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The Nexus Among CO_2, Renewable Energy, Agricultural Production and Financial Development: Empirical Evidence from China and India

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ABSTRACT

This study examines the relationship between CO_2, Renewable Energy, Agricultural Production and Financial Development for the 30-year period of 1993-2022 in China and India. The data for our variables, CO_2 and Renewable Energy, were obtained from the official website of the World Bank, the Agriculture data from the official website of the Food and Agriculture Organization of the United Nations, and the Financial Development data from the official website of the International Monetary Fund. Our article was evaluated by empirical analyzes examining long-term and short-term relationships, as well as Multiple Regression Analysis, ADF and PP unit root tests, Johansen Cointegration test, VAR Analysis, Impulse Response analysis, Variance Decomposition analysis, FMOLS, DOLS and CCR analyzes. According to the analysis results, the model has a strong explanatory power of 99.48% in China and 99.54% in India. In addition, it was determined that agricultural activities increase CO_2 emissions, while the use of renewable energy reduces emissions. It was observed that the effect of financial development on CO_2 emissions was not statistically significant, but it could have indirect effects. Analyses conducted specifically for China and India revealed the strong effect of the agricultural sector on carbon emissions and emphasized that sustainable agricultural practices and green financing projects should be encouraged. In line with these results, supporting financial development with environmentally friendly policies, prioritizing green financing projects, and implementing incentives that will increase renewable energy use will contribute to controlling CO_2 emissions in the long term.

Keywords: CO_2 Emissions, Renewable Energy, Agricultural Production, Financial Development, Time Series
JEL Classifications: Q53, Q2, Q1, G00, C22

1. INTRODUCTION

Climate change and sustainable development policies, which are among the most debated issues of our day, are seen to have strategic importance for both developed and developing countries. Global warming and climate change concerns have revealed the necessity of reducing CO_2 emissions created by fossil fuel consumption. In this context, the dissemination of renewable energy technologies plays a key role in controlling emissions. According to the International Energy Agency (IEA, 2021) report, the transition from fossil fuels to renewable energy sources is seen as one of the most important tools for achieving CO_2 emission reduction targets, especially in developing economies with large populations such as China and India. This transformation is made possible by supporting technological innovations and energy efficiency improvements (IEA, 2021).

Agricultural production stands out as a critical element of both economic growth and environmental sustainability. The agricultural sector is of vital importance in terms of food security, rural development and environmental sustainability. However, intensive agricultural activities can increase environmental pressures due to increased energy use and chemical inputs. In addition, the United Nations Food and Agriculture Organization

(CPI and FAO, 2024) report is the first comprehensive analysis addressing climate finance needs for agricultural systems. The report emphasizes that low-carbon and resilient agricultural systems are vital for ensuring food security and sustainable development of a growing human population and global economic development. In this context, increased financial support will reduce carbon emissions and climate change.

Increasing financial development facilitates the implementation of innovative projects in these sectors through risk distribution and capital mobilization. Again, according to World Bank (2021) data, it is observed that financial market development in developing economies positively affects investments in energy transformation and environmental technologies. This situation is similar in the examples of China and India; financial development supports both the increase in renewable energy capacity and the spread of sustainable practices in the agricultural sector (World Bank, 2021). In another report by World Bank (2025), it is emphasized that the transition to renewable energy technologies plays a critical role in reducing CO_2 emissions.

In this regard, when we examine China, it has implemented comprehensive state-supported policies in the last decade to support economic growth strategies and technological transformation. The "14th Five-Year Plan" documents published by China's National Development and Reform Commission (NDRC) reveal that the country supports renewable energy, agricultural modernization, environmental sustainability with state incentive mechanisms, tax reductions, subsidies, and low-interest loan practices. In addition to accelerating industrial transformation, the documents also aim to develop environmentally friendly production models by increasing agricultural productivity and integrating energy efficiency practices into the agricultural sector (National Development and Reform Commission, 2024).

In India, the government's financial reforms supported by strategic initiatives such as "Make in India" and "Digital India" are being implemented within the framework of comprehensive incentive programs such as agricultural modernization and strengthening rural development. The Economic Survey 2020-2021 report published by the Ministry of Finance of India reveals that modern agricultural techniques and renewable energy integration in the agricultural sector contribute to food security by increasing productivity and play a critical role in achieving environmental sustainability goals (Ministry of Finance, Government of India, 2021). These reforms pave the way for significant developments in areas such as financial development, energy efficiency, renewable energy investments and agricultural modernization in line with the country's sustainable development goals.

Both countries are increasing financial support for renewable energy investments and green technologies by supporting agricultural modernization through financial reforms and international collaborations. The World Bank (World Bank, 2021) reports argue that these reforms implemented in China and India have positive results in increasing energy efficiency in the agricultural sector and reducing environmental impacts. In addition, Unoosa and Fao (2025) emphasize in their publication titled "Using Space Technology for Agricultural Development and Food Security" that modern agricultural techniques and renewable energy applications are effective in increasing productivity and ensuring environmental sustainability. This comprehensive range of policies makes not only industrial and technological innovation but also developments in the agricultural sector part of a holistic strategy in the economic transformation processes of China and India.

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In this context, the data of our article, which examines the relationship between CO_2 emissions, renewable energy, agricultural production and financial development in the example of China and India, was used between 1993 and 2022. The data of our variables, CO_2 and Renewable Energy, were obtained from the official website of the World Bank, Agriculture data from the official website of the Food and Agriculture Organization of the United Nations, and Financial development data from the official website of the International Monetary Fund. Our article was evaluated by conducting empirical analyzes examining long-term and short-term relationships, as well as Multiple Regression Analysis, ADF and PP unit root tests, Johansen Cointegration test, VAR Analysis, Impulse Response analysis, Variance Decomposition analysis, FMOLS, DOLS and CCR analyzes. Thus, as a result of the findings we obtained, it will show policy makers and researchers how important the investments to be made in renewable energy technologies and sustainable agricultural practices by deepening financial systems for climate change play. In addition, it will shed light on the studies that will positively affect climate change by reducing carbon emissions.

2. LITERATURE REVIEW

Global climate change, carbon emissions, renewable energy use, sustainable agricultural production and financial support on these issues have been discussed intensively in academic literature in recent years. Especially in countries with rapid economic growth such as China and India, the interactions of these dynamics are of great importance. When we examine both international and domestic literature, it is seen that there are many studies that address each variable with different variables.

In recent academic literature, a significant number of studies have explored the relationship between environmental degradation, economic development, and policy interventions. Many of these studies focus on the Environmental Kuznets Curve (EKC) hypothesis, assessing its validity across different economic and geographical contexts. In this regard, various scholars have examined the impact of factors such as trade liberalization, energy consumption, and institutional quality on environmental sustainability. Notable contributions in this field include works by Kalayci (2020), Öztürk (2021), Bahadir (2022), Dursun (2022), Yazici (2022), Kayabas (2022), Kirikkaleli et al. (2021), Sarigul and Apak (2024) who have investigated the link between economic activities and ecological outcomes from both theoretical and empirical perspectives.

In the literature, it is seen that articles written especially on environmental pollution are conducted within the framework of the Environmental Kuznets Curve (EKC) hypothesis when associated with growth. For example, Efeoğlu (2022) conducted a panel data analysis with fixed effects and the Parks-Kmenta Estimator model in the E7 countries for the period 1989-2016 and confirmed the validity of the EKC hypothesis. Again, Oğul (2023) examined agricultural value added, economic growth, renewable energy consumption and trade openness rate with ARDL analysis in the example of Turkey and found that developments in the agricultural sector may increase environmental pollution, but renewable energy consumption reduces CO_2 emissions. This study found that economic growth, agricultural production and trade liberalization lead to environmental pollution in the long term; and the EKC hypothesis is valid with the inverted-U shaped relationship. Ozdemir and Koç (2020) tested the EKC hypothesis in Turkey and determined the positive effects of energy use, the negative effects of renewable energy, and the positive effects of trade openness; Han (2024) showed that there was no direct causality between carbon emissions and economic growth in BRICS-T countries, but found a one-way causality relationship from carbon emissions to renewable energy and from economic growth to renewable energy. Shahbaz et al. (2015) and Leitão (2014) found that the EKC hypothesis was confirmed in both the short and long term in their analysis conducted for Portugal and revealed that energy consumption and globalization have positive effects on economic growth. Similarly, for Turkey, Ozturk and Acaravci (2013) examined the relationship between variables such as financial development, trade openness and energy consumption and CO_2 emissions and found that the EKC hypothesis is valid for Turkey. Okumuş (2019) analyzed the relationship between variables such as agricultural value added, economic growth, non-renewable and renewable energy consumption, urbanization, and trade openness rate with CO_2 emissions using the ARDL method over the data for the period 1968-2014 in Turkey; and found a significant relationship between all variables in the model in the long term. In the research confirming the existence of the CCE hypothesis in Turkey, it was determined that agricultural production, trade liberalization and urbanization in particular increased CO_2 emissions, while renewable energy consumption reduced carbon emissions in the short term.

Haseeb et al. (2019) found both short and long term positive effects of renewable energy on economic welfare in Malaysia in their study and supported it with policy recommendations advocating the increase of green energy production. Maradin (2021) generally discussed the advantages and disadvantages of renewable energy sources and emphasized the positive aspects such as environmental protection, emission reduction and technological development as well as the limitations such as dependence on weather conditions in energy production. Rusiadi et al. (2024) stated that renewable energy, natural resources and foreign direct investments positively affect economic growth, but CO_2 emissions do not have a significant effect on growth, and thus the region is turning to clean energy. In the study conducted for South Africa (Khobai and Roux, 2017), a bidirectional relationship was found between energy consumption and economic growth in the causality analysis and long-term relationships were emphasized between energy consumption, emissions and economic growth. Kurmanov et al. (2025), who analyzed the relationship between information and communication technologies (ICT), energy consumption and economic growth in Central Asian countries, stated that digitalization positively affects economic growth in Kazakhstan and Uzbekistan and that trade openness plays an important role in growth.

It has been observed that similar results have been reached especially in studies conducted on financial development and renewable energy. In the study of Aslan and Ataklı Yavuz (2023), in the panel data analysis conducted with the sample of BRICS and MINT countries, it was determined that there is a long-term cointegration relationship between renewable energy, financial development and economic growth; in addition, unidirectional causality relationships from financial development to economic growth and renewable energy were determined. These findings show that the financial system and renewable energy investments play an important role in terms of environmental sustainability in developing economies. Çağlar and Kubar (2017), while examining the relationship between financial development and energy consumption for Turkey, expressed energy consumption separately as fossil and renewable; using the structured Fourier Toda Yamamoto causality approach, they determined the causality relationship of financial development to fossil fuel consumption. This result shows that financial markets affect energy consumption based on fossil fuels and therefore contribute to environmental pollution. Yıldırım and Şenol (2024) examined the causality relationship between financial development and renewable energy consumption using data from 14 European countries and Turkey in the period 2004-2019; they determined a one-way causality from renewable energy consumption to the financial development index, indicating that renewable energy investments will be supported through financial markets. While examining the asymmetric causality relationship between agricultural loans and financial development in the period 2005-2013, Çevik and Zeren (2014) revealed that positive shocks Granger cause financial development; this shows that the agricultural sector still has an important place in the financial structure. Taşkın and Vardar (2016), on the other hand, discussed the use of renewable energy sources in agricultural production and emphasized that renewable energy applications can contribute to energy security and socio-economic development in agriculture, considering the increasing cost of fossil fuels and environmental pollution. Yıldırım and Everest (2020) examined the climate change and renewable energy awareness levels of cooperative managers, and concluded that education and awareness-raising activities could be important in reducing the environmental impacts of agricultural production. Karaca (2013), while evaluating sustainable agricultural policies, argued that the use of renewable energy resources in agriculture would increase environmental quality and support rural development.

In addition, Kalayci and Artekin (2024) evaluated CO_2 emissions in their article. And again, Bese and Kalayci (2021) addressed the EKC hypothesis for CO_2 emissions. In a similar study published in 2023 as a method, I examined the relationship between loans and R&D investments, which are among the supporters of financial growth, and economic growth, and as a result, I found that the variables had an empirically significant relationship with each other (Çelik, 2023). Finally, the Aydın and Çamkaya (2024) study examined the effects of nuclear and renewable energy consumption on carbon emissions and health expenditures, emphasizing that the use of clean energy can be beneficial for both the environment and public health.

According to the panel data analysis by Yang and Lo (2024), increasing renewable energy consumption in China reduces CO_2 emissions by reducing energy intensity. This study shows that technological innovations and financial support mechanisms are effective in improving environmental performance.

India, as an economy with a dense population and significant agricultural production, focuses on energy efficiency and green agricultural practices. The ARDL approach-based study conducted by Sahu and Kumar (2020) revealed that renewable energy consumption plays a decisive role in reducing CO_2 emissions in India. It has also been empirically found that financial development indicators support renewable energy investments and agricultural modernization.

In general, the literature review we examined nationally and internationally summarizes the findings of studies examining the effects of industrialization, energy consumption, agricultural production, financial development and renewable energy use on CO_2 emissions with various methodologies (panel data analysis, ARDL bounds test, causality tests, etc.) and shows that the interaction between these dynamics offers important implications for policy makers, especially for developing economies (e.g. China and India), in the light of both Turkish and international examples.

3. METHODOLOGY AND MODEL

This study examines the relationship between CO_2, Renewable Energy, Agricultural Production and Financial Development in China and India for the 30-year period from 1993 to 2022.

3.1. Data

This study examines the relationship between CO_2, Renewable Energy, Agricultural Production and Financial Development for China and India over the 30-year period from 1993 to 2022. The data for our variables, CO_2 and Renewable Energy, were obtained from the official website of the World Bank, the Agriculture data from the official website of the Food and Agriculture Organization of the United Nations, and the Financial Development data from the official website of the International Monetary Fund.

3.2. Methodology

Our article is evaluated by empirical analysis of long-term and short-term relationships, Multiple Regression Analysis, ADF and PP unit root tests, Johansen Cointegration test, VAR Analysis, Impulse Response analysis, Variance Decomposition analysis, FMOLS, DOLS and CCR analyses.

$$\ln (CO_2)_t = \alpha_0+\alpha_1 \ln (YEN\_EN)_t + \alpha_2 \ln (TAR)_t + \alpha_3 \ln(FIN\_GEL)_t + e_t \quad (1)$$

$$\ln (CO_2)t = \alpha_0+\alpha_1 \ln(YEN\_EN)_t+\alpha_2 \ln(TAR)_t+\alpha_3 \ln(FIN\_GEL)_t+e_t \quad (2)$$

3.3. Modelling

$$\ln (CO_2)_t = V_0+V_1 \ln(YEN\_EN)_t +V_2 \ln (TAR)_t +V_3 \ln (FIN\_GEL)_t+ b_t \quad (3)$$

The relationship between the variables is examined with FMOLS, DOLS and CCR model (Equation 4). N is for long run coefficients and M is for short run coefficients for the related variables. b_t is for white noise residuals. Logarithmic form of the variables is used except FF and INFS.

$$\Delta LnCO2_t = N_0 + N_1 LnCO2_{t-1} + N_2 YEN\_EN_{t-1} + N_3 lnTAR_{t-1} + \sum_{i=1}^{s} M_{1i} \quad LnCO2_{i-1} + \sum_{i=0}^{h} M_{2i} \quad YEN\_EN_{i-1} + \sum_{i=0}^{c} M_{3i} \quad TAR_{i-1} + \sum_{i=0}^{m} M_{4i} \quad LnFIN\_GEL_{i-1} + b_t \quad (4)$$

Hypothesis of no cointegration is $H_0 = N_1 = N_2 = N_3 = N_4 = 0$

Hypothesis of cointegration is $H_1 = N_1\ No_2\ No_3 \neq N_4 \neq 0$

After cointegration is confirmed, long run coefficients are calculated according to the model of FMOLS, DOLS and CCR in equation 4. Short-run coefficients are calculated as in equation 3.

4. ANALYSIS OF RESULTS

In Table 1, logarithms of all our variables were taken to prevent the explosion of variance that may occur in our Multiple Regression analysis. Then, @trend was added to our model to find the spurious regression that may occur between our variables, and AR(1) term was added to our model to find the random distribution of error terms and residuals. After all these operations, the following data belonging to our multiple regression analysis were obtained.

4.1. Multiple Regression Analysis

According to the data of the China country analysis in Table 1, it was determined that the power of our independent variables to explain the dependent variable was quite high and significant with a rate of 99.48% with the R-squared (R^2) value of 0.994842. The Adjusted R-squared (Adjusted R^2) value showed that our independent variables made a significant contribution to our model with 0.993496. Another value showing that our model is significant is Prob (F-statistic) with 0.000000. Again, since the Durbin-Watson statistic value is close to 2 with 1.96, it was seen that autocorrelation is not a major problem.

When other data are examined, although the coefficient of our financial development variable is positive and increases CO_2 emissions with a value of 0.273806, it is determined that it is not statistically significant since the P value is above 0.05 with 0.1730. Agricultural production, on the other hand, is seen to increase CO_2 emissions quite strongly with a coefficient of 0.9054 and a P = 0.0000. In other words, with the results obtained, it is determined that a one-unit increase in agricultural production in the short term increases CO_2 emissions by approximately 0.90 units. The coefficient of the increase in renewable energy use is −0.4530 and with the negative value it takes, it is determined that a one-unit increase in renewable energy use reduces CO_2 emissions by 0.45 units in the short term.

According to the data of India country analysis in Table 2, it was determined that the power of our independent variables to explain the dependent variable was quite high and significant with a rate of 99.54% with R-squared (R^2) value of 0.995435. The Adjusted R-squared (Adjusted R^2) value showed that our independent variables made a significant contribution to our model with 0.994244. Another value showing that our model is significant is the F-statistic of 835.9043 and the corresponding Prob (F-statistic) of 0.000000. Again, it was seen that it was above the ideal value expected from the Durbin-Watson statistics with 2.0074 and it was determined that there was no autocorrelation.

When we look at the short-term effects of our independent variables on our dependent variable CO_2, it is seen that the effects of agricultural production and financial development variables are not statistically significant since the P value is above 0.05 and we cannot say whether they exactly affect CO_2 emissions. The renewable energy variable stands out as the most important and significant variable. The negative value it takes with its coefficient of −1.5051 shows that as the use of renewable energy increases, there is a significant decrease in CO_2 emissions.

4.2. Autocorrelation Graph

When we examine our autocorrelation graph in Figure 1, it is seen that all the residues are randomly distributed and it is clearly found that there is no autocorrelation problem.

4.3. Unit Root Tests

In order to perform our next test, the Johansen Cointegration test, all the numbers that were not stationary at the I(0) level in the ADF/PP unit root tests were made stationary by taking their differences from the 1st degree of I(1) in all country data in Table 3. Our variables that were not stationary at the I(1) level, CO_2 and Renewable energy, were made stationary in I(2) and then the Johansen cointegration test was carried out.

4.4. Johansen Cointegration Test Results

In Table 4, in the Johansen Cointegration test that we conducted to find the long-term balance relationship between the variables, the trace statistic is expected to be greater than the critical value and the P-value is expected to be <0.05. In this case, in the "r=0" and "r=1" hypotheses for China, the trace statistic is greater than the critical value and the P < 0.05, and both hypotheses are rejected. Thus, it is seen that there are at least two cointegration relationships. In the "r=2" and "r=3" hypotheses, the hypothesis could not be rejected because the desired values could not be obtained, and it was seen that there was no cointegration at these stages. As a result, it was determined that there is a long-term balance relationship between the two variables for China.

In the analysis of India, the hypothesis "r=0" was rejected, but the hypotheses "r=1", "r=2", "r=3" could not be rejected because the desired values were not reached. As a result, it was determined that there was only one cointegration relationship for India. It was seen that our variables moved together in the long run but in a single common equilibrium relationship.

4.5. VAR Analyses

In Figure 2, which belongs to the Var analysis, which is another analysis we carried out to detect stationarity, it was seen that all

Table 1: Multiple regression analysis for China

Dependent V: CO_2, Sample: 1993-2022				
Independent variable	Coefficient	Standard error	t-statistic	Probability
FIN_GEL	0.273806	0.194691	1.406365	0.1730
TAR	0.905378	0.141629	6.392602	0.0000
YEN_EN	−0.453035	0.151732	−2.985751	0.0066
C	6.348649	0.896239	7.083657	0.0000
AR (1)	0.795626	0.202953	3.920243	0.0007
R-squared		0.994842	Mean dependent var	8.755901
Adjusted R-squared		0.993496	S.D. dependent var	0.486582
F-statistic		739.3070	Durbin-Watson stat	1.960944
Prob(F-statistic)		0.000000	Inverted AR Roots	0.70

Table 2: Multiple regression analysis for India

Dependent V: CO_2, Sample: 1993-2022				
Independent variable	Coefficient	Standard error	t-statistic	Probability
FIN_GEL	0.131748	0.254035	0.518621	0.6090
TAR	0.208654	0.215262	0.969305	0.3425
YEN_EN	−1.505131	0.325377	−4.625811	0.0001
C	12.07780	1.689420	7.149078	0.0000
AR (1)	1.448732	0.348108	4.161727	0.0004
R-squared		0.995435	Mean dependent var	7.270410
Adjusted R-squared		0.994244	S.D. dependent var	0.454410
F-statistic		835.9043	Durbin-Watson stat	2.007449
Prob (F-statistic)		0.000000	Inverted AR Roots	0.98

Table 3: ADF and PP unit root tests for China and India at I (0), I (1) and I (2) levels

Variables	ADF unit root test I (0)		ADF unit root test I (1) and I (2)	
	Countries		Countries	
	China	India	China	India
CO_2	−0.678200 (−2.971853)	1.153853 (−2.967767)	−2.606973 (−2.971853) −4.241423* (−3.020686)	−5.260083 (−2.971853)
YEN_EN	−1.693171 (−2.971853)	−1.750051 (−2.967767)	−2.157152 (−2.971853) −3.167037* (−3.012363)	−3.758424 (−2.971853)
TAR	−0.786326 (−2.986225)	0.666256 (−2.967767)	−3.170668 (−2.986225)	−6.252544 (−2.971853)
FIN_GEL	−0.703193 (−2.967767)	−1.645844 (−2.967767)	−6.273723 (−2.971853)	−4.675106 (−2.971853)
Variables	**PP unit root test I (0)**		**PP unit root test I (1)**	
	Countries		**Countries**	
	China	**India**	**China**	**India**
CO_2	−0.234987 (−2.967767)	1.554314 (−2.967767)	−2.600994 (−2.971853) −10.42412* (−2.986225)	−5.260083 (−2.971853)
YEN_EN	−1.482345 (−2.967767)	−1.520655 (−2.967767)	−2.209794 (−2.971853) −10.86800* (−2.986225)	−3.903449 (−2.971853)
TAR	−0.736677 (−2.967767)	2.198226 (−2.967767)	−7.360042 (−2.971853)	−6.350000 (−2.971853)
FIN_GEL	−0.647039 (−2.967767)	−1.701624 (−2.967767)	−6.273723 (−2.971853)	−4.670087 (−2.971853)

The findings series at 5% significance level were taken into account. *Our variables that were not stationary at the I (1) level, CO_2 and Renewable energy, were made stationary in I (2).

points were located within the shape and it was determined that they were stationary.

4.6. Impact Response Analysis

When we examine the Impact Response analysis of China in Figure 3, the dependent variable CO_2 emissions shown by the blue line show a significant increase in the first period. However, there is a rapid decrease immediately after and it relatively stabilizes as of the third period. While it approaches a stationary point as of the 4th period, slight fluctuations continue and neutralize in the last period and approach zero. Our independent variable agriculture shown by the green line creates a negative shock in the first period and causes a decrease in CO_2 emissions. However, this effect weakens and becomes neutral in the second and third periods, suggesting that the effect of agricultural activities on CO_2 emissions may be negative in the short term but does not show a significant trend in the long term. Financial development shown by the red line has a positive effect in the first period, i.e. an increase in financial development is observed to increase CO_2 emissions. However, there is a rapid decrease in the second period and it becomes neutral as of the third period. This shows that financial development may initially increase carbon emissions but this effect decreases over time. In the medium term, the effect of financial development on CO_2 is seen to show a positive trend again, but it does not have a significant effect. The renewable energy variable shown with the black line is seen to have a negative effect in the first and middle periods and causes a decrease in CO_2 emissions. This confirms the CO_2 reducing effect of renewable energy use. However, its effect decreases over time and becomes neutral towards the last period.

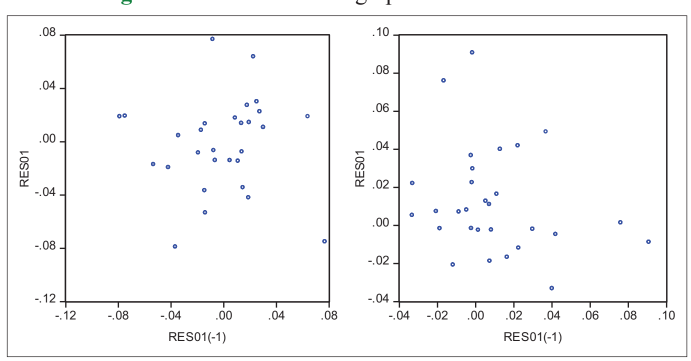
In the impact response analysis for India, a strong and sharp decrease is observed in CO_2 at the beginning, and this shows that our dependent variable is quite sensitive to shocks from independent variables in the first period. In the 3-6 period, it exhibits irregular fluctuations against the shocks of independent variables and is seen to become stable over time towards the last period. The effect of a shock from agriculture in our independent variable first goes up in the first period, then creates irregular fluctuations in the medium term and continues to approach zero in the last period. It can be said that the effect of agricultural activities on CO_2 is the variable that has the most effect in the short term. As for financial development, it is observed that fluctuations affect CO_2 slightly upwards and relatively more balanced in the short and medium term. This shows that financial development does not have a direct and rapid effect, but may cause some fluctuations over time. When we examine the renewable energy variable, it is seen that it gives a neutral response in the initial period and becomes

Table 4: Johansen cointegration test results for China and India

Country	H.	Eigenvalue	t-statistic	0.05 critical value	P*
China	r = 0	0.566462	51.77878	47.85613	0.0204
	r = 1, r ≥ 1	0.509965	30.04864	29.79707	0.0468
	r = 2, r ≥ 2	0.283621	11.50338	15.49471	0.1823
	r = 3, r ≥ 3	0.103172	2.831167	3.841466	0.0924
India	r = 0	0.583517	50.88956	47.85613	0.0252
	r = 1, r ≥ 1	0.463628	27.23997	29.79707	0.0959
	r = 2, r ≥ 2	0.279437	10.42091	15.49471	0.2497
	r = 3, r ≥ 3	0.056574	1.572413	3.841466	0.2099

Trace test expresses 3 cointegration equations at 0.05 level. *indicates that the hypothesis is rejected at 0.05 level.

Figure 1: Autocorrelation graph of China and India



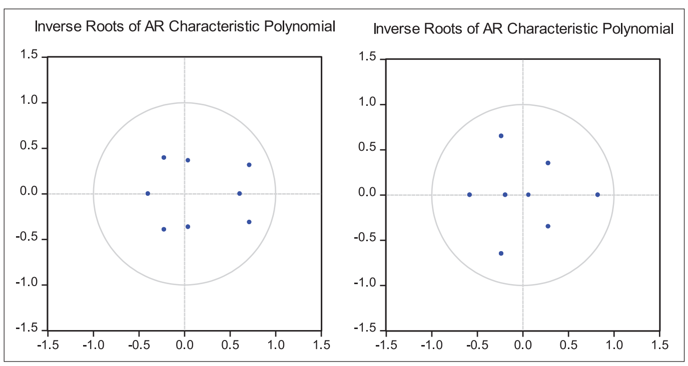
negative over time, and then in the medium term, the effect of its shocks is generally negative and shows a tendency to reduce CO_2 over time. This shows that although renewable energy investments do not significantly affect CO_2 emissions in the initial phase, they play a reducing role in the long term.

4.7. Variance Decomposition Analysis

In Table 5, in the Variance decomposition analysis of China, it was seen that the fluctuations on our dependent variable CO_2 were affected by its own shocks by 100% in the initial period, then as of the 2nd Period, other variables showed their effect, but the clearest CO_2 emission in the 4th period decreased to 68% and the effect of our independent variables began to become apparent. Although it showed minor changes until the last period, it was seen that in the 10th period, CO_2 was formed by its own shocks by 58.92% and renewable energy was the most affected by our independent variables with a rate of 31.58%, followed by agriculture with 7.41% and financial development with 2.08%.

Table 6. India In the variance decomposition analysis, it is seen that the fluctuations on our dependent variable CO_2 were affected by their own shocks at 100% in the beginning of the 1st period. With the 2nd period, the independent variables started to affect our dependent variable CO_2, but they started to become more pronounced after the 4th period. While our CO_2 variable was affected by its own shocks at 76.86%, agriculture had the most effect at 15%. In the last period, which is the 10th period, our CO_2 variable was affected by its own shocks at 74.52%, and it was found that our independent variable that affected our dependent

Figure 2: VAR analyses of China and India



variable CO_2 the most was agriculture at 15%. The effect of other independent variables was seen as 6.56% financial development and 3.5% renewable energy.

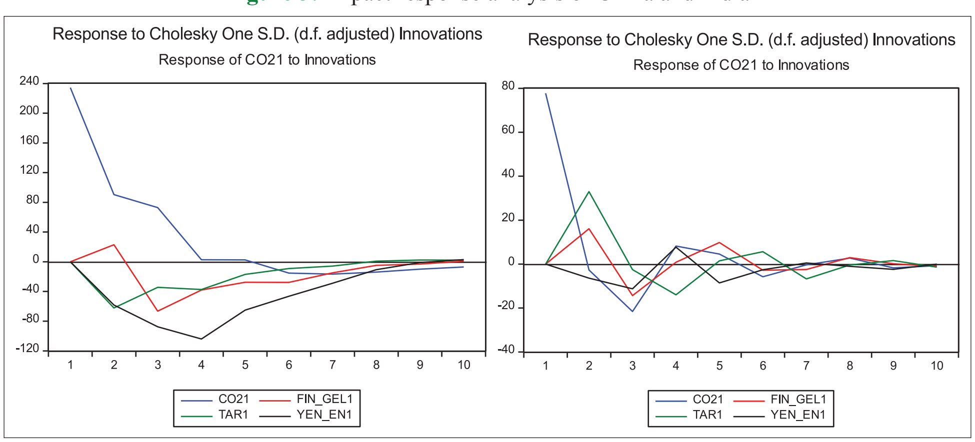
4.8. FMOLS, DOLS and CCR Analyses

When we examine the FMOLS analysis of China in Table 7, the financial development P value was obtained as 0.1316 and it was found to be statistically insignificant. According to other data, there is a positive relationship between financial development and CO_2 emissions. However, the fact that the variable is not statistically significant shows that the effect of financial development on CO_2 is not definite. Agriculture is statistically significant with P = 0.0038 and when we look at other values, it is seen that the T-statistic is 3.188563 and the coefficient is 78.09219 and it is determined that 1 unit increase in agriculture increases CO_2 emissions by 78.092 units. Renewable energy is statistically significant with P = of 0.0054, the T-statistic is negative as −3.048339 and the coefficient is 90.70850. This shows that 1 unit increase in renewable energy reduces CO_2 emissions by 90.70850 units.

According to DOLS analysis, the coefficient of financial development variable was found to be −5528.176, T-statistics −0.728222, P = 0.4785 and it was found to be statistically insignificant. Unlike FMOLS model, DOLS model shows that financial development reduces CO_2 emissions. However, the fact that this relationship is not statistically significant shows that the effect of financial development on CO_2 is not clear and reliable. The P-value of agriculture variable is statistically significant with 0.0015 and T-statistics 3.940658 and coefficient 153.988, and it was found that 1 unit increase in agriculture increases CO_2 emissions by 153.9887 units. Renewable energy T-statistics is −1.056040 and coefficient −46.24263, but it is not significant with P = 0.3088.

When we examined it in CCR analysis, financial development coefficient was obtained as 6447.521, T-statistic as 1.404015 but it was seen that it was not statistically significant with P = 0.1726. Agriculture variable was significant with P = 0.0067 and T-statistic as 2.956285 and coefficient as 77.11776, it was found that 1 unit increase in agriculture increased CO_2 emissions by 77.11776 units. Renewable Energy was also significant with P = 0.0068 and T-statistic as −2.949406 and coefficient as −93.58687 and it

Figure 3: Impact response analysis of China and India



was found that 1 unit increase in renewable energy use decreased CO_2 emissions by 93.58687 units.

As a result, all three models show that agriculture increases CO_2 emissions. While the fact that renewable energy reduces CO_2 emissions is supported in FMOLS and CCR analyses, it is not found significant in DOLS analysis. The effect of financial development on CO_2 is ambiguous and not statistically significant. The most critical message for policy makers is to continue to promote sustainable methods in the agricultural sector and to support the transition to renewable energy.

According to the results obtained from the FMOLS analysis of India in Table 8, although the Financial Development coefficient is −70.38474 and the T-statistic is −0.113273, it is not statistically significant with a P = 0.9107. This situation can be interpreted as the environmental effects of financial development in India have not yet become apparent or effective environmental policies are lacking. It is seen that the P-value of the agriculture variable is significant with a coefficient of 0.0000 and the coefficient is 26.44202, T-statistic: 10.17958, and that a 1 unit increase in agriculture increases CO_2 emissions by 26.44 units. Renewable Energy P-value is significant with 0.0044 and T-statistic is −3.131821, coefficient is −23.56687 and it is determined that 1 unit increase in renewable energy use reduces CO_2 emissions by 23.57 units.

According to DOLS analysis, financial development T-statistics were found to be 0.373997, coefficient was found to be 278.8980 and P-value was found to be insignificant with 0.7140. Agriculture variable T-statistics were found to be 1.346500, coefficient was found to be 10.21368 and P-value was found to be 0.1995, this variable was also not significant. Renewable energy, P = 0.0045 was significant, T-statistics were found to be −3.379414 and coefficient was found to be −67.26183, it was found that a one-unit increase in renewable energy consumption reduced CO□ emissions by approximately 67 units in the long term.

In the CCR analysis, although it was observed that financial development had a negative effect with T-statistics −0.030150 and coefficient −17.06542, it was found to be statistically insignificant with P = 0.9762. Agriculture P = 0.0000 was significant, with T-statistics 8.984148 and coefficient 26.48771, it was found that one unit increase in agricultural activities increased CO_2 emissions by approximately 26.49 units. Renewable energy, on the other hand, was found to be significant with P = 0.0109, with T-statistics −2.750828 and coefficient −23.22077, it was found that one unit increase in renewable energy use reduced CO_2 emissions by approximately 23.22 units.

Table 5: Variance decomposition analysis of China

Prd	Standard error	$CO_2$1	FIN_GEL1	TAR1	YEN_EN1
1	281.2836	100.0000	0.000000	0.000000	0.000000
2	413.5256	91.96981	0.471290	5.330763	2.228132
3	488.2141	79.29093	2.073630	8.263556	10.37188
4	532.8873	68.60761	2.311751	8.502401	20.57824
5	560.3277	62.05599	2.111959	8.070246	27.76181
6	576.9411	59.10815	1.999389	7.633817	31.25864
7	587.1551	58.35950	1.972637	7.390418	32.27745
8	593.4354	58.52823	2.008579	7.327096	32.13610
9	597.1383	58.81330	2.055600	7.360974	31.77012
10	599.2535	58.92073	2.087131	7.411258	31.58088

Table 6: Variance decomposition analysis of India

Prd	Standard error	$CO_2$1	FIN_GEL1	TAR1	YEN_EN1
1	77.72653	100.0000	0.000000	0.000000	0.000000
2	86.23418	81.33933	3.477875	14.63439	0.548399
3	90.78313	79.05995	5.631092	13.28080	2.028158
4	92.54562	76.86859	5.427059	15.06447	2.639879
5	93.58233	75.41426	6.411724	14.75780	3.416224
6	94.00746	75.11415	6.442395	14.98400	3.459453
7	94.28333	74.67661	6.473406	15.40773	3.442254
8	94.37669	74.61435	6.558701	15.37916	3.447789
9	94.43664	74.55248	6.550591	15.38810	3.508829
10	94.45689	74.52729	6.561857	15.40352	3.507334

5. CONCLUSION AND POLICY IMPLICATIONS

In the research based on the years 1993-2022, the independent variables renewable energy, agricultural production, financial development and the dependent variable CO_2 were first considered and Multiple Regression Analysis was performed. As a result of this analysis, it was seen that the model had a very strong explanatory power and was significant with a rate of 99.48% in China, but the effect of the financial development variable was

Table 7: China's FMOLS, DOLS and CCR analyses

China	Dependent variable CO_2		FMOLS		
	Independent variables		t-statistic	Probability	Coefficient
	FIN_GEL		1.558951	0.1316	6513.449
	TAR		3.188563	0.0038	78.09219
	YEN_EN		−3.048339	0.0054	−90.70850
	C		−0.431570	0.6698	−617.6915
	DOLS			CCR	
t-statistic	Probability	Coefficient	t-statistic	Probability	Coefficient
−0.728222	0.4785	−5528.176	1.404015	0.1726	6447.521
3.940658	0.0015	153.9887	2.956285	0.0067	77.11776
−1.056040	0.3088	−46.24263	−2.949406	0.0068	−93.58687
−0.839107	0.4155	−2448.370	−0.283015	0.7795	−460.7743

Table 8: India's FMOLS, DOLS and CCR analyses

China	Dependent variable CO_2		FMOLS		
	Independent variables		t-statistic	Probability	Coefficient
	FIN_GEL		−0.113273	0.9107	−70.38474
	TAR		10.17958	0.0000	26.44202
	YEN_EN		−3.131821	0.0044	−23.56687
	C		0.726947	0.4740	360.2344
DOLS			CCR		
t-statistic	Probability	Coefficient	t-statistic	Probability	Coefficient
0.373997	0.7140	278.8980	−0.030150	0.9762	−17.06542
1.346500	0.1995	10.21368	8.984148	0.0000	26.48771
−3.379414	0.0045	−67.26183	−2.750828	0.0109	−23.22077
2.497176	0.0256	3374.274	0.548075	0.5885	320.1796

not statistically significant. It was determined that the agricultural production variable significantly increased CO_2 emissions in the short term. For this reason, sustainable agricultural policies should be developed. Again, researchers who will conduct research with these variables can strengthen their studies by adding more specific variables such as agricultural technologies and fertilizer use to better understand the effect of agriculture on emissions. The renewable energy variable was found to reduce CO_2 emissions. Therefore, policies that will increase the use of renewable energy should be encouraged by the government and policy makers and green energy investments should be increased. The fact that the financial development variable was not significant indicates that there may be other missing variables or possible multicollinearity problems in the model. The model can be improved by adding alternative variables.

According to the India Multiple Regression analysis in Table 2, it was found to be quite high and significant with a rate of 99.54%. When we look at the short-term effects of our independent variables on our dependent variable CO_2, it was seen that the effects of agricultural production and financial development variables were not statistically significant since the P value remained above 0.05 and we cannot say whether they exactly affect CO_2 emissions. The renewable energy variable stood out as the most important and significant variable. The negative value it took with its coefficient of −1.5051 shows that as the use of renewable energy increases, there is a significant decrease in CO_2 emissions.

When we examine our autocorrelation graph in Figure 1, it is seen that all the residues are randomly distributed and it is clearly found that there is no autocorrelation problem.

In order to perform our next test, the Johansen Cointegration test, all the non-stationary numbers at the I(0) level in the ADF/PP unit root tests were made stationary by taking their differences from the I(1) 1st degree in all country data. Non-stationary variables were made stationary by taking their differences at the I(2) level.

In the Johansen Cointegration test we conducted in order to find the long-term balance relationship between the variables in Table 4, it was determined that there was a long-term balance relationship between the two variables for the country of China, while there was only a cointegration relationship for the country of India.

In Figure 2, which belongs to the Var analysis, which is another analysis we carried out to detect stationarity, it is seen that all points are located within the shape and are stationary.

When we examine the impact-response analysis of China, sustainable management of agricultural activities can be effective in reducing CO_2 emissions in the short term. Since financial development initially has an increasing effect on CO_2, green finance projects should be given priority. In the medium term, renewable energy investments seem to be effective in reducing CO_2 emissions. In the long term, the impact of shocks decreases over time and CO_2 emissions become stable. As a result, continuing investments in renewable energy and supporting financial development with environmentally friendly policies seem critical to controlling CO_2 emissions in the long term.

In the Indian impact response analysis, in the short term, policies aimed at reducing CO_2 emissions should take into account fluctuations resulting from agricultural activities. Green finance projects should be encouraged, as financial development may have indirect effects over time, although it is not directly effective. In the medium term, regulating agricultural activities and increasing sustainable practices can reduce uncertainty in CO_2 emissions. When we examine it in the long term, it is seen that emissions can be reduced sustainably by increasing renewable energy investments. The study confirms the long-term benefits of renewable energy. In light of these comments, increasing renewable energy investments and implementing emission reduction policies, especially in the agricultural sector, will contribute to reducing CO_2 levels.

In Table 5, in the Variance decomposition analysis of China, it was seen that especially in the recent period, CO_2 was 58.92% due to its own shocks and among our independent variables, renewable energy affected it the most with a rate of 31.58%, followed by agriculture with 7.41% and financial development with 2.08%. Table 6. In India, in the recent period, our CO_2 variable was 74.52% due to its own shocks and it was found that our independent variable that affected our dependent variable CO_2 the most was agriculture with a rate of 15%. The effect of other independent variables was seen as 6.56% financial development and 3.5% renewable energy.

When we look at the data of China in the FMOLS, DOLS and CCR analyses where we examine the long-term effects, it is revealed that agriculture and renewable energy have a significant effect on CO_2 emissions in the FMOLS analysis. The effect of financial development is not statistically significant but positive. These findings indicate that the transition to renewable energy should be supported, sustainable methods should be adopted in agriculture and financial development should be directed with environmental policies. It was observed that financial development increases CO_2 emissions, but it was not statistically significant. Although this shows that economic activities have the potential to increase CO_2 emissions, it suggests that the effect of other variables such as industrialization or energy policies may be more decisive. In addition, incentives for green finance and sustainable investments should be increased. The agriculture variable has a significant and positive effect on CO_2 emissions. Probably, the main reason for this increase is the fossil fuels, fertilizers or other greenhouse gas emission-causing activities used in agriculture. Therefore, sustainable agricultural practices that lead to less carbon emissions in the agricultural sector should be encouraged, and environmentally friendly policies should be developed with low-carbon fertilizers, organic farming and precision farming technologies. Again, increasing the use of renewable energy reduces CO_2 emissions. This result shows that the transition to renewable energy is critical for environmental sustainability.

In the DOLS analysis of China, the finding that agriculture increases CO_2 emissions is strong in both FMOLS and DOLS analyses. It is seen that agricultural activities can cause greenhouse gas emissions and sustainable agricultural policies are gaining importance. The agricultural sector is one of the most important variables that increase CO_2 emissions. The same relationship was found in the FMOLS model, but the coefficient is larger in the DOLS model (increased from 78 to 153). This shows that the effect of the agricultural sector on carbon emissions is strong and the model supports this result. The evidence that renewable energy reduces CO_2 emissions is mixed. While this relationship is strong in the FMOLS model, it is not significant in the DOLS model. This suggests that the effectiveness of renewable energy policies may vary over time or the model may capture different dynamics. It was seen in the FMOLS model that renewable energy reduces CO_2 emissions and this relationship is significant. However, the DOLS model does not support this relationship. This difference may be due to the model capturing different dynamics. The effect of financial development on CO_2 emissions is ambiguous in this analysis. While financial development increases CO_2 in the FMOLS model, it decreases it in the DOLS model. However, this effect is not statistically significant in both models. This suggests that financial development is not a factor that directly affects CO_2 emissions or that its effect works through indirect mechanisms. The most critical message for policy makers will be to continue to promote sustainable methods in the agricultural sector and to support the transition to renewable energy.

In the China CCR analysis, the finding that agriculture increases CO_2 emissions is strong in this analysis as in all analyses. While the fact that renewable energy reduces CO_2 emissions is found to be significant in the FMOLS and CCR models, it is not significant in the DOLS model. The effect of financial development on CO_2 emissions is unclear.

As a result, the contribution of agriculture to CO_2 emissions in China was strong in all analyses. This result shows that the contribution of agricultural activities to CO_2 emissions is consistently significant. In this context, investments should be made in organic agriculture, low-emission fertilizer use and sustainable agricultural practices. Again, the use of renewable energy appears to be an important factor reducing CO_2 emissions. Government support and investment incentives should be increased and more resources should be allocated to renewable energy projects. In parallel with the results in the FMOLS model, the CCR model also shows that renewable energy reduces CO_2 emissions and this effect is significant. However, this relationship was not found significant in the DOLS model. This suggests that renewable energy can be a strong factor in reducing CO_2 emissions in the long term, but different results may be obtained depending on the modeling approach. The effect of financial development on CO_2 emissions varies depending on the model. Green financing should be encouraged and environmentally friendly projects should be supported. The CCR model shows that financial development increases CO_2 emissions, similar to the FMOLS model.

In the Fmols analysis of India, the result that agriculture increases CO_2 emissions is very strong. The agriculture variable has a statistically significant positive effect on CO□ emissions. This shows that agricultural activities (e.g., use of agricultural machinery, fertilizer applications, land use changes) lead to high carbon emissions and the need to switch to sustainable agricultural practices. Organic farming, water-saving irrigation systems and low-carbon fertilizer use should be encouraged. It has been observed that renewable energy reduces CO_2 emissions in India. This shows that the use of renewable energy is an effective solution to reduce environmental impacts and that investments in renewable energy reduce carbon emissions by providing positive environmental impacts. Investments in solar and wind energy should be increased and fossil fuels such as coal should be gradually reduced. The effect of financial development on CO_2 is not statistically significant. However, this can be strengthened with environmental policies. Incentives for green finance investments should be increased and the financial sector should be more supportive of environmental projects. As a result, the agricultural sector stands out as the largest cause of CO_2 emissions. Renewable energy is effective and significant in reducing CO_2 emissions. The impact of financial development on CO_2 is not statistically significant. It is critical to make agricultural policies sustainable and increase investments in renewable energy in India.

When we evaluate the India DOLS analysis, renewable energy use reduces CO_2 emissions and this effect is statistically significant. The effects of financial development and agriculture variables on CO_2 emissions are not statistically significant. The widespread use of low-carbon energy sources should be encouraged. Government incentives, subsidies and financial support should be increased. Green financing and environmentally friendly investments should be supported. Banks and financial institutions should develop special funds for environmental sustainability projects. More sustainable agricultural practices should be adopted. Organic agriculture, low-carbon agricultural technologies and efficient land use should be encouraged. This result may indicate that the effect of financial development in India on increasing or decreasing carbon emissions is not obvious in the short term. However, if financial development encourages environmentally friendly investments, it may have indirect effects.

According to the India CCR analysis, the agricultural sector significantly increases CO_2 emissions and this effect is statistically very significant. This result shows that agriculture in India makes a significant contribution to carbon emissions and that attention should be paid in terms of environmental sustainability. In particular, sustainable irrigation systems should be developed by encouraging lower carbon emission methods in agricultural production. Renewable energy use reduces CO_2 emissions and this effect is statistically significant. This shows that investments in renewable energy are critical for environmental sustainability in India. In this context, investments in solar and wind energy should be increased and incentives should be provided for the use of renewable energy in industry and households. More solar and wind energy investments should be made and fossil fuel use should be gradually ended. The effect of financial development on CO_2 emissions was found to be insignificant. It may indicate that the effect of financial development on environmental factors has not yet become apparent in India. If green financing, sustainable investments and environmentally friendly projects are supported more, this effect may become more significant. In this context, banks and governments should develop special financial instruments to support environmental projects by encouraging green financing and environment-friendly investments. In this context, it will be critical for India to implement reforms in the agricultural sector to reduce carbon emissions and accelerate investments in renewable energy for environmental sustainability.

In addition, the literature review conducted on the examples of China and India also points to the potential of financial development to improve environmental performance through renewable energy investments and sustainable agriculture projects. In the light of empirical findings obtained from different countries, this literature review has been seen to address the effects of agricultural production, energy consumption, renewable energy and financial development on CO_2 emissions. In this context, in order to reduce CO_2 emissions and establish a balance between economic growth and environmental sustainability; the importance of strengthening financial markets at the national level and the integration of renewable energy and environmental agricultural policies is emphasized. The findings of the studies indicate complex, often inverted-U shaped (Environmental Kuznets Curve) relationships between economic growth and environmental pollution; while revealing that variables such as renewable energy and financial development play an important role in improving environmental performance. In this context, important implications are presented in terms of observing similar dynamics in developing countries such as China and India and developing applicable strategies for policy makers.

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