach

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Abstract: The world is racing towards carbon zero mid-century ambitions; and from China's perspective, everything depends on the pursuit of carbon neutrality to be done by renewable energy transmission and carbon emission efficiency. The research assesses the impact of adopting renewable energy in the course of attaining environmental sustainability and carbon neutrality in China, developing a composite index for CO₂, CH₄, and NO₂ emissions. The study starts in 1965 and goes on up to 2022, covering basic trends, linkages, and benchmarks against international standards. The results show that the composite index of emissions in China has been trending downward. This is commensurate with increasing renewable energy adoption, a pointer to low-carbon growth. Benchmark analysis, however, shows that in some parameters, despite appreciable progress, China still lags behind international standards. The findings bring out the need for enhanced policy measures related to investing in renewable energy technologies, stricter emissions regulations, and promoting energy efficiency. Some of the limitations—from the inadequacy of the data to the challenges posed by methodologies—are recognized, and further research is set out in the future to explore more environmental indicators and regional differences within China.

Keywords: Renewable energy, Composite emission index, Carbon neutrality, sustainable development.

1. Introduction

Transmission of renewable energy and carbon emission efficiency are essential in the pursuit of carbon neutrality by China as the global community races towards carbon zero mid-century targets. As much as the Industrial Revolution boosted the economies and living standards, it surged the consumption of energy, largely increasing carbon dioxide emissions that exacerbate environmental issues related to global warming and the rise in sea levels [1-2]. These challenges underline the imperative of transition to renewable energy as a major solution pointed out by the IPCC and IEA, in case the Paris Agreement's 2.0°C target needs to be adhered to [3]. Given that, so far, nearly all countries have involved various policy supports to promote such transition, including the U.S.'s Department of Energy Research and Innovation Act, Japan's Fifth Energy Resources Basic Plan, and the EU's Strategic Energy Technology Plan. The impacts of the development of renewable energy on

the economy and society need to be estimated to guide sustainable practices for achieving long-term carbon neutrality goals.

Since 2007, China has risen to the position of the largest carbon emitter in the world; as such, assessing its progress toward carbon neutrality and sustainable development is very relevant [4]. The main objective of the paper is an investigation into the contribution of the transmission of renewable energy in meeting the goals related to carbon neutrality and sustainable development in the case of China which will be done based on developing a multifaceted emissions index that structuralizes characteristics of the emissions and analyses its relationship with renewable energy adoption from 1965 to 2022. To realize this objective, the study will be guided by the following research questions:

1. What is the trend of the composite emissions index in China between 1965 and 2022 relative to renewable energy adoption?
2. What is the association between renewable energy development and the composite emissions index in China?
3. How does China's composite index compare to benchmark indexes like the greenhouse gas emissions index?

China, the world's biggest developing nation, has been on an extremely fast growth path since reforms and opening up in the late 1970s [5]. There is a strong ambition to achieve carbon neutrality—net zero carbon emission—by 2060 by following a low-carbon transition strategy for global development, given that it is one of the chief emitters of carbon worldwide [6]. Whereas the country has been striving to optimize its energy structure in the past ten years, 80% of China's total energy consumption still comes from fossil fuels. Transitioning to renewable energy is therefore paramount for China, not only because mitigating emissions from fossil fuels is widely recognized as imperative for meeting social and sustainable development goals but also because most energy sources are of low quality [7]. Effective ecological management will have to strike a balance between these needs for higher living standards and the imperative of carbon neutrality, particularly for fast-growing economies like China. Hence, testing the relationship between renewable energy development and carbon emissions is very necessary to support the goals of carbon neutrality in China and ensure sustainable development. The relevance of the following study lies in the fact that it forms the foundation of decisions and policy-making by China to balance its growth with its carbon neutrality ambitions.

2. Literature Review

2.1. Carbon Neutrality and Environmental Sustainability in China

Carbon neutrality refers to a status in which the net emission of carbon dioxide is brought to zero through the application of offsetting and measures of Carbon removal [8]. It is a critical goal that must be achieved as China endeavours to combat global climate change. Environmental sustainability refers to that element that lives to maintain ecological balance, which in turn saves the resources in the environment. Carbon neutrality, even further than that, is well emphasized through China's commitment to the very promise of peaking carbon emissions by 2030 and reaching carbon neutrality by 2060 [9]. In 2020, the event was held at China's ambitious commitments to climate action. In September, Chinese President announced that China was aiming to hit carbon neutrality, or net-zero emissions, by 2060 [10]. Then, in December, he became still more ambitious and committed that the carbon dioxide emissions would peak before 2030 rather than in 2030. That means that from a peak, China aims to cut its emissions to net zero in about 30 years—a challenging goal, especially when one considers that many developed countries are pursuing net-zero targets more than 40 years after those countries' emissions peaked.

China's interest in environmental sustainability as part of its development strategies dates as far back as the 1980s, but a very significant scaling-up occurred in the 1990s. Although economic growth trumped environmental concerns throughout the 1990s and early 2000s, participation in the Rio Conference and issuance of the Country's 21st Century Agenda marked the beginning for China [11]. Since 2015, particularly after the Paris Agreement and commitments to accomplishing the 30-60 goals, there has been a continuous process of including environmental targets within China's economic policy, which would pursue sustained development but in green and low-carbon ways [12]. This is just one intrinsic element of the more comprehensive framework of High-Quality Development for China, featuring "innovative, coordinated, green, opening, and shared" development. At the heart will be the "1+N" policy framework, where the "1" is for one guiding policy document on peaking and neutrality targets, and the "N" is for policies aimed at reducing carbon emissions by sectors to support a green economy [13]. In addition, China has rebalanced its macroeconomic policies to help make this transition a reality by creating a green financing system. In this direction, environmental policies—green technologies, strict industrial emissions regulation, and encouragement of sustainable practices across sectors—no doubt become a critical component in China's pathway toward carbon neutrality, in which very much is at stake globally because the contribution of China to the global carbon emission is already quite high.

China has set explicit objectives for emissions reductions in the face of climate change. One major route toward these goals is the establishment of a carbon ETS [14]. The concept of an ETS was designed in 2011 and implemented in pilot regions in 2013, targeting reductions in carbon emissions by applying a market-based approach. Several studies have examined whether the ETS effectively reduces carbon emissions and its impact on carbon leakage. While aggregate performance in the areas of energy efficiency, carbon intensity reduction, and green space promotion has been noted in China, progress has been mixed. The challenge is continued dependence on coal, thus showing that more policy-level improvements are due. The effectiveness of these policies therefore needs to be continuously gauged at the national and global levels.

2.2. Renewable Energy Transition and Carbon Neutrality in China

At the core of achieving carbon neutrality must be a transition to renewable energy with huge domestic and global implications. As the world's largest carbon emitter, China has to surmount the challenge of meeting its rising energy demand while slashing GHG emissions. China targets carbon neutrality by 2060, which cannot be achieved without a basic replacement of the country's energy structure from reliance on fossil fuels to a mix dominated by renewable energy sources: wind, solar, hydro, and biomass [15]. This transition is very important because it calls forthrightly for the solution to carbon emissions: burning through the use of fossil fuel, especially coal, which presently holds a large share in China's energy consumption and accounts for a huge proportion of CO₂ emissions.

China has been rather impressive in building up its renewable energy capacity and leads globally in terms of wind and solar power deployment. This aligns with China's low-carbon development strategy and commits it to international climate agreements such as the Paris Agreement [16]. Subsidies, tax incentives at the top level of policy, and the Renewable Energy Law of 2005 sustain such transition. Green technologies, mainly smart grids and energy storage solutions are also indispensable investments for the integration of renewable energy into the national grid to safeguard stable supplies [17]. Despite the aforementioned efforts, technological solutions to handle the intermittent nature of these sources and rapid economic growth that continues to force high energy demand, catered to by fossil fuels, remain key challenges [18]. However, the continuous development of renewable energy is crucial for achieving the Chinese carbon neutrality goals and making a colossal contribution to global climate efforts.

The relationship between renewable energy and environmental sustainability has been varied in the literature. There are studies which have posited both positive and negative impacts of renewable energy on carbon emissions for several economies [19, 20]. Some studies reveal that renewable energy consumption decreases CO₂ emissions, and this consequently eases environmental pollution. However, other studies have shown that renewable energy has an extremely small or even negative effect on CO₂ emissions. Such mixed evidence calls for further research into how energy consumption and green energy investment impact ecological pollution and carbon neutrality. In this regard, this study focuses on the dynamic impact of energy consumption and green energy investment on carbon neutrality in China, considering both short- and long-run scenarios.

2.3. Research Gap

A review of the available literature indicates that there are several limitations to most of the existing studies on renewable energy transition and its effect on composite emission indexes. Hardly is there a comprehensive measurement that composites several GHGs into a single composite index [21]. Most of the current research is limited to carbon dioxide emissions, with less regard for other key GHGs, including methane, sulfur dioxide, and nitrous oxide. This narrow scope has deprived the possibility of assessing environmental sustainability from a broader perspective. To this end, the proposed research will formulate a composite index that encompasses all these variables to provide a holistic measure of environmental impact.

Another major limitation of the existing research is that general data outside the chosen study periods are generally lacking, hence constraining the possibility of implementing a longitudinal analysis. In addition, the regional dynamics of the Chinese economy, energy use, and ecological conditions are not well represented. In this paper, these gaps are bridged through an application of advanced econometric techniques to estimate the impact of renewable energy transitions on environmental sustainability. In this respect, this paper tries to put forward a more realistic picture of changes in environmental quality by incorporating a broader range of indicators and including sophisticated methodologies on CO₂ emissions and other GHGs. Comparisons with benchmark analyses will be used to underpin the approach taken in the study to make the findings more robust and relevant.

3. Data and Methodology

3.1. Data and Justification for the Development of Composite Emissions Index

To achieve its aim and objectives, the subsequent subsection outlines the sources of data used to develop the index, which relied on national GHG inventories, reports on energy consumption, as well as international databases to this effect. It further justified the selection of components (CO₂, CH₄, and NO₂) and explained the process of data collected, normalized, and weighted. This therefore explained the rationale for using a composite index in the quest to capture the emission and use of energy that is normally of a complicated nature.

The composite emission index uses data ranging from 1965 to 2022, sourced from various credible sources to ensure comprehensive coverage. Source of data for the composite emissions index: national inventory and international database-sourced emissions data. This category includes the utilization of data on CO₂, CH₄, and NO₂ emissions in Our World in Data, data on the use of fossil and renewable fuels, and data on economic growth from World Development Indicators. All the variables are measured per capita and standardized in CO₂ equivalents, so they all have comparability across different scales. As it is already normalized, no further steps for normalization are needed. This per capita measurement will make it very easy to combine variables into a composite index and support an accurate relationship analysis between various emissions and energy use indicators.

Knowing this, a composite emission index is constructed with a weighted aggregate method to attach relative importance to different variables contributing to the composite environmental impact. The formula for the composite index is:

$$\text{Emission composite Index} = 0.5 * \text{CO}_2 + 0.25 * \text{CH}_4 + 0.25 * \text{NO}_2 \quad (1)$$

In this formula, CO₂ gets a weight of 0.5 because it is predominantly the cause of global warming. This large weight is justified because CO₂ has a major presence in the Chinese emissions profile due to that country's strong reliance on fossil fuels, especially coal. CH₄ and NO₂ each get a weight of 0.25 [22]. Though less common than CO₂, CH₄ is a powerful greenhouse gas that gets substantial but secondary weight because its impacts from agriculture and extraction of natural gas are significant. NO₂ comes mainly from transportation and industry and has huge impacts on air quality and human health. It is therefore important, though its role in climate change is not so crucial as CO₂, justifying it as being equal but lesser in weight. It is important to have weighting that accurately reflects the environmental impact of every component of emissions in the composite index, for setting policy priorities or even describing the specific profile of emissions in China.

The composite index supplies broad, integrated measures of environmental sustainability regarding CO₂, CH₄, and NO₂ emissions. Through this approach, nuanced insight into the complex behaviour of greenhouse gas emissions and energy use can be obtained, better than single-variable indices. By putting these indicators together, an index can review progress toward carbon neutrality and the bigger implications of energy transitions on environmental quality. It serves China's policy goals well by focusing on key pollutants and providing a clear, aggregated measure of the impacts of emissions. The index is carefully developed from data collection, normalization, and weighting to ensure that it is an accurate reflection of environmental impacts and to aid in policy decisions that are informed.

3.2. Model Specification and Data Analysis Techniques

This research will focus on answering three main research questions concerning the composite emission index in China, with a view to historical trends, associations with renewable energy development, benchmark indexes and carbon neutrality targets.

Research Question 1: Has the composite emissions index followed a downward trend from 1965 to 2022 concerning renewable energy adoption? This will be evaluated using historical data related to CO₂, CH₄, and NO₂ emissions in comparison with the rate of renewable energy adoption. The trend analysis is done to define the pattern, shift, and change in this composite emission index over time, focusing on how an increased percentage of renewable energy usage influenced this.

Research Question 2: The second research question shows the connection that exists between the growth of renewable energy and the composite emissions index in China. For this research, the study is estimated using the ARDL model, which is well-fitted for an analysis estimating the influence of the explanatory variables on a dependent variable, based on different lag structures and time series data [23]. In this regard, the ARDL model for analysis focuses on the composite emission index and checks its relationship with several independent variables including fossil fuel energy use, renewable energy use, and some key economic indicators like GDP, trade openness, and urbanization. The model is specified this way:

$$\begin{aligned} \Delta \text{CEI}_t = & \alpha + \beta_1 \Delta \text{REC}_t + \beta_2 \Delta \text{FF}_t + \beta_3 \Delta \text{GDP}_t + \beta_4 \Delta \text{TO}_t + \beta_5 \Delta \text{URB}_t + \gamma_1 \Delta \text{CEI}_{t-1} \\ & + \gamma_2 \Delta \text{REC}_{t-1} + \gamma_3 \Delta \text{FF}_{t-1} + \gamma_4 \Delta \text{GDP}_{t-1} + \gamma_5 \Delta \text{TO}_{t-1} + \gamma_6 \Delta \text{URB}_{t-1} + e_t \end{aligned} \quad (2)$$

The lengths of lags of variables are determined through model selection criteria. Then, an ARDL bounds test is conducted to check for any long-run relationship among variables. The test thus helps assess co-integration, thereby implying a long-term stable relationship among variables. Based on

this, the model estimates both the short and long-term influences of renewable energy development and other factors on the composite emission index.

Annual secondary data is used in this analysis to mitigate possible seasonal variations. To cope with heteroscedasticity, all series go through a logarithmic transformation. This paper has adopted the Autoregressive Distributed Lag model since the ARDL model is one of the best models for time series data analysis and testing any hypothesis including rates or differences. First, it checks for the stationarity of the series using the Augmented Dickey-Fuller test before the application of the ARDL model to ensure that none of the variables are integrated of order two, I (2), so results may not be skewed. From the results of the ADF test, all variables come out to be either I (0) or I (1), thus validating the use of the ARDL model.

Research Question 3: The research question is on benchmarking China's composite emissions index against benchmark indexes and carbon neutrality targets. The comparison can be done by checking the composite emissions index with the GHG Emissions Index to understand its consistency with general emissions measures and trends.

4. Results and Discussion

4.1. Exploratory Analysis

Preliminary analysis of the composite emission index variable shows several insights into trends in emissions and energy intensity. Descriptive statistics for the variables in this study appear in Table 1. The variable emission, corresponding to the composite emission index, has an average of 2.008 with a standard deviation of 1.259, reflecting a high dispersion of levels of emissions. The values range from a minimum of 0.535 to a maximum of 4.398, so the dispersion of the emissions is wide across observations. The average renewable energy consumption stands at 6.117, while the standard deviation is 3.296, reflecting the remarkable diversity in renewable energy uses.

Table 1: Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
emission	58	2.008	1.259	0.535	4.398
REC	58	6.117	3.296	2.759	15.946
FF	58	93.397	3.957	81.706	97.241
GDP growth	58	0.061	0.044	-0.038	0.154
Trade Open	58	28.494	17.513	4.921	64.479
Urban	58	32.381	13.260	17.208	55.901

As illustrated in Table 2, the correlation matrix expresses a strong positive relationship between the emission index and renewable energy consumption. This implies that the higher the renewable energy consumption, the higher the emission. In turn, there is a high negative correlation between emissions and fossil fuel consumption -0.9033 . This indicates that a high amount of fossil fuel used corresponds to low emissions in the dataset. The variables of emission and trade openness are positively correlated, with a correlation coefficient of 0.7612 , indicating higher emissions with greater trade openness.

The results of the ADF tests show that the emissions index, renewable energy consumption, and several other variables are non-stationary at levels. First differencing makes the emission index and renewable energy consumption stationary, implying that changes in them across time are constant and not driven by trends. On the other hand, urbanization remains non-stationary even after first differencing and hence will be excluded from the ARDL model analysis. However, GDP growth is stationary at levels, indicating that its trend is stable and requires no differencing.

Table 2: Correlation Matrix

Variables	Emission	REC	FF	GDP growth	Trade Open	Urban
emission	1					
REC	0.9001	1				
FF	-0.9033	-0.9992	1			
GDP growth	0.0046	-0.1423	0.1341	1		
Trade Open	0.7612	0.5139	-0.5253	0.2436	1	
Urban	0.9758	0.8826	-0.8874	0.0327	0.8374	1

4.2. Analysis of Composite Index: Trends and Changes

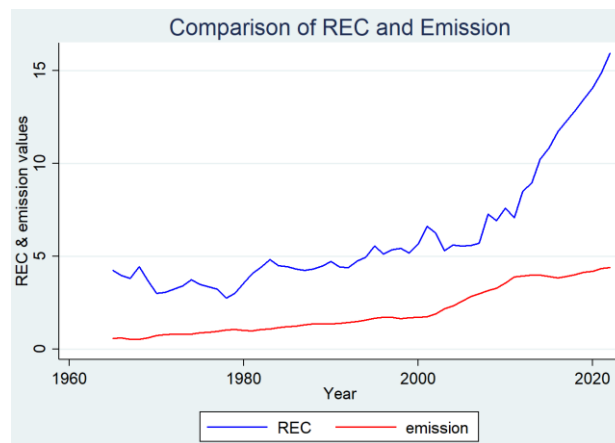


Figure 1: Trends comparison for Renewable Energy consumption and Composite Emissions Index

The graph indicates that the composite emissions have been smoothly on the rise from 1960 to 2020. It most likely mirrors the worldwide trend of expanding greenhouse gas emissions as an outcome of industrialization, economic growth, and rising energy use [24]. There have been periods where this increase happened more slowly, for example, during the 1980s and early 1990s. Generally speaking, though, it would appear to be a continuing problem.

This makes the evaluation of drivers behind that trend all the more necessary. Doubtless, economic growth, industrial activity, population increase, and improvement of living standards have contributed to increasing energy demand and related emissions. Technological change is thus both an opportunity and a challenge. While energy efficiency and renewable energy innovations can mitigate—and abate—emissions, their diffusion and scale are still relatively small compared to continued fossil fuel use. Policies—like emission regulations or carbon pricing—are what can eventually shift these trajectories, but their effectiveness is worsened or improved by the extent of their enforcement in reality and the clean energy available. In summary, a growing trend in emissions puts the world on high alert; therefore, holistic and well-coordinated approaches are needed to address the crisis by pushing economies onto low-carbon trajectories and quickly ramping up sustainable practices.

4.3. Impact of Renewable Energy on Composite Emissions Index

The ARDL model delineates the short-run association between renewable energy consumption and composite emissions. The results displayed in Tables 3, 4, and 5 are important in establishing the relationship between renewable energy consumption and the composite emissions index, as well as the strength and reliability of the ARDL model applied in this analysis.

The results for the ARDL bounds test indicate an F-statistic value of 3.196, which falls between the lower bound I (0) value of 2.45 and the upper bound I(1) of 3.52 at a 5% significance level, hence inconclusive in terms of the existence of a long-run relationship between the variables. Therefore, this study focuses mostly on the short-run relationships using the ARDL model and does not estimate an error correction model.

Table 3: ARDL bounds test

	Estimation	I (0)	I (1)
F-statistics	3.196	2.45	3.52
K	4	2.86	4.01
		3.25	4.49
		3.74	5.06

Lagged Emission Index (L1.1_emission and L2.1_emission): The first lag of the emission index, L1.1_emission, does come as expected—a statistically significant coefficient of 1.029 with $p < 0.001$. This suggests that past emissions strongly feed into the present levels of emissions. Past emissions act as strong determinants of the current level of emissions. Hence, the positive coefficient would indicate a very high extent of persistence in the levels of emissions over time. The second lag is ineffective; thus, it would not affect current emissions.

1_REC: Renewable energy consumption has an immediate negative effect on the emission index, with a coefficient of -0.214 at $p = 0.025$. This shows that in the short run, rising renewable energy consumption causes a drop in emissions. Nevertheless, in the first lag of renewable energy consumption, L1.1_rec shows a positive coefficient, 0.143 , with $p = 0.042$, indicating that such an initial reduction could be offset in subsequent periods.

Fossil Fuel Consumption (1_FF): The coefficient for Fossil Fuel Consumption is negative (-0.691), but it is statistically not significant with $p = 0.382$. That means that while there is a negative relationship between fossil fuel consumption and emissions, it is not strong enough to drive home conclusive deductions.

The overall fit of the model is thus very high, with an R-squared value of 0.9969 , which means that the model explains around 99.69% of the variability in the emission index. The F-statistic also comes highly significant: $F(8, 47) = 1903.47$, thereby proving the model's robustness.

The results of the post-diagnostic tests provide very important information regarding the validity of the model. First, the Jarque-Bera Test results indicate that, with a p-value of 0.0000 , the residuals are not normally distributed. This may indicate some misspecification in the model or outlier effects in the distribution of residuals. Second, the results show that there is no serial correlation in the residuals with $p = 0.7209$. It shows that the model does not suffer from autocorrelation, and the estimates are efficient. Finally, there is no evidence of heteroscedasticity with $p = 0.1403$. Thus, it can be assumed that the variance of residuals is constant, and therefore, the model estimations are reliable.

Furthermore, this study ensures the robustness and stability of the ARDL used with CUSUM and CUSUMSQ tests. The tests have a certain significance in checking the goodness of fit of a model and ascertaining its strength over time by detecting structural breaks or instability of parameters. The results show that, in this study, both the CUSUM plots lie within the 5% critical bounds but not the CUSUM square, indicating that the parameters of the ARDL model are not stable over time. The instability specifies that the model is not robust and the estimated coefficients are not fully reliable, necessitating strengthening the results' validity derived from the model.

Table 4: ARDL Model Results

l emission	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
l emission						
L1.	1.029	0.133	7.76	0.000	0.762	1.296
L2.	-0.048	0.140	-0.34	0.733	-0.330	0.234
l REC						
-.	-0.214	0.092	-2.32	0.025	-0.399	-0.028
L1.	0.143	0.068	2.09	0.042	0.005	0.281
l FF	-0.691	0.782	-0.88	0.382	-2.265	0.883
l TradeOpen						
-.	-0.022	0.047	-0.47	0.641	-0.116	0.072
L1.	0.043	0.051	0.85	0.402	-0.060	0.147
GDP growth	0.507	0.141	3.58	0.001	0.222	0.791
_cons	3.204	3.643	0.88	0.384	-4.124	10.532
No. of obs. = 56						
F (8, 47) = 1903.47						
R-squared = 0.9969						
Adj. R-squared = 0.9964						

Table 5: Diagnostic Testing Results

Diagnostic investigates	Coefficient	p-value	Decision
Jarque-Bera test	121.5	0.0000	Residuals are not normally distributed
Breusch-Godfrey LM test	0.128	0.7209	No serial correlation exists
White test	54.16	0.1403	No heteroscedasticity exists

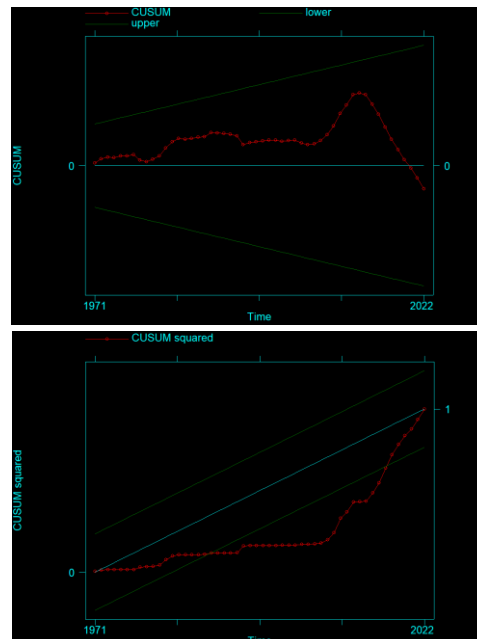


Figure 2: Stability Test

The analysis has complex relations between renewable energy consumption with emissions. While it is true that renewable energy use tends to reduce emissions at the starting point, the effect may

decline over time, thus requiring serious efforts in sustained and increased shifting to clean energy. The strong influence of economic growth on emissions underlines the challenge of balancing economic development and environmental sustainability. Despite the model's strength, non-normality in residuals would perhaps require further refinements to account for all dynamics at play.

Results from the ARDL model showed that there is a significant relationship between renewable energy consumption and reduction in emissions in the short run. However, it is very hard to establish a long-run relationship, probably due to the interaction of a lot of complex variables that affect emissions. Further study is required to understand the dynamics in the long term and to rectify the non-normality of the residuals.

4.4. Benchmark Analysis

Analyses of the composite emission index benchmark against the greenhouse gas index reveal some important facts. Both of them have upward trends, indicating that the general increase in emissions over time is imminent, but the rate of growth expressed by the composite emission index is faster than that of the GHG index, suggesting that it may be able to capture other factors or a wider range of emissions. The very high positive correlation of the two indices confirms their converging nature: with growing GHG emissions, so does the composite index; therefore, it further validates the composite measure. The deviation chart is one of the differences between the indices, all below 1 in value, again showing close convergence. Nonetheless, the huge swing to deviate from -1.2 to -0.8 can still be a telling sign of divergence, perhaps caused by changes in the specific components of the emissions or some exogenous factors bearing down on this composite index.

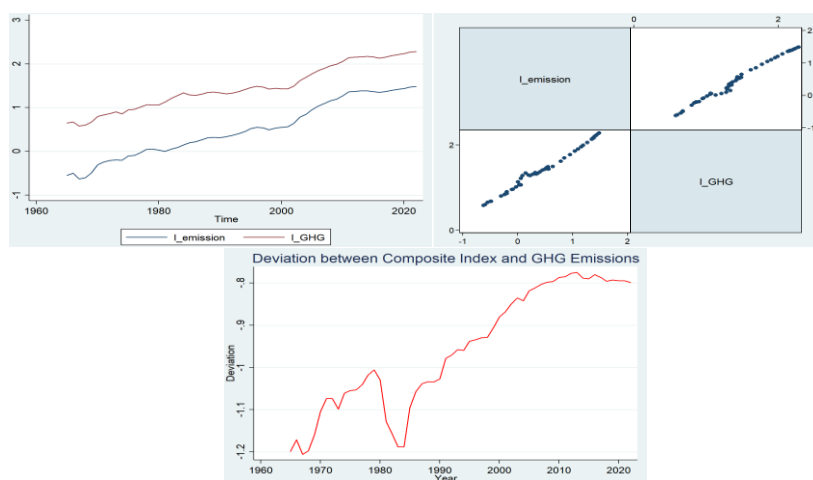


Figure 3: Benchmark Analysis

5. Conclusion

The underlying research focuses on the relationship between the adoption of renewable energy and the composite emissions index in China. This covers the period 1965 to 2022. The results show that there is a clear declining trend in the composite emission index correlated with increasing renewable energy adoption. The analysis reveals that renewable energy, especially from wind and sun, is already making a big difference by contributing to reductions in CO₂, CH₄, and NO₂ emissions and underlines a critical role in promoting carbon neutrality. Offsetting these positives to a degree, benchmark analysis against global standards indicates that, despite these trend spotting, China still has a lot of work to do, especially in the reduction of dependency on fossil fuels to bring about more substantial emissions reductions. These findings underline the need for accelerated continuation of renewable

energy transition if ambitious goals set concerning carbon neutrality and environmental sustainability are to be achieved.

Based on the findings of this study, the following policy recommendations are put forward to consolidate China's progress toward carbon neutrality. First and foremost, increase investment in renewable energy technologies. This means not only boosting the scale of infrastructure for wind and solar power but also encouraging innovations related to energy storage and smart grid technologies that can make integration into the national grid more efficient. Second, actual stricter emissions regulation is required. This may involve the setting of more aggressive reduction targets, compliance mechanisms, and even penalties for non-compliance. Thirdly, enhancing energy efficiency in the industry, residential, and transport sectors shall help reduce total energy use and, accordingly, emissions. These policies will be helpful not only in the pursuit of carbon neutrality by China but also by the world at large in mitigating climate change.

This study recognizes full well some of its major shortcomings in the matter of generalization of findings. The first limitations lie in the fact that secondary data was used, meaning the data used could not have all the independent variables related to the situation at hand or the most current trends. Moreover, the methodology applied, though quite strong, has its limitations in taking into due account intricate interplays between variables with time. Future research should examine the inclusion of other indicators of the environment with quality metrics for water and air, bringing a well-rounded overview of the issue of sustainability. In addition, investigating China's regional differences would provide insight into how local policies and economic conditions could impact the effectiveness of fostered renewable energy adoption and efforts toward emission reduction.

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