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The Relationship Between Banking Sector Development, Financial Development, Economic Growth, Renewable Energy and Co_2 Emissions: Evidence from Brazil and Türkiye

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Abstract In this research article, the impact of CO2 emissions on the environmental improvement of the financial structure in Brazil and Türkiye, two emerging economy countries, is observed using comprehensive econometric methods in terms of banking sector development, financial development, economic growth and renewable energy variables. In particular, the research on financial and environmental transmission channels with the Environmental Kuznets Curve (EKC) hypothesis, which is widely mentioned in the literature, was examined with powerful econometric methods such as FMOLS, DOLS, CCR, ARDL, ECM, F-Bounds and CUSUM using annual data in the period 1990-2021. The findings indicate notable differences between these two countries. While the banking sector development variable was found to increase CO_2 emissions in Türkiye, it had no significant effect in Brazil. Furthermore, the renewable energy variable was clearly found to reduce emissions in both countries. In terms of the EKC hypothesis, Brazil is still in the rising phase, while Türkiye has entered a declining phase. The lack of such a comprehensive analysis and research examining these two countries at similar development stages makes this article unique and offers the opportunity for a detailed methodological comparison. The findings emphasise that green finance policies should be designed differently, considering the dynamics of each country, and that uniform policies will not be sufficient.

Keywords Green Finance · Environmental Kuznets Curve · Financial Development.

JEL Classification Q56 · C33 · G00.

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The Relationship Between Banking Sector Development, Financial Development, Economic Growth, Renewable Energy and Co_2 Emissions: Evidence from Brazil and Türkiye

Global climate change, in terms of sustainable development goals, is a global issue. Carbon dioxide (CO_2) emissions, in particular, have led countries to repeatedly reexamine their economic and financial growth strategies and sparked international debate. The Environmental Kuznets Curve (EKE) hypothesis, which addresses both economics and environmental pollution in academic terms, offers important findings at the heart of these discussions. This hypothesis posits that environmental pollution increases in the early stages of growth and, that economic recovery begins after a certain level of per capita income. However, limiting this relationship to this extent is insufficient; it is also important to examine the impact of the financial structure, a component of growth, on development. The concept of "Green Finance," which has received considerable attention recently, is among the environmental sustainability goals and is considered an international policy tool. This concept involves directing financial resources to support environmentally sensitive and low-carbon investments. Both private companies and governments are increasingly focusing on green financial support. Furthermore, banking sector development is increasingly being studied in academic research on financial development, economic growth, and renewable energy. Green finance practices, designed to reduce existing negative air and environmental pollution, not only support environmentally friendly projects but also aim to reduce the carbon footprint of the financial system. Therefore, the impact of variables such as banking sector development, financial development, economic growth, and renewable energy on carbon emissions is of strategic importance for environmentally sustainable development goals. In this sense, this study aimed to further shape the relationship by taking the EKC hypothesis as its main focus and adding the banking sector development and financial development as components of the financial structure. The full impact of the current, traditional financial system structure on environmental improvement remains unclear. This uncertainty also raises questions about whether financial development, considered as a scale effect, supports economic growth and increases emissions, and whether it reduces emissions by financing renewable technologies, as a technological effect. Therefore, by addressing these financial components, we aim to provide empirically based evidence that will prompt companies and governments to reconsider their green finance policies.

Recent academic studies have focused on examining the environmental impacts of the financial structure on CO_2 emissions. Increasing the use of renewable energy technology has been a significant factor in reducing carbon emissions. However, different economic, political, and financial infrastructures across countries lead to different outcomes in this relationship. Therefore, examining the study with empirical studies at the country level will make policy recommendations more effective. Therefore, this research empirically compares the relationship between banking sector development, financial development, renewable energy, and CO_2 emissions in two developing G20 countries, Brazil and Türkiye, within the framework of the EKC hypothesis. However, the structural characteristics and energy resources of these two countries are also considered. While Brazil stands out with its infrastructure for renewable energy systems such as biofuels and hydroelectricity, Türkiye's energy needs are met by fossil fuel imports. Furthermore, it's important to note that Türkiye is increasing its investment in renewable energy sources. These differences and similarities offer a unique comparison for analysing the EKC hypothesis and the financial structure.

The basis of this article is to increase financial support within the scope of green investments by examining the relationship between financial development, banking sector development, renewable energy, economic growth and CO_2 emissions, also touching on green finance. Furthermore, the literature review has not yielded any original studies that examine the aforementioned variables simultaneously and in this context, focusing on green finance in these two countries. Therefore, this study will enhance its originality and contribute to the literature. The dataset used in the study contains annual data for the period 1990-2021 and was obtained from the World Bank database. The empirical review ended in 2021, as some of the data obtained from the World Bank were available until 2021. Because a 30-year period is sufficient to analyse the long-term relationship, data were collected starting from 1990.

To analyse the long-term relationship in the empirical analyses, the data were first tested for stationarity using the ADF/PP unit root tests. The existence of long-term relationships was examined using the Johansen co-integration test, and short-term and long-term effects were analysed using the FMOLS, DOLS, CCR, and ARDL methods, respectively. Additionally, VAR models, impulse/response analysis, and variance decomposition methods were applied to assess the dynamic interactions within the system. The Ramsey RESET test and the Breusch-Pagan-Godfrey test were used to test the validity and statistical reliability of the model. Thus, the combination of complementary and robust estimators contributes to the originality of the paper. The findings in the article highlight the critical role of the banking sector and financial structure in low-carbon growth and show how renewable energy investments contribute to the environmental recovery process thanks to the increasing green financial support. Moreover, the article will provide insights for policy makers in developing economies to strengthen effective growth pathways through green finance studies and will make a unique contribution to the academic literature.

Literature Review

Although the literature examining the relationship between financial development, banking sector development, renewable energy, economic growth and carbon emissions evaluated in the article has investigated the variables from various perspectives, there are inconsistencies in the findings across countries and variables. The literature reviewed under this heading is detailed under three subheadings: financial development and environmental impacts of the banking sector, renewable energy, economic growth and the Environmental Kuznets Curve (EKC) hypothesis, and developing economies.

Environmental Impacts of the Financial Development and Banking Sector

The environmental impact of the banking sector and financial development variables has yielded mixed findings in the literature, with no consensus. Some studies show that these variables have an increasing effect on carbon emissions. For example, Bayrak (2024), using panel data analysis for the EU-27 countries, evaluated the period 2006-2022 and found that banking sector development significantly increased CO_2 emissions, highlighting the limited impact of current environmental practices. Similarly, Aıgbovo and Isıbor (2024), using the ARDL method for the period 1981-2021 in Nigeria, found that banking sector loans to the private sector increased CO_2 emissions in both the short and long term. Similarly, analysing the 1980-2021 period in Australia with the ARDL method, Wijethunga et al. (2025) revealed that financial development reduces emissions both directly and through regulatory effects and said that financial resources should be directed to green investments. Using ARDL, FMOLS and CCR methods in Türkiye with data for the period 1980-2014, Samour et al. (2019) found that banking sector development increased CO_2 emissions and said that renewable energy investments should be supported by regulatory reforms in the banking sector. Al Zarooni (2022) examined the period 1980-2014 in the Gulf countries using the NARDL method and found that financial development significantly increased CO_2 emissions. Usman et al. (2025), using panel cointegration and panel ARDL methods to examine 70 developing countries over the 2022-2023 period, found that financial development increased environmental degradation, while renewable energy demonstrated limited but promising mitigating effects. They also emphasised the need to develop environmentally sensitive financial strategies to support economic growth with environmental sustainability. Ebrahim ElSaid et al. (2025) found that the negative impact of financial development on the environment is short term.

On the other hand, there is also literature that finds that financial development can improve environmental sustainability. Tekbaş (2024) used the FMOLS and CCR methods for the 1990-2020 period in Türkiye and found that banking sector development and economic growth reduce CO_2 emissions. Pala and Barut (2021) used panel CADF and AMG estimators for the period 1990-2014 in E-7 countries and found that financial development improves environmental quality in Türkiye, Indonesia, and Russia, and also that economic growth increases emissions in Türkiye and Russia, while decreasing them in India, China, Brazil, and Mexico. Analysing the period 1972-2021 in Germany using the Bootstrap ARDL method, Wang et al. (2023) suggested that banking development improves environmental quality and that green energy should be supported for the 2045 carbon neutrality target of the banking sector. Using the CCEMG and AMG methods for the period 1990-2022 in Next-11 countries, Abbass et al. (2025) found that financial development reduced emissions by 1.25%. Murro and Peruzzi (2025) analysed the period 2010-2022 in Italy using panel data analysis and found that cooperative banks facilitated large-scale renewable energy projects, while traditional banks negatively impacted solar installations. Additionally, Ateş et al. (2025), Mehmood and Kaewsaeng-on (2025), Elmonshid et al. (2024), and Akinsola et al. (2022), who examined different variables, stated that financial development reduces environmental degradation. These two different findings in the reviewed articles indicate that each country's economy needs to be examined financially with its unique structure.

Energy, Economic Growth and the EKC Hypothesis

The mitigating effect of renewable energy on environmental degradation is widely encountered in the literature. Ateş et al. (2025) applied the Dumitrescu-Hurlin causality test and CS-ARDL method for the period 2000-2021 in the 20 countries with the highest carbon emissions and found that renewable energy reduced emissions by 4.2%. Abd Alah and Ojekemi (2025) similarly confirmed that renewable energy reduces emissions in Brazil using the QQKRLS and QQGC methods for the period 1990-2020. Raihan and Tuspekova (2022), who analysed different variables using the ARDL and DOLS methods in Brazil for the period 1990-2019, found that renewable energy reduces emissions from the variables. Elmonshid et al. (2024) examined the period 2001-2021 in the Gulf Cooperation Council (GCC) countries using Quantile Regression, finding that renewable energy consumption reduced emissions. Çelik (2025), in his study examining the period 1993-2022 in China and India using FMOLS, DOLS, and CCR analyses, found that renewable energy reduced emissions while agricultural production increased them. In addition, Wang et al. (2023), who emphasised in the studies mentioned in other headings, found that renewable energy has a positive impact on the environment and demonstrated the validity of the EKC, while Chiu and Zhang (2023) found that the emission-reducing impact of renewable energy becomes stronger as financial development increases.

The validity of the EKC, which explains the relationship between environmental degradation and economic growth, varies across countries. First, using multiple regression analysis, Grossman and Krueger (1995) found that environmental quality does not deteriorate consistently with economic growth; on the contrary, most indicators tend to deteriorate and then improve, with turning points generally occurring before per capita income reaches $8,000. Naqvi et al. (2025) analysed the period 1960-2023 in Pakistan using Stochastic Differential Modelling, predicting that the EKC hypothesis is valid and that clean technology investments can reverse the emissions trend. Aıgbovo and Isıbor (2024), whose work was also mentioned in the previous section, confirmed the EKC and argued that economic growth reduces emissions eventually. Mehmood and Kaewsaeng-on (2025) used panel quantile regression for the period 1990-2023 in BRICS countries, confirming the EKC hypothesis by reversing the impact of economic growth on environmental degradation after a certain income level, and found that renewable energy reduces environmental degradation in all time periods. Shahbaz et al. (2013) supported the EKC hypothesis by examining the period 1971-2009 in Pakistan using teh Granger Causality and Co-integration Analysis. Shahbaz et al. (2017) analysed the period 1960-2016 in the United States using the VECM Granger Causality Test and, found that the EKC relationship is N-shaped. Houfi and Farhat (2025) examined the 1990-2021 period in 16 developing countries using the ARDL method and found findings supporting the EKC hypothesis in the short run. Artekin and Kalaycı (2025) found that the EKC hypothesis was valid in the short run for the 1980-2022 period in Türkiye using the FMOLS, NARDL, and Johansen Co-integration methods. Similarly, Öztürk and Acaravcı (2013) examined the 1960-2007 period in Türkiye using ADF and F-tests and found that the EKC hypothesis was valid.

On the other hand, Beşe and Kalaycı (2021), using ARDL and Granger causality analyses for Denmark, the United Kingdom and Spain for the period 1960-2014, found that the EKC hypothesis is not valid even in these developed economies. Similarly, Katırcıoğlu and Katırcıoğlu (2017) argued that the EKC is not valid in Türkiye. Analysing the 1965-2022 EKC period in Egypt using the NARDL method, Ebrahim ElSaid et al. (2025) found that the EKC is N-shaped. This show that the EKC is not a general rule and depends on country-specific economic and financial conditions.

Emerging economies and comparative studies

Studies focusing on developing economies have observed the same complexity of the relationships among variables within these countries. A case in point is the study by Pala and Barut (2021) on the E-7 countries, mentioned in the previous section, who found that economic growth increased emissions in Türkiye and Russia, while decreasing them in the same group of countries including Brazil, India, China, and Mexico. This is a significant finding, as developing economies are not homogeneous, and significant structural differences can exist even among countries with similar global positions. Again, Alam et al. (2025), who analysed the period 1985-2021 in BRICS countries using Quantile Regression, found that renewable energy was effective in lower emissions and financial development was effective in higher emissions, pointing to resource efficiency and the importance of green finance policies to reduce emissions in BRICS regions. Akinsola and colleagues (2022) confirmed that renewable energy and financial development reduce the ecological footprint in Brazil using the ARDL and DOLS methods for the period 1983-2017. Chiu and Zhang (2023), examining the period 1990-2015 across 37 OECD countries using panel data, found that the emission-reducing effect of renewable energy becomes stronger as financial development increases. They also found that banking sector development has an inverted U-shaped effect.

This literature review found no studies comparing Brazil and Türkiye, two G20 member, middle-income, and rapidly industrialising economies. Brazil's biofuel and hydroelectric infrastructure, and Türkiye's dependence on fossil fuel imports and recent renewable energy investments make these two countries an important comparative study to examine the relationship between economic, financial, renewable energy, and CO2 emissions.

The Research Gap and Contribution of the Study

The studies reviewed in the literature section have been found to have comprehensively investigated the relationship between banking sector development, financial development, economic growth, renewable energy and carbon emissions with different variables. However, most of these studies have either focused on developed economies or, by employing only a few methods such as panel data analysis, have overlooked country-specific dynamics. Therefore, this study focuses specifically on Brazil and Türkiye, two emerging economies that are members of the G20 and have similar development stages but differing energy profiles. As previously mentioned in the Introduction, these two countries share similarities due to their middle-income status, their ideal potential to approach the EKC reduction level, and their G20 membership. However, Brazil has a strong infrastructure in renewable resources such as hydropower and biofuels, while Türkiye meets a significant portion of its energy needs through fossil fuel imports and has recently accelerated its renewable energy investments. These similarities and differences provide a unique comparative analysis to determine the impact of financial factors on the EKC curve of these two countries. However, in the existing literature, there is no study that examines the banking sector development, financial development, renewable energy, economic growth and CO_2 emissions variables of these two economies simultaneously and in a comparative framework, and at the same time uses a set of robust econometric methods such as Johansen cointegration, FMOLS, DOLS, CCR and ARDL.

Therefore, by providing country-specific and comparative empirical evidence on the finance, energy, and emissions nexus for Brazil and Türkiye, this study will provide findings that will help policymakers develop differentiated green finance and energy policies tailored to the unique circumstances of each country. It will also shed light on future studies.

Data, Methodology, and the Empirical Model

Data Set and Variable Definitions

In this study, the research variables banking sector development, financial development, economic growth, renewable energy and CO_2 emissions were evaluated for Brazil and Türkiye between 1990 and 2021. The empirical review ended in 2021 because some of the data obtained from the World Bank were not accessible after 2021. Because a 30-year period is sufficient to analyse the long-term relationship, data were collected starting from 1990. Table 1, created by the author, aims for methodological transparency by including detailed definitions and explanations of each main variable used in the study.

Table 1

Variable Definitions and Sources

Variable	Definition	References
CO_2	The combustion of fossil fuels is addressed, including emissions from cement production, the consumption of liquid, solid, and gaseous fuels, and carbon dioxide produced during gas flaring.	(World Bank Database, 2025a)
Banking Sector Development	Domestic loans provided to the private sector are considered by including financial resources provided to the private sector by financial companies, non-equity securities purchases, commercial loans and other receivables that create repayment demands.	(World Bank Database, 2025b)
Economic Growth	GDP at purchaser prices is the total gross value provided by existing producers in the economy, excluding subsidies and product taxes not included in the value of the product. It is calculated without making deductions for the depreciation of manufactured goods or the depletion of natural resources.	(World Bank Database, 2025c)
Financial Development	This variable is based on the "4x2 framework." Specifically, it includes measures of the reach, depth, stability and efficiency	(World Bank Database, 2025d)

Variable	Definition	References
	of financial systems. Each of these attributes encompasses both financial institutions (such as insurance companies and banks) and financial markets (such as bond and stock markets).	
Renewable Energy	It shows the share of renewable energy in the total final energy consumption.	(World Bank Database, 2025e)

Source: The table was created by the researcher.

Empirical model and theoretical justification

Drawing on the theoretical framework presented in the paper, which integrates the EKC hypothesis and financial environmental transmission channels, the following empirical model is developed to investigate the relationships in Brazil and Türkiye as follows:

$$lnCO2_t = \beta_0 + \beta_1 lnBNK\_SEK_t + \beta_2 lnFNS\_GEL_t + \beta_3 lnEKO\_BUY_t + \beta_4 lnYEN\_ENJ_t + \varepsilon_t)) \quad (1)$$

In the formula, $lnCO2_t$: Natural logarithm of CO_2 emissions per capita (dependent variable), $lnBNK\_SEK_t$: Natural logarithm of the division of the banking sector, $lnFNS\_GEL_t$: Natural logarithm of financial development, $lnEKO\_BUY_t$: Natural logarithm of economic growth (GDP per capita), $lnYEN\_ENJ_t$: Logarithm of the type of renewable energy consumption, ε_t: Error term.

The inclusion of economic growth, a variable discussed in this article, in the model allows the testing of the Environmental Kuznets Curve (EKC) hypothesis. According to theoretical expectations, if $\beta_3 > 0$, the economy is on the ascending branch of the EKC, while $\beta_3 < 0$ would suggest that the economy has reached a turning point and is on the descending branch. The banking sector development and financial development variables directly test the financial-environmental transmission channels. The β_1 and β_2 coefficients will capture the net effect of competing scale effects (positive impact on emissions) and technological/structural effects (negative impact on emissions). The uncertain theoretical expectation (β_1, β_2 can be positive or negative) reflects the context-dependent nature of the environmental impact of financial development. The renewable energy variant is expected to have a significantly negative impact ($\beta_4 < 0$) on CO_2 emissions, representing a transition to cleaner energy sources as a key component of environmental sustainability.

In the review of the article, we aimed to strengthen the validity of the findings by considering the FMOLS, DOLS, CCR and ARDL methods together, which investigate similar findings in terms of the reliability of long-term relationships and to test the robustness of the results under different econometric assumptions.

Empirical Results

The empirical literature contains numerous studies examining the relationship between carbon emissions and macroeconomic indicators. This empirical study strengthens the validity of the research by using a combination of econometric methods such as ARDL, FMOLS, DOLS, CCR, Johansen cointegration, VAR, impulse response analysis, and unit root tests. The analyses are presented below under various headings.

ADF and PP Unit Root Tests

These tests, developed by Dickey and Fuller (1979: 427) and Phillips and Perron (1988), assess whether a time series contains a unit root, that is, whether it is stationary. These analyses are an important step in time series modelling because many models require stationary data (Stock and Watson, 2003).

Table 2

ADF and PP Unit Root Test (Türkiye, 1990-2021)

Variables	ADF I(0)		ADF I(1)	
	Brazil	**Türkiye**	**Brazil**	**Türkiye**
CO2	-1307092 **(-2.960411)**	0.286997 **(-2.960411)**	-4518110 **(-2.963972)**	-4935996 **(-2.963972)**
BNK_SEK	-2416725 **(-2.971853)**	0.552047 **(-2.960411)**	-4874824 **(-2.963972)**	-4422284 **(-2.963972)**
FNS_GEL	-1729027 **(-2.960411)**	-1583942 **(-2.960411)**	-4693558 **(-2.963972)**	-6513579 **(-2.963972)**
EKO_BUY	-1202406 **(-2.960411)**	-0.777905 **(-2.960411)**	-4370833 (-2.963972)	-4867787 **(-2.963972)**
YEN_ENJ	-2491596 **(-2.963972)**	-1744804 **(-2.960411)**	-3754838 **(-2.963972)**	-5970815 **(-2.963972)**
Variables	**PP I(0)**		**PP I(1)**	
	Brazil	**Türkiye**	**Brazil**	**Türkiye**
CO_2	-1302756 **(-2.960411)**	1988369 **(-2.960411)**	-4509364 **(-2.963972)**	-6270785 **(-2.963972)**
BNK_SEK	-2372074 **(-2.960411)**	0.347936 **(-2.960411)**	-6262039 **(-2.963972)**	-4465780 **(-2.963972)**
FNS_GEL	-2243855 **(-2.960411)**	-2151641 **(-2.960411)**	-5122731 **(-2.963972)**	-6857015 **(-2.963972)**
EKO_BUY	-1311773 **(-2.960411)**	-0.828749 **(-2.960411)**	-4409700 **(-2.963972)**	-4929298 **(-2.963972)**
YEN_ENJ	-2251753 **(-2.960411)**	-1744804 **(-2.960411)**	-3764212 **(-2.963972)**	-5978359 **(-2.963972)**

Note: The finding series at the 5% significance level were considered.

When the ADF and PP tests in Table 2 are examined, it is seen that the data at the I(0) level for both Brazil and Türkiye are not stationary, but when their first differences are taken at the I(1) level, they become stationary and do not contain a unit root, eliminating the risk of spurious regression and paving the way for cointegration analysis and subsequent stages.

Johansen Co-integration Test

The Johansen cointegration test is an econometric method that tests whether multiple variables in time series analysis are dependent on each other and whether they exist in a long-term equilibrium relationship (Lütkepohl, 2013; Johansen, 1991).

Table 3

Johansen Cointegration Test (Brazil and Türkiye, 1990-2021)

Country	H.	Eigenvalue	T. Sta.	0.05 Critical Value	P.*
BRAZIL	r=0	0.574462	70.79067	69.81889	0.0418
	r=1, r=>1	0.532570	46.01302	47.85613	0.0737
	r=2, r=>2	0.321525	23.95835	29.79707	0.2022
	r=3, r=>3	0.219310	12.70902	15.49471	0.1259

Country	H.	Eigenvalue	T. Sta.	0.05 Critical Value	P.*
	r=4, r=>4	0.173591	5.529287	3.841466	0.0187
	r=0	0.799954	111.1343	69.81889	0.0000
	r=1, r=>1	0.709953	64.46720	47.85613	0.0007
TÜRKİYE	r=2, r=>2	0.332315	28.57355	29.79707	0.0687
	r=3, r=>3	0.298461	16.85931	15.49471	0.0310
	r=4, r=>4	0.202981	6.579440	3.841466	0.0103

**indicates that the hypothesis is rejected at the 0.05 level.*

When the Johansen co-integration test in Table 3 is examined, the null hypothesis of r = 0 for Brazil is rejected, indicating the existence of at least one co-integrating relationship. Hypotheses "r=1" through "r=4" are not rejected, and once again, a single co-integration relationship is indicated. However, although the "r=4" hypothesis can be rejected, this result is not considered due to the status of the intervening hypotheses. Thus, since no more co-integration vectors are found in the steps following the "r=1" hypothesis, a single long-term equilibrium relationship is observed between the series.

In Türkiye, the "r=0" hypothesis was rejected, and it was determined that there was at least one co-integration relationship between the series. Similarly, the "r=1" hypothesis was also rejected, and it was determined that there were at least two co-integration relationships between the series. Subsequently, the "r=2" hypothesis was not rejected, and it was concluded that there were exactly two co-integration vectors between the series. Later, other hypotheses were rejected and the existence of exactly two co-integration relationships was found.

Long-term relationships: FMOLS, DOLS, and CCR findings

First, the FMOLS (Fully Modified Ordinary Least Squares) fully modified least squares method is an econometric analysis method that works with time series data to determine whether there are long-term relationships between the series in the data set and to estimate the coefficients of these relationships. When the FMOLS data were examined, the magnitudes of the variables and the direction and intensity of this relationship were determined by checking whether the signs of the coefficients were negative or positive (Phillips and Hansen, 1990). The FMOLS method is supported by the panel regression model given below.

$$y_{it} = \alpha_i + \beta x_{it} + \mu_{it} \tag{2}$$

$$x_{it} = x_{it-1} + \varepsilon_{it} \tag{3}$$

Equation (2) represents the dependent variable y_{it}, the independent variable x_{it}, and the fixed effects α_i. The long-term cointegration coefficient represented by β, which indicates the long-term cointegration relationship between y_{it} and x_{it}, namely the dependent variable CO_2 emissions and banking sector development, financial development, renewable energy and economic growth, will be estimated. Equation (3) represents the stochastic process, which indicates that the variable x_{it} covers a unit root and is not stationary (Phillips and Hansen, 1990).

Ther dynamic ordinary least squares (DOLS) method is an econometric analysis method used to estimate the final unbiased coefficients of the relationship between variables. The DOLS equation is as follows:

$$y_t = a + \beta x_t \sum_{i=-q}^{p} yi\Delta x_{t-i} + e_t \tag{4}$$

In Equation 4, y_t represents the dependent variable, x_t represents the independent variables, Δx_{t-i} represents the difference terms of the independent variables, q and p represent the numbers of lag and forward differences, α symbolises the constant term, β symbolises the long-term coefficient, γ_i symbolises the coefficients of lag and forward differences, and ε_t represents the error term (Bai et al., 2009).

CCR is (Canonical Cointegrating Regression) a regression method used to estimate long-term relationships by correcting the autocorrelation and heteroskedasticity problems of the error terms. Its equation is as follows:

$$y_t = a + \beta x_t + u_t \tag{5}$$

In the CCR version of this equation, the error terms ut are corrected for autocorrelation and heteroskedasticity, and then the transformed dependent and independent variables are used. Thus, the regression equation becomes:

$$\breve{y}_t = a + \beta \tilde{x}_t + \breve{e}_t \tag{6}$$

In this formula, $\breve{y}_t$ and $\tilde{x}_t$ are the transformed dependent and independent variables, and $\breve{e}_t$ is the transformed error term (Park, 1992: 119). The CCR method allows for more consistent results by eliminating autocorrelation and heteroskedasticity while correcting the error terms (Saikkonen, 1991: 5).

Table 4

FMOLS, DOLS, and CCR Analysis (Brazil, 1990-2021)

			Dependent Variable CO_2	**FMOLS**		
			Independent Variables	T-sta	P	Co.
BRAZIL			BNK_SEK	0.092722	0.9268	15255.45
			EKO_BUY	6.145921	0.0000	5.25E-05
			FNS_GEL	8.712333	0.0000	4.19E+08
			YEN_ENJ	−5.226667	0.0000	−8653874.
			C	6.976139	0.0000	5.05E+08
	DOLS				**CCR**	
T-sta	P		Co.	T-sta	P	Co.
3.818781	0.0024		690406.3	0.222998	0.8253	40701.86
5.712107	0.0001		4.96E-05	5.628772	0.0000	4.98E-05
7.937989	0.0000		4.19E+08	8.908312	0.0000	4.35E+08
−8.338052	0.0000		−16226022	−5.495932	0.0000	−8928918.
10.64642	0.0000		8.13E+08	6.906042	0.0000	5.13E+08

In the analyses in Table 4, FMOLS and CCR analyses were found to overlap, with banking sector development not being significant in either analysis, but being significant in the DOLS analysis. Other variables, however, showed similar results in all analyses. For example, the carbon emission-reducing effect of renewable energy was clearly identified in all analyses. Thus, the need for increased support for renewable energy investments in Brazil within the context of green finance is clearly evident. Meanwhile, the positive values of the other independent variables highlight their increasing impact on carbon emissions.

Table 5

FMOLS, DOLS, and CCR Analysis (Türkiye, 1990-2021)

		Dependent Variable CO_2	**FMOLS**		
		Independent Variables	T-sta	P	Co.
		BNK_SEK	9.040264	0.0000	2877728.
BRAZIL		EKO_BUY	-2.106177	0.0450	-6.38E-05
		FNS_GEL	1.767303	0.0889	1.66E+08
		YEN_ENJ	-4.506708	0.0001	-9359163.
		C	4.500805	0.0001	3.02E+08
	DOLS			**CCR**	
T-sta	P	Co.	T-sta	P	Co.
4.099892	0.0015	3315033.	7.729691	0.0000	2926380.
-1.220022	0.2459	-8.16E-05	-1.832476	0.0784	-6.42E-05
0.452178	0.6592	1.06E+08	1.497157	0.1464	1.59E+08
-2.429134	0.0318	-11074570	-3.570096	0.0014	-9328780.
2.141883	0.0534	3.44E+08	3.639894	0.0012	3.02E+08

In Table 5 examining Türkiye, the DOLS and CCR analyses overlapped with each other and it was found that the economic growth variable was negative although insignificant, and in the FMOLS analysis it was found to be significant and negative. The financial development variable was found to be insignificant in all analyses, the banking sector variable was found to be positively significant, and the renewable energy variable was found to be negatively significant.

Furthermore, unlike the Brazilian analyses, the economic growth variable in Türkiye has a negative coefficient, indicating the reducing effect of economic growth on carbon emissions and supporting the decreasing phase of the EKC hypothesis in the long run.

Short- and Long-Term Dynamics: ARDL (Auto Regressıve Dıstrıbuted Lag) Model Findings

The relationship between variables was examined using another analysis, the ARDL (Auto Regressive Distributed Lag) test. This test is a regression model used to analyse the dynamic relationships between the independent and dependent variables, both short term and long term, when working with time series data (Pesaran et al., 2001: 289). The ARDL formula for the model is as follows:

$$+\sum_{i=1}^{P} M_{1\dot{\imath}} \Delta\, lnCO2_{t-1} + \sum_{i=0}^{q1} M_{2\dot{\imath}} \qquad \Delta\, lnBNK\_SEK_{t-1} + \sum_{i=0}^{q2} M_{3\dot{\imath}} \Delta\, lnEKO\_BUY_{t-1} + \sum_{i=0}^{q3} M_{4\dot{\imath}}$$
$$\Delta\, lnFNS\_GEL_{t-1} + \sum_{i=0}^{q4} M_{5\dot{\imath}} \qquad \Delta\, lnYEN\_ENJ_{t-1}\varepsilon_t \tag{7}$$

In the formula, Δ represents the first difference, short-term changes, α represents the constant term, N symbolises the long-term coefficients, M symbolises the short-term coefficients, p and q symbolises the lag lengths, and ε_t represents the error term. Furthermore, the following hypotheses are used to test whether the long-term coefficients are zero:

$$H0: N_1{=}N_2{=}N_3{=}N_4{=}N_5{=}0 \text{ (no cointegration)}$$
$$\text{H1: at least one } N_k{\neq}0 \text{ (There is cointegration)} \tag{8}$$

In the estimation process, the model also includes an error correction model (ECM). The ECM equation is calculated as follows:

$$\Delta \ln CO2_t = a_0 + \sum_{i=1}^{P} M_{1i} \Delta\, lnCO2_{t-i} + \sum_{i=0}^{q1} M_{2i} \Delta\, lnBNK\_SEK_{t-i} + \sum_{i=0}^{q2} M_{3i} \Delta\, lnEKO\_BUY_{t-i} + \sum_{i=0}^{q3} M_{4i} \Delta\, lnFNS\_GEL_{t-i} + \sum_{i=0}^{q4} M_{5i} \Delta\, lnYEN\_ENJ_{t-i} + \phi ECM_{t-1} + \varepsilon_t \quad (9)$$

In this equation, the expression ECM_{t-1} represents the error correction from the previous period, the ECM coefficient, and the others represent the short-term coefficients. In this context, the ARDL tests for Brazil and Türkiye are examined below.

Table 6

FMOLS, DOLS, and CCR Analysis (Türkiye, 1990-2021)

Variable	Co.	Standard Error	t-Sta	P
$CO_2$1(-4)	−1.245973	0.210244	−5.926318	0.0273
BNK_SEK1(-3)	729779.4	200965.5	3.631367	0.0682
EKO_BUY1	0.000102	1.46E-05	6.994212	0.0198
EKO_BUY1(-4)	4.77E-05	1.12E-05	4.262543	0.0509
YEN_ENJ1(-2)	−14431356	3266983.	−4.417334	0.0476
C	23378452	3126630.	7.477205	0.0174
R^2	0.995916		Adjusted R^2	0.946908
Durbin-Watson		2.593736		

Note: Results with P-values below 0.05 are included in the table.

An examination of the ARDL (4,4,4,4,4) model estimation results for Brazil revealed a significant and negative decrease in CO_2 emissions in the fourth lag period. No significant relationship was found with banking sector development in any period, but if interpreted at the tenth percentile, it could be interpreted as increasing carbon emissions in the third lag period. When we look at economic growth, we see that its immediate impact is increasing carbon emissions, and it also increases the fourth period. Similarly, financial development has no significant impact on any period. Renewable energy, on the other hand, decreased carbon emissions in the second lag period. The model's explanatory power is also quite high, with an R2 value of 99.5%. Additionally, the Durbin-Watson statistic was found to be 2.593736, once again demonstrating that there is no autocorrelation.

Table 7

ARDL Error Correction Model Result (Brezilya, 4, 4, 4, 4, 4, 1990-2021)

Variable	Co.	Standard Error	t-Sta	P
D($CO_2$1(-1))	1.755845	0.138697	12.65959	0.0062
D($CO_2$1(-2))	1.567582	0.110986	14.12414	0.0050
D($CO_2$1(-3))	1.245973	0.109197	11.41028	0.0076
D(BNK_SEK1(-1))	−1465340.	145152.5	−10.09518	0.0097
D(BNK_SEK1(-2))	−1281262.	137858.4	−9.294042	0.0114
D(BNK_SEK1(-3))	−551482.8	98943.42	−5.573719	0.0307
D(EKO_BUY1)	0.000102	4.90E-06	20.90622	0.0023
D(EKO_BUY1(-3))	−4.77E-05	4.89E-06	−9.768827	0.0103
D(FNS_GEL1)	2.69E+08	34266814	0.000000	0.0000
D(FNS_GEL1(-1))	3.54E+08	43904360	0.000000	0.0000
D(FNS_GEL1(-2))	3.50E+08	57631396	0.000000	0.0000

Variable	Co.	Standard Error	t-Sta	P
D(FNS_GEL1(-3))	1.68E+08	32372735	0.000000	0.0000
D(YEN_ENJ1)	−6724332.	731093.6	−9.197635	0.0116
D(YEN_ENJ1(-1))	32211793	2458792.	0.000000	0.0000
D(YEN_ENJ1(-2))	17780437	1708902.	0.000000	0.0000
D(YEN_ENJ1(-3))	10538093	1560206.	0.000000	0.0000
CointEq(-1)*	-3.112743	0.175335	−17.75313	c
R^2		0.997613	Adjusted R^2	0.991132

Note: Results with P-values below 0.05 are included in the table.

When examining the ARDL error correction model (4,4,4,4,4) for Brazil, the CointEq(-1) probability value is 0.0032 and the coefficient is negative and significant with values of −3.11, indicating a very rapid equilibrium. Similarly, CO_2 was significant in all three periods and showed an increasing trend. Banking sector development was significant in all three periods and was observed to have reduced CO_2 emissions. While the immediate impact of economic growth was significant and positive in the third period, a significant negative effect was found, and it was found to tend to reduce carbon emissions after a certain period. Financial development, with its high coefficient, was found to be significant in every period and increased CO_2 emissions. Renewable energy, on the other hand, was observed to have a reducing impact on carbon emissions in the immediate period, but increased it in the subsequent three periods. This reflects the system's temporary reactions to short-term imbalances and does not alter the long-term reducing effect found in the ARDL analysis. In addition, R2 and adjusted R2 were found to be above 99%, indicating that the model was quite compatible.

Table 8

ARDL F-Bounds Test Result (Brazil, 4, 4, 4, 4, 4, 1990-2021)

Test Sta.	Value	Signif.	I(0)	I(1)
F-sta.	15.00827	10%	2.2	3.09
k	4	5%	2.56	3.49

When the F-Bounds test value of 15.00 was checked at the 5% limit, it was found to be 3.49, and it was clearly determined that there was a long-term equilibrium relationship between the variables.

Table 9

ARDL Error Correction Model Result (Türkiye, 4, 4, 4, 4, 3, 1990-2021)

Variable	Co.	Standard Error	t-Sta	P
$CO_2$1(-1)	1.044672	0.181437	5.757753	0.0104
$CO_2$1(-2)	-1.319670	0.271818	−4.854980	0.0167
$CO_2$1(-4)	1.224630	0.212708	5.757322	0.0104
BNK_SEK1(-1)	2219464.	344914.9	6.434816	0.0076
BNK_SEK1(-2)	4176561.	810095.8	5.155639	0.0141
EKO_BUY1(-3)	−0.000189	4.38E-05	−4.323470	0.0228
EKO_BUY1(-4)	−0.000253	4.99E-05	−5.070274	0.0148
FNS_GEL1(-2)	3.21E+08	66271337	4.846127	0.0168
YEN_ENJ1	−15940172	2124435.	−7.503252	0.0049
YEN_ENJ1(-2)	−13488939	3867795.	−3.487501	0.0398
YEN_ENJ1(-3)	−18057212	3572275.	−5.054821	0.0149

Variable	**Co.**	**Standard Error**	**t-Sta**	**P**
C	−22296043	5433620.	−4.103350	0.0262
R^2		0.991761	Adjusted R^2	0.928593
Durbin-Watson			2.243815	
Note: Results with P-values below 0.05 are included in the table.				

The ARDL (4,4,4,4,3) model estimation results for Türkiye show that the instantaneous effect on CO_2 emissions increases with a positive value and then decreases with a negative value in the second lag. However, it increases again in the fourth lag. Banking sector development was found to be significant in the first and second lag periods and increased CO_2 emissions. When the economic growth variable was examined, it was found to be significant in the third and fourth lag periods and was found to reduce CO_2 emissions. Financial development was found to be significant in the second lag period and was found to increase CO_2 emissions. The instantaneous effect of renewable energy is significant and its reducing effect is observed, and it is clearly determined that it reduces carbon emissions with its negative value, which is significant in the second and third delay periods. R2 shows that the model has a clear explanatory power of 99% and there is no autocorrelation with the Durbin-Watson statistic value of 2.243815.

Table 10

ARDL Error Correction Model Result (Türkiye, 4, 4, 4, 4, 3, 1990-2021)

Variable	Co.	Standard Error	t-Sta	P
D($CO_2$1(-2))	−1.060555	0.090190	−11.75913	0.0013
D($CO_2$1(-3))	−1.224630	0.081152	−15.09049	0.0006
D(BNK_SEK1(-1))	−6486549.	788236.3	−8.229193	0.0038
D(BNK_SEK1(-2))	−2309988.	454969.1	−5.077241	0.0148
D(BNK_SEK1(-3))	−1864165.	307275.1	−6.066762	0.0090
D(EKO_BUY1)	−5.37E-05	9.56E-06	−5.618062	0.0111
D(EKO_BUY1(-1))	0.000448	5.16E-05	8.696175	0.0032
D(EKO_BUY1(-2))	0.000442	4.41E-05	10.02614	0.0021
D(EKO_BUY1(-3))	0.000253	2.32E-05	10.91964	0.0016
D(FNS_GEL1)	3.31E+08	45738813	0.000000	0.0000
D(FNS_GEL1(-1))	34614484	47007914	0.000000	0.0000
D(FNS_GEL1(-2))	3.56E+08	50312165	0.000000	0.0000
D(FNS_GEL1(-3))	1.50E+08	23987306	0.000000	0.0000
D(YEN_ENJ1)	−15940172	923492.0	−17.26076	0.0004
D(YEN_ENJ1(-1))	31546151	3491630.	0.000000	0.0000
D(YEN_ENJ1(-2))	18057212	1726464.	0.000000	0.0000
CointEq(-1)*	−0.214443	0.021425	−10.00918	0.0021
R^2		0.995705	Adjusted R^2	0.986043

Note: Results with P-values below 0.05 are included in the table.

An examination of the Türkiye ARDL error correction model (4,4,4,4,3) reveals that the CointEq(-1) probability value is negative and significant with values of 0.0021 and the coefficient is −0.214443, indicating that the balance has been reached. CO_2 was also found to be significant in the second and third periods and showed a decreasing trend with negative values. Banking sector development was found to be significant in three periods and was found to reduce CO_2 emissions. Economic growth was found to be significant in three periods and had an increasing impact on CO_2 emissions. Financial development, with its high coefficient, was found to be significant in all periods and increased CO_2 emissions. Renewable energy, on the other hand, was observed to have a reducing impact on carbon emissions in the immediate period, but was found to increase in the subsequent two periods. This situation, compared with the ARDL analysis, is interpreted as its temporary response to short-term imbalances. The ARDL analysis clearly demonstrated the reduced impact of renewable energy on CO_2 emissions. The finding of R2 99% and adjusted R2 98% indicates that the model is quite compatible.

Table 11

ARDL F-Bounds Test Result (Türkiye, 4, 4, 4, 4, 3, 1990-2021)

Test Sta.	Value	Signif.	I(0)	I(1)
F-sta.	6.261481	10%	2.2	3.09
k	4	5%	2.56	3.49

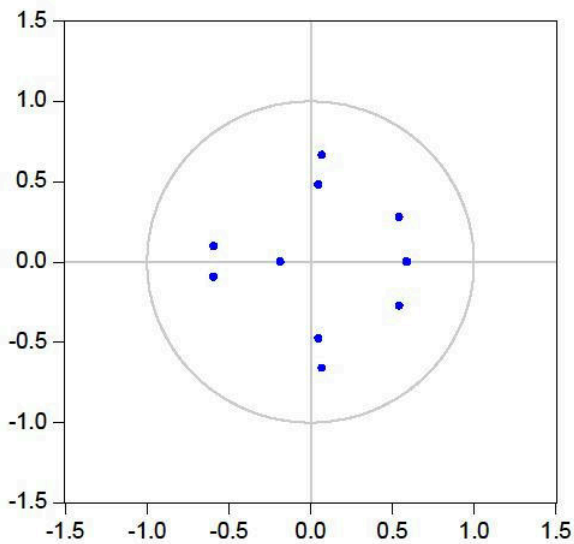
When the result of 6.261 was examined in the 5% range in the F-Bounds test, it was 3.49 and it was clearly found that there was a long-term balance relationship between the dependent and independent variables.

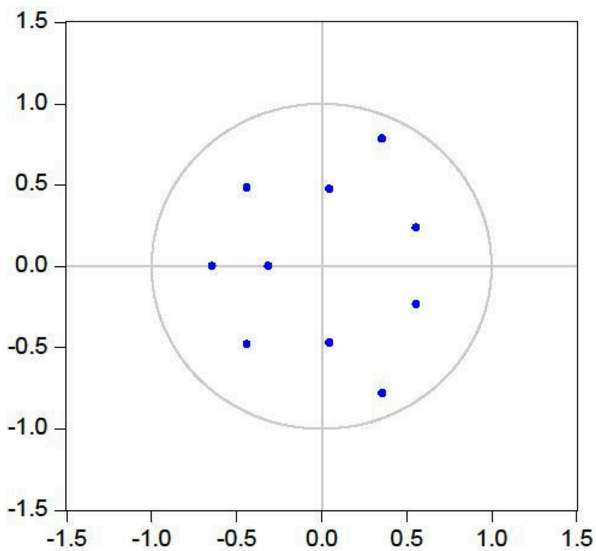
Dynamic Interactions: VAR, Impulse-Response Analysis, and Variance Decomposition

VAR analysis is a frequently preferred method for time series analysis because it can present dynamic relationships without imposing any constraints on structural models (Keating, 1990: 453–454). In the figures below, the fact that the inverse roots of the AR characteristic polynomial are located within the unit circle is an indication of the stationarity of the model.

Figure 1

Var Analysis (Brazil and Türkiye, respectively)





Variance decomposition is generally preferred in time series analyses and especially in forecasting models, providing a deeper understanding of the predictive power of the model and the relationship between variables (Demirci, 2017: 157).

Table 12

Varıance Decomposıtıon (Brazil, 1990-2021)

Prd	S.E.	CO_2	BNK_SEK1	EKO_BUY1	FNS_GEL1	YEN_ENJ1
1	23156047	100.0000	0.000000	0.000000	0.000000	0.000000
2	26002617	79.60153	0.625663	4.541179	0.705780	14.52584

Prd	S.E.	CO_2	BNK_SEK1	EKO_BUY1	FNS_GEL1	YEN_ENJ1
3	28581011	78.55825	0.535997	6.916663	1.141714	12.84738
4	29018954	77.89750	1.399493	6.762559	1.367519	12.57293
5	29602059	75.51831	1.925172	6.759782	1.616349	14.18038
6	29738558	75.66641	1.908204	6.747065	1.626029	14.05229
7	29815159	75.31248	1.951503	6.737844	1.712755	14.28542
8	29851366	75.28459	1.972624	6.760277	1.715628	14.26688
9	29858378	75.25487	1.986845	6.757872	1.720107	14.28031
10	29862804	75.24466	1.986328	6.764004	1.722502	14.28250

When we examine the impact of the independent variables on the dependent variable in the variance decomposition analysis for Brazil in Table 12, we see that carbon emissions were affected by internal shocks in the first period, while the other independent variables had no effect. After the second period, the effects of the independent variables began to be clearly observed, and in the most recent period, the 10th period, renewable energy had a 14.28% impact on carbon emissions, economic growth had a 6.76% impact, banking sector development had a 1.98% impact, and financial development had a 1.72% impact.

Table 13

Varıance Decomposıtıon (Türkiye, 1990-2021)

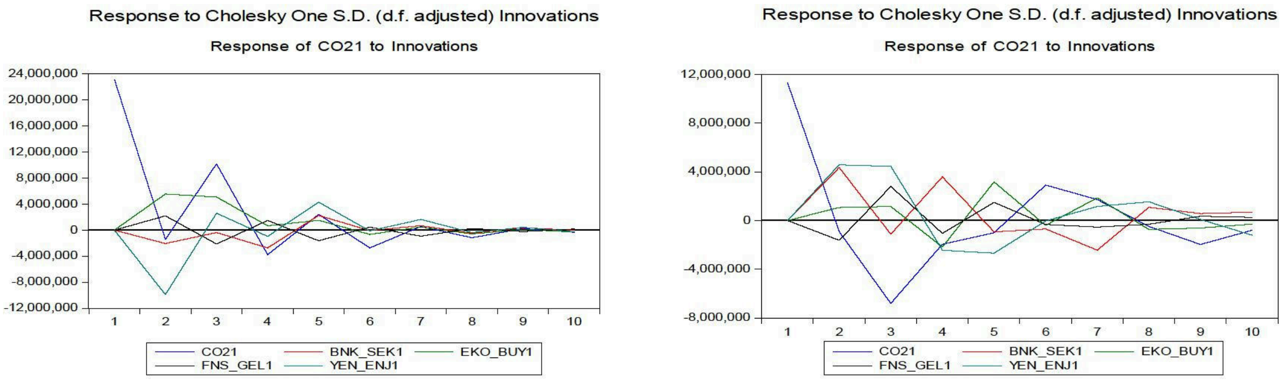
Prd	S.E.	CO_2	BNK_SEK1	EKO_BUY1	FNS_GEL1	YEN_ENJ1
1	11308124	100.0000	0.000000	0.000000	0.000000	0.000000
2	13124921	74.71268	10.99048	0.653261	1.534991	12.10858
3	15773935	70.36638	8.116744	0.980115	4.204482	16.33228
4	16652547	64.50649	11.91823	2.585696	4.175308	16.81427
5	17280111	60.24713	11.36130	5.744956	4.619758	18.02686
6	17543795	61.18854	11.17844	5.626822	4.516734	17.48947
7	17938221	59.44915	12.53952	6.455814	4.413122	17.14240
8	18060931	58.71712	12.72602	6.534717	4.382400	17.63975
9	18191050	59.05330	12.64197	6.558127	4.356178	17.39043
10	18265572	58.76200	12.67990	6.531155	4.341033	17.68591

In the variance decomposition analysis for Türkiye in Table 13, it is seen that carbon emissions were affected by internal shocks in the first period, and other independent variables had no effect. The effects began after the second period, and in the 10th period, renewable energy had a 17.68% impact on carbon emissions, banking sector development had a 12.67% impact, economic growth had a 6.53% impact, and financial development had a 4.34% impact.

Impulse response analysis is an important analysis method that allows understanding how variables affect each other after a shock and the magnitude, duration and direction of this effect (Lipsey and Chrystal, 2011).

Figure 2

Impact Response Analysis (Brazil and Türkiye, respectively)



Examining the Brazilian impact-response analysis in Figure 2, renewable energy, shown in turquoise, exhibited a large negative trend in the initial period, then recovered and turned positive. However, this effect stabilised over time. Economic growth, shown by the green line, initially exhibited a negative and then a positive effect after the shock and was found to be the second most volatile variable. Financial development, shown by the black line, had a relatively balanced effect on carbon emissions, with small positive and negative fluctuations. Banking sector development, observed in the red line, initially had a positive impact on carbon emissions, but then quickly turned negative. In other words, while the banking sector development shock initially increased carbon emissions, this effect soon reversed and decreased. The renewable energy variable appeared as the variable showing the highest fluctuation. This finding from the impulse response analysis is consistent with the results from the variance decomposition.

When we examine the Türkiye graph in Figure 2, we see that the turquoise line, representing renewable energy, is the variable that fluctuates the most. Renewable energy is an effective independent variable in reducing carbon emissions. Banking sector development, shown in red, appears as the second most important variable affecting carbon emissions in the graph. While economic growth, shown in green, initially exhibits slight postshock fluctuations, it follows a more balanced course over time than other variables. Financial development, shown in purple, stands out as the least volatile variable compared to the other variables in the impulse-response analysis.

Model diagnostic and robustness tests

The Breusch-Pagan-Godfrey tests check the validity of the statistical tests by testing whether there is heteroskedasticity (variance is not constant) in the error terms in the regression analysis (Alpay, 2013: 20).

Table 14

Heteroskedasticity Tests: Breusch-Pagan-Godfrey (Brazil, 1990-2021)

F-sta	0.148059	**F(24,2) P.**	0.9953	**Number of observations × R^2**	17.27625	**Chi-square (24) P.**
0.8366	**Scaled explained sum of squares**	0.110230	**Chi-square (24) P.**	1.0000		

According to the Breusch-Pagan-Godfrey test results for Brazil in Table 14, the probability values of all test statistics are quite high, the null hypothesis of no heteroskedasticity could not be rejected, and it was determined that the model was homoskedastic, that is, the variance of the error terms was not affected by the independent variables.

Table 15

Heteroskedasticity Tests: Breusch-Pagan-Godfrey (Türkiye, 1990-2021)

F-sta	0.465654	**F(23,3) P.**	0.8782
Number of observations × R^2	21.09193	**Chi-square (23) P.**	0.5755
Scaled explained sum of squares	0.202220	**Chi-square (23) P.**	1.0000

The Breusch-Pagan-Godfrey test performed for Türkiye, shown in Table 15, shows that the model assumptions are valid and the error variance is constant. In other words, the heteroskedasticity hypothesis cannot be rejected, and the variance of the error terms in the model is found to have no significant relationship with the independent variables.

The Ramsey RESET (Regression Specification Error Test) test is used to identify missing or incorrect definitions of the model in regression models and to detect functional form errors (Yavan, 2022 : 27).

Table 16

Ramsey RESET Tests (Brazil, 1990-2021)

	Value	**d**	**P.**
t-sta.	2.894129	1	0.2118
F-sta.	8.375985	(1, 1)	0.2118
	Sum of the Squares	**d**	**Mean Squares**
Test SSR	4.78E+13	1	4.78E+13
Limited SSR	5.35E+13	2	2.67E+13
Unlimited SSR	5.70E+12	1	5.70E+12

When the data for Brazil in Table 16 is examined within the Ramsey RESET test, the p-value obtained is 0.2118, which is higher than the commonly used 0.05 significance level. This rejects the null hypothesis and determines that there is no specification error in the model. When we look at other statistical values, we find that the difference between the Test SSR, Restricted SSR, and Unrestricted SSR values is not large, thus supporting the findings that there is no specification error.

Table 17

Ramsey RESET Tests (Türkiye, 1990-2021)

	Value	**d**	**P.**
t-sta.	0.126574	2	0.9109
F-sta.	0.016021	(1, 2)	0.9109
	Sum of the Squares	**d**	**Mean Squares**
Test SSR	3.32E+11	1	3.32E+11
Limited SSR	4.18E+13	3	1.39E+13
Unlimited SSR	4.14E+13	2	2.07+13

In the Ramsey RESET test of Türkiye, when the values were examined in the same way, no specification error was observed and it was determined that the current model was sufficient.

In order to see the structural stability of all the analyses performed, first, the changes in the mean of the regression coefficients were tested with the CUSUM test, and then the changes in the variance of the residuals were shown with the CUSUMSQ test (Muyambiri, 2025: 500).

Figure 3

CUSUM and CUSUMQ Tests (Brazil)

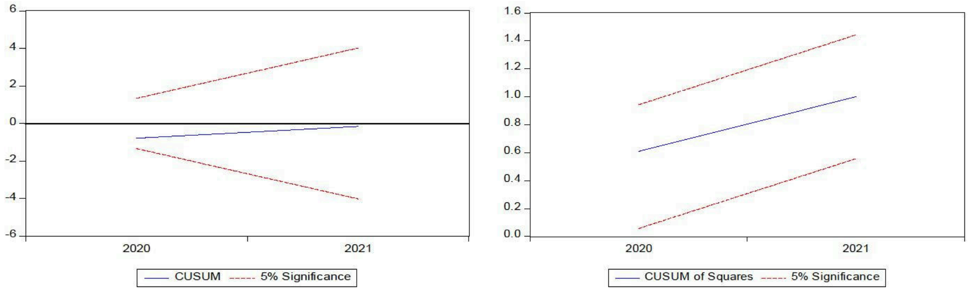
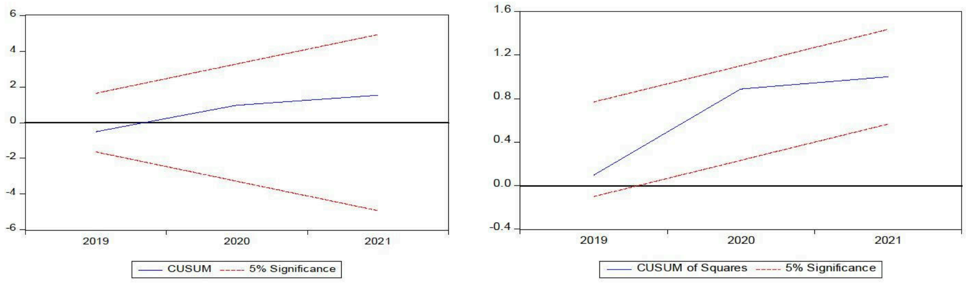


Figure 4

CUSUM and CUSUMQ Tests (Türkiye)



When the CUSUM and CUSUMQ graphs for Brazil and Türkiye are examined, it is seen that the blue line remains within the red line, and there is no change in the structural break or error variance. Thus, the stationarity of the constructed model is clearly established.

Conclusion and Recommendations

This research uses comprehensive econometric methods to analyse the relationship between CO2 emissions and banking sector development, financial development, economic growth, and renewable energy variables to examine the impact of the financial system on environmental quality in emerging economies, including Brazil and Türkiye. The analyses use unit root tests, VAR, variance decomposition, impulse-response and FMOLS/DOLS/CCR, ARDL, ECM, F-bound tests, and validation methods. This is the first study to examine this topic in such detail and will make a significant contribution to the literature.

Initially, unit root tests proved that all variables were nonstationary at level, but became stationary after taking their first differences (I(1)). This finding highlights the necessity of co-integration analysis, as it may create a risk of spurious regression when traditional regression models are used (Stock and Watson, 2003). The findings from the Johansen cointegration test confirmed one long-run relationship in Brazil and two in Türkiye, allowing us to determine that the variables examined in both economies move together and are in equilibrium in the long run. This empirical finding demonstrates that the long-term FMOLS, DOLS, CCR, and ARDL models are methodologically appropriate.

Longterm findings obtained using FMOLS, DOLS, and CCR methods reveal the distinct relationship between finance and the environment in Brazil and Türkiye. These theoretically analysed findings reveal a statistically significant and positive impact of banking sector development on CO_2 emissions in Türkiye. In Türkiye, the scale effect, which is defined as the increase in credit and economic growth resulting in increased energy consumption, suggests that the banking system's theoretical framework is more dominant than the technological impact of financing renewable technology investments and reducing emissions. In this sense, this finding is consistent with the findings of Samour et al. (2019) and Bayrak (2024), who emphasise that the Turkish banking system has traditionally provided credit flows to energy-intensive sectors. In Brazil, most analyses have found no significant impact on the banking sector, recommend that the economy's financial structure does not have a clear direction on emissions. The most striking difference between the two economies, however, is the impact of economic growth. In Brazil, growth has steadily increased emissions, confirming that the economy is still in the growth phase of the EKC hypothesis. On the other hand, in Türkiye, the negative, albeit insignificant, effect of economic growth in the DOLS and CCR analyses, and the significant and negative effect and tendency to reduce emissions in the FMOLS analysis, provide strong empirical evidence that this indicates a declining period of EKC. This is consistent with the view of Pala and Barut in their 2021 study that emission-reducing growth can be interpreted as an indicator of the economy undergoing a structural transformation from energy-intensive sectors to services and less polluting industries, or as an indicator of significant improvements in energy efficiency. Furthermore, across all analyses in both countries, renewable energy clearly has a statistically significant and reducing effect on CO_2 emissions, as found in the articles by Ateş et al. (2025) and Raihan and Tuspekova (2022). In other words, although Brazil and Türkiye are classified as developing countries, these analyses demonstrate that they are at different stages within the EKC hypothesis. While the findings in Türkiye address the need to increase sustainable banking practices within the context of green finance, they also indicate that Brazil should focus on renewable energy policies to reduce the environmental impact of growth.

When examined according to the ARDL and error correction model (ECM) results, the error correction coefficients [CointEq(-1)] obtained for Brazil and Türkiye also indicate differences in the response mechanisms to shocks between the two economies. The error correction coefficient in Brazil, found to be very high and significant at −3.11, indicates that imbalances resulting from CO_2 emissions were corrected very quickly, with a value of 311%. On the other hand, the coefficient for Türkiye, at −0.21, indicates that the process of returning to balance is slower and more gradual (with an adjustment speed of 21%). This finding recommend that the financial, energy, and carbon emission systems in Türkiye may have more deep-rooted structural impediments or that the effects of political interventions are being felt with a lag. Furthermore, the long-term coefficients obtained from the ARDL model are largely similar to the FMOLS, DOLS, and CCR estimates. In particular, the consistent long-term emission-reducing effect of renewable energy in both countries demonstrates that our findings regarding the role of this variable are highly robust. The ARDL model's finding that economic growth is positive in Brazil and negative in Türkiye aligns with our other analyses of the EKC, clarifying our comparative finding. Furthermore, the ARDL analysis demonstrates that even variables with no long-term impact can cause significant fluctuations in the short term. For example, the short-term emissions-reducing impact of banking sector development in Brazil, according to the ECM results, highlights the complexity of the financial system's behavioural responses. Unlike previous analyses, the finding that renewable energy leads to a short-term increase in emissions in Türkiye demonstrates a temporary adjustment until renewable energy reaches a recovery phase. However, the F-bound test, which demonstrates the existence of a long-term relationship in both countries, indicates that these short-term fluctuations are not permanent.

In the variance decomposition and impulse-response analyses, the 10-period period is carefully preserved. In the first period, the largest portion of the change in CO_2 emissions at both levels was due to past shocks. However, the explanatory power of the independent variables was observed to be different in both periods. In Türkiye, the performance of the financial system and credit preferences, which facilitate the development of the banking sector, have the highest impact on emissions at 12.7%. In this sense, the banking sector is crucial for environmental sustainability in Türkiye. In Brazil, renewable energy, accounting for approximately 14.3% of the total, has become the most important variable to be considered in the country's emissions reduction policies. Moreover, the fact that a shock experienced in the banking sector in Türkiye has a stable and permanent effect on emissions in the impact-response analysis indicates that the current credit structure can encourage growth in a polluting way. For this reason, we are seeing an increase in green banking practices in Türkiye and an acceleration of sustainable finance studies. In Brazil, renewable energy is seen as the strongest shock, highlighting the benefits of the country's energy transition. Policymakers in this country should particularly focus on encouraging investment in renewable energy technologies and accelerating green financing efforts.

The long-term findings obtained through these empirical analyses indicate the need to create different scenarios. In Türkiye, the dominant and negative role of the banking sector in both the short and long term in emissions suggests that the green transformation of the financial system should be a priority for policymakers. In Brazil, the prominence of renewable energy as both the main long-term solution and the most effective policy tool in the short term justifies the path followed by this country in its energy policies and indicates that this focus should be maintained.

All the applied model diagnostic tests demonstrate that the estimated models are econometrically reliable and robust. The insignificant results of the Ramsey RESET test for both countries indicate that there is no serious functional form error or significant omitted variable in the model specification, providing strong evidence that our model is correctly specified. Furthermore, the Breusch-Pagan-Godfrey test results indicated no heteroskedasticity in the models. The constant variance of the error terms ensured the effectiveness of the resulting estimators (FMOLS, DOLS, CCR, ARDL) and confirmed the reliability of the standard errors. Finally, the fact that the line in the CUSUM and CUSUMSQ tests graphs remained within the critical limits at the 5% significance level for both countries showed that our model was not affected by structural breaks in the period 1990-2021, confirming the consistency of our findings and the robustness of the expressed policy recommendations.

In conclusion, renewable energy investments are the most effective route in both countries. Therefore, it is crucial to diversify and implement "Green Finance" programmes for renewable energy investments and to strengthen the necessary technological research in this area.

This study has several limitations. As of the period under review, direct and standard indicators of green finance (e.g., green bond issuance and, green loan volume) are not widely available for either country. Therefore, the analysis was conducted using traditional financial indicators, and the findings offer indirect but strong implications for green finance policies. Furthermore, as green finance becomes measurable at the country level in future research, studies that directly include this variable in the model will directly complement our current findings. Similarly, future studies could examine the environmental effect of financial development in more detail at the sectoral level by considering the sectoral distribution of banking loans. A similar methodological framework could be applied to different groups of developing countries to conduct a comparative analysis of the finance environment relationship at the global level.

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