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Regenerating Sustainable Energy and Environmental Solutions: Challenges and Opportunities in Belt and Road Initiative Countries.

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Abstract: This study examines financial development, economic growth, energy consumption, trade openness, urbanization, and environmental degradation in 47 Belt and Road Initiative (BRI) countries from 1980 to 2022. Panel unit root tests (IPS, LLC, PP, and ADF) ensured data correctness and stationarity. Three co-integration tests examined the relationships among the variables. Difference of means (DOLS) and functional moment (FMOLS) tests examined the co-integration of the BRI economies. A paired Granger causality test found bidirectional relationships among CO2 emissions, urbanization, financial development, economic growth, and gross fixed capital formation. Trade openness only correlated with ecological well-being.

International study suggests regional, state, and federal policy implications. The empirical investigation used a panel causal heterogeneous test, dynamic ordinary least squares (DOLS), and fully modified ordinary least squares (MOLS) with fixed and random effects. Trade openness negatively affected CO2 emissions, but all other regressors positively affected environmental quality. Good governance and country-specific policies are needed to maximize the benefits of the BRI. Despite conflicting energy statistics, the study found that economic development hurt the environment in all 47 countries. Industrialized nations generally use renewable energy, which helps minimize ecological issues; hence, their exclusion from the BRI full panel may explain the negative coefficient.

Since most BRI economies are in emerging and growing countries, environmental preservation and renewable energy technologies need more time and money. Instead of coal, the Chinese government and other BRI nations are urged to invest in wind, hydro, solar, and biomass. Sharing green energy technology might help BRI economies. A cross-national urbanization strategy should incorporate eco-friendly solutions. The panel and governments may utilize the paper's substantial policy recommendations.
Keywords: Environmental sustainability, CO2 emissions, Economic Growth, Financial Development, Trade Openness,

1. Introduction:

A connection, the Belt and Road Initiative (BRI) includes 71 nations, or 65% of the world's population. The project helps nations share resources, technology, and trained labor, modernize industrial infrastructure, and boost economic development. China's president, Xi Jinping, originally introduced the BRI to expand China's markets in Asia, Africa, and Europe.

As a result, the region's industrial infrastructure will be strengthened, technology will progress, and commodities will be transported more conveniently. The International Energy Agency estimated that the financing for BRI projects ranges from US$4 to US$8 trillion (Tomasic).

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The majority of Belt and Road Initiative (BRI) funding is directed toward underdeveloped countries to accelerate economic growth. It has been reported that the BRI has initiated more than 7,000 projects, including industrial expansion, power generation facilities, transportation infrastructure such as roads and railways, and poverty alleviation programs (Holmberg & Erdemir). The Solow growth model highlights the importance of capital and labor in driving economic development. Subsequent extensions of this model incorporated energy as a key input, emphasizing its essential role in production processes and long-term economic growth (Pedroni).

Despite this, existing studies have largely overlooked the impacts of BRI projects across the 47 participating countries on economic development, energy consumption patterns, and environmental sustainability. This study, therefore, investigates the relationships among economic development, energy consumption, urbanization, gross fixed capital formation, trade openness, financial development, and carbon dioxide emissions—used as a proxy for environmental degradation—across 47 BRI economies over the period from 1980 to 2022 (Laurance).

The findings are expected to provide valuable policy insights for regional and country-specific decision-making, enabling policymakers to identify key opportunities and challenges in economic growth, energy systems, and environmental sustainability. Furthermore, the estimated results offer strategic guidance to policymakers and governing institutions by promoting efficient governance, environmentally sustainable waste management practices, a transition toward renewable energy, and the implementation of critical measures to restore ecosystems (Shahbaz & Ozturk).

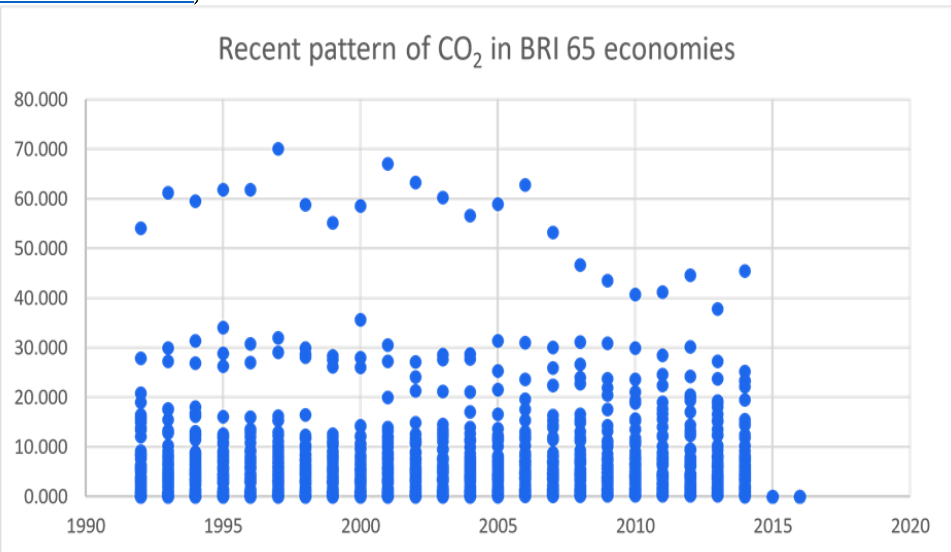

Figure 1: The BRI Countries' Recent Pattern of CO2 Emission

The BRI program has had a variety of direct and indirect effects on human activities. It is crucial to note that while globalization will benefit economies, it may also entail drawbacks, including environmental degradation from increased energy use (Cao & Qu).

China has the highest energy consumption and CO2 emissions, accounting for around 30 percent of worldwide emissions. According to (Shi), China's CO2 emissions are caused mainly by economic development and industrialization.

As a result, China is rapidly developing its reliance on energy power production. In the meantime, as a result of the BRI plan, certain environmentally harmful power generation facilities and polluting industrial sectors are going overseas. In BRI projects, coal-based power plants receive 65% of the funding allocated to energy production, whereas wind energy receives only 1%.

Between 2007 and 2013, China accounted for around 40 percent of global state spending on coal-based initiatives. It is important to note that China is constructing 240 coal-fired power plants with a combined installed capacity of 251 Gigawatts in 25 BRI nations. The proportion of global CO2 emissions attributable to BRI countries, excluding China, has risen to almost 61.4 percent (Howard & Howard).

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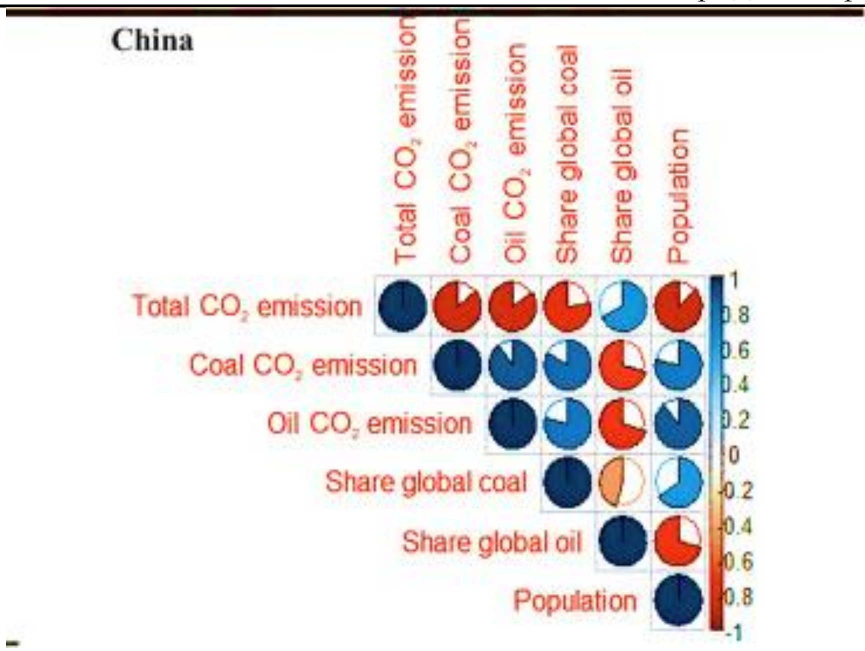

Figure 2: Coal emission trends in China (Mehmood et al., 2024).

Additionally, the BRI economies account for nearly 80% of the world's energy-intensive CO2 emissions, highlighting the vital role the energy sector plays in accelerating environmental deterioration. Proceeding with this premise, it is difficult to avoid the decision that BRI schemes will benefit the economy while also harming the environment (Smyth). A few academics additionally stated that the "global shifting tsunami" of BRI projects may harm local ecosystems and resources (Cerdeira & et al.). As a result, it has become a key factor influencing the success of BRI projects in low-income economies.

1.1 Hypothesis:

H1: There is a positive relationship between economic growth and environmental degradation in the 47 Belt and Road Initiative (BRI) countries.
H2: Energy consumption is positively associated with environmental degradation in the BRI countries.
H3: Financial development positively impacts environmental degradation in the BRI countries.
H4: Trade openness hurts CO2 emissions in the BRI countries.
H5: Urbanization is positively correlated with environmental degradation in the BRI countries.
H6: Gross fixed capital formation is positively related to environmental degradation in the BRI countries.

2. Literature Review

Numerous studies have examined the relationship between economic development, carbon dioxide (CO_2) emissions, and energy consumption. Global analyses suggest that the interconnection between oil-driven economic growth and electricity consumption implies that increased investment in the energy sector may help reduce CO_2 emissions, thereby improving environmental quality, and vice versa(Sharif Hossain).

However, this relationship has also been critically assessed in the literature, particularly with respect to the sensitivity of econometric methodologies and country classification approaches. These critiques emphasize that exogenous shocks can significantly influence economic outcomes, thereby affecting empirical results and policy conclusions (Sharif Hossain).

Recent studies have extended the Environmental Kuznets Curve (EKC) framework by incorporating additional factors such as financial development, urbanization, and technological innovation. Empirical evidence indicates a strong positive association between energy consumption and urbanization, which contributes to increased CO_2 emissions (Dogan). Urban areas, which accommodate more than 50% of the global population, are responsible for approximately 70% of global greenhouse gas emissions (Dogan).

An assessment of total factor energy efficiency across 35 Belt and Road Initiative (BRI) countries reveals that nations with lower energy efficiency tend to generate higher emissions. Similarly, empirical investigations confirm significant relationships among energy consumption, income levels, CO_2 emissions, capital formation, and labor inputs (Shahbaz & et al., 2016). Recent research on large-scale infrastructure initiatives, such as the BRI, has further evaluated environmental impacts using both single-country case studies and multi-country panel analyses (Vaona).Early empirical studies established a causal relationship between economic growth and energy consumption, identifying both short- and long-run interdependencies between the two. Policy-oriented research has highlighted environmental challenges arising from industrial modernization in developing economies. Sectoral analyses of industrial activity demonstrate both unidirectional and bidirectional relationships between electricity demand and industrial value added, with key determinants of CO_2 emissions including industrial growth and population size. At the same time, foreign direct investment (FDI) mitigates emissions (Chen & Chen).

Empirical evidence from developing economies further supports these findings. A study examining the effects of energy consumption, financial development, economic growth, and trade openness on CO_2 emissions over the period 1971–2010 identifies a long-run cointegration relationship among these variables. Economic growth, financial development, and energy consumption are found to have positive effects on CO_2 emissions, whereas trade openness shows a negative association (Selden & Song, 1994). Based on these findings, policy recommendations emphasize the need for strengthened government programs and strategies to reduce carbon emissions and promote sustainable development (Xu & Lin).

3. Methodology

3.1 Data Sources and Variables

The panel dataset of the 47 economies was extracted from the WDI database. Going global

Bilateral ties are the driving force behind the BRI, which was initiated by the Chinese government (Shi, 2003). All sectors must engage in economic activity for an economy to flourish and be sustainable. Investment in fixed capital, trade openness, Urbanization, labor activities, gross domestic product (GDP), environmental health, and energy use are a few examples of these contributions. Additionally, all of these must be done to speed economic development and attain sustainability (Zhao & et al.). The BRI spans more than 68 nations, enabling the assessment of supply and demand for ecological quality, sustainable development, and commercial and occupational cooperation. Therefore, for the BRI to succeed across the board and in light of the debates discussed previously, it is crucial to evaluate the difficulties and prospects for the future. Therefore, CO2 emissions are included in the current research as a dependent variable to assess environmental sustainability. All variables are presented in Table 1 with the appropriate justification (Liu & Lu, 2017). In this study, variables are used in logarithmic form.

Table 1: Variables measurement

Variables	Elaboration	Data Source
Carbon emission (CO2)	CO2 equivalent (metric tonnes per person)	WDI
Energy consumption (ECON)	Energy consumption (k ilograms of oil equivalent per capita)	WDI
Gross domestic product (GDPPC)	GDP per capita (constant at 2010 US $)	WDI
Financial development (FDEV)	Domestic credit to private sector as percentage of GDP	WDI
Gross Fixed Capital Formation (GFC)	Gross Fixed Capital Formation% of GDP	WDI
Urbanization (URBN)	Urban population of the total population	WDI
Trade Openness (TROPS)	Total value of imports and exports imports% of GDP	WDI

3.2 Econometric Methodology

Typically, individual time-series datasets are analyzed using a variety of unit root tests, including the Augmented Dickey–Fuller (ADF), Phillips–Perron (PP), Kwiatkowski–Phillips–Schmidt–Shin (KPSS), and generalized least squares (GLS) tests.

It is widely acknowledged that conventional unit root tests may have limited power in small samples when distinguishing between stationary and non-stationary series. In contrast, panel data provide more observations, which help reduce multicollinearity and increase degrees of freedom by pooling information across cross-sectional units and time periods (Kraft & Kraft).

For panel unit root analysis, several testing approaches are available (Clement). In this study, four panel unit root tests were employed. Based on the results of these tests, the Pedroni cointegration test was applied to examine the long-run relationships between the dependent variables and their regressors (Wang & Fang).

3.3 Panel Co-integration Tests

The panel unit root inquiry may examine the dataset series at the level or in first differences, depending on the inference. Further, the co-integrating relationship between dependent and independent variables is the same whether the series is stationary at the first difference (Toman & Jemelkova). Use typical OLS panel measures if the data set sequence is stationary at that level.

Even though panel cointegration is fundamentally unstable, the linear-patterned stationarity of the (1, 1) order of cointegration for two variables suggests it occurs. Panel cointegration tests (Guojian & et al.) were used to determine the stationarity of the variables.

For co-integration testing, the variables that integrate at first order (I (1) will be used. Seven residual-based statistical methods are used to examine panel cointegration for long-term links between data sequences(Zhang).

H0: No cointegration connection for all I and H1: A cointegration link for all I is the Pedroni cointegration test's hypothesis and null hypothesis. The predicted variables and regressors are associated over the long term if the panel data statistics show a larger positive weight than the statistics. According to the "H0" hypothesis, the two-dataset series are not cointegrated.
The following equation represents the Pedroni cointegration test:

$$\text{CO2i, t} = \alpha + \delta\text{it} + \beta1\text{lnECONi, t} + \beta3\text{lnGDPi, t} + \beta2\text{lnFDEVi, t} + \beta4\text{lnGFCi, t} + \beta5\text{lnTOPSi, t} + \beta5\text{lnURBNi, t} + \varepsilon\text{i, t} \qquad (1)$$

Equation (4) illustrates the cointegration test's foundation, where I denotes a country-specific constant and "it" denotes the corresponding single country's deterministic trend across the selected panel of countries. The results from the Pedroni cointegration test represent standardized evidence under an asymptotic distribution. Consequently, the following is a possible formulation for the Pedroni equation:

$$\sqrt{\ }\text{NN, T'-}\mu\sqrt{\ }\text{N} \ \sqrt{\ }\text{V}\rightarrow\text{N (0,1)} \qquad (2)$$

Equation (5) reveals the Monte Carlo (MC)-shaped term and the variance term V, respectively.

3.4 Dynamic Panel Modeling

Fully modified OLS (FMOLS) and dynamic OLS (DOLS) panels were used in the research to examine the long-run cointegrating association between the independent and the dependent variable (CO2). The correlation drawbacks among the panel-intensive-error terms are the primary justification for using DOLS and FMOLS. To normalize the findings, all variables under study are turned into logarithms. The FMOLS and DOLS estimates during the research will be determined and measured using the following equations:

$$\hat{\beta}\text{NT} = [\Sigma\Sigma(\text{xit} - \bar{\text{x}}\text{i})(\text{yit} - \bar{\text{y}}\text{i})\text{Tt} = 1\text{Ni} = 1 - \text{T}\hat{\gamma}\text{i}\Sigma(\text{xit} - \hat{\text{x}}\text{i})2\text{Tt} = 1] \qquad (4.6)$$

where

$$\hat{\gamma}i = \hat{\Gamma}21i + \hat{\Omega}21i0 - \hat{\Omega}21i\hat{\Omega}21i(\hat{\Gamma}22i + \hat{\Omega}22i2) \quad (4.7)$$

And

$$\hat{\Omega}i = \hat{\Omega}i0 + \hat{\Gamma}i + \hat{\Gamma}'i \quad (4.8)$$

The long-run stationarity matrix is shown by the I term, which is followed by the i0 term, which deals with the covariance between stationary error terms. The i provide a further illustration of the corrected covariance term between the regressor variables.

3.5 Heterogeneous Panel Causality Test

The next step in establishing relationships among the variables is to use Granger causality analysis to trace the causal chain. Here, the heterogeneous Granger causality test (Ali & et al.) will be used to find the estimators and focus on Wald asymptotic values.

This evaluation has the advantage of accounting for variation and dependence across particular economies (Meng & Niu). Additionally, it may work when the time (T) is longer or shorter than the cross-country distance (N).

4. Results

The FMOLS and DOLS models were used to derive the empirical values. To highlight long-term estimates of policy choices and effects across countries, a total of 47 BRI economies were considered. Across the whole panel and in the cross-country studies, these countries were examined with respect to total energy, economic, and environmental sustainability.

4.1 Descriptive Statistics

The overall data for all the factors considered are shown in Table 2. It includes 1719 observations throughout 37 time intervals and 47 cross-sections. To avoid unfavorable shocks, the variables were mainly transformed to natural logarithms; however, these estimates may also have weakened the present study's reliability. Table 2 shows the mean, median, maximum, and minimum values. These indicate the dataset's series and distribution.

Table 2: Descriptive statistics

	CO2	ECON	GDPPC	GFC	FDEV	TROPS	URBN
Mean	0.76	6.16	7.106	19.744	30.535	68.44	52.14
Median	0.68	6.811	7.874	21.254	24.208	67.489	54.345
Max	3.57	9.436	11.631	65.55	166.514	251.149	98.348
Min	-3.556	0	0	0	0	0	6.09
Std. Dev.	1.366	2.652	2.94	11.081	30.622	47.647	21.549
skewness	-0.262	-1.484	-1.532	-0.268	1.34	0.443	-0.033
Kurtosis	2.849	4.105	4.445	3.376	4.983	2.958	2.154
JB. Test	24.215	727.247	832.789	31.381	799.507	59.06	50.411
Prob.	0	0	0	0	0	0	0
Sum	1317	10512	12218	33941	52473	117666	91330
Sq. Dev.	3251	12171	14955	210972	16099	38986	79852
Obs.	1719	1719	1719	1719	1719	1719	1719

Author's Estimations.

4.2 Impact on Retention

The correlational statistics are presented in Table 3. In 47 BRI economies, there appears to be a strong correlation among all factors and CO_2 emissions. Urbanization and energy use had greater than 50% impacts on environmental excellence, while trade openness, GDP, and corresponding impacts were 42.32%, 36.52%, 25.92%,

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and 20.96%, respectively. This suggests that, compared to other regressors, urbanization and energy use have a substantially greater negative impact on the environment.

Table 3: Correlation Statistics

Probability	CO2	ECON	GDPC	GFC	FDEV	TROPS	URBN
CO2				1			
ECON		0.565358			1		
0.0000							
GDPPC		0.423292		0.504484		1	
0.0000		0.0000					
GFC	0.209665		0.325132	0.575475		1	
0.0000		0.0000		0.0000			
FDEV	0.259249	0.180134		0.408942	0.423395	1	
0.0000	0.0000		0.0000	0.0000			
TROPS	0.365223	0.360227	0.542231	0.508871	0.45238	1	
0.0000	0.0000	0.0000		0.0000	0.0000		
URBN	0.769096	0.30611	0.305279	0.043016	0.212563	0.286609	1
0.0000	0.0000	0.0000	0.0746	0.0000	0.0000		

Note: Author's table where CO2 stands for carbon emissions, ECON for energy usage, GDPPC for gross domestic product per person, and FDEV for financial development. The abbreviations GFC, URBN, and TROPS stand for Gross Fixed Capital Formation, Urban Population, and Trade Openness, respectively. Statistics are 10%, 5%, or 1% significant, respectively, as indicated by the symbols *, **, and ***.

4.3 Data Diagnostics

The stationarity of the study dataset was observed using the panel unit root tests (LLC, IPS, ADF, and PP). Table 5 presents the obtained estimates. All variables were stable and stationary at the first difference for the LLC, IPS, PP, and ADF tests.

As a result, it is necessary to investigate the cointegration between the anticipated variables and regressors, as this indicates that all variables are stationary at the initial difference (Banerjee & Rahman). However, the PP and ADF unit root tests indicated that commerce and urbanization both had substantial probabilities at the 10% level. However, once the variables were transformed into first differences, they all began to stabilize (Ali & et al.).The model's computations determined the degree of cointegration among the variables. Seven tests in Table 6 verified that the variables exhibit long-run cointegration at I(1, 1) and rejected the null hypothesis (H0) (Wang & Wang). Additionally, the Pedroni-based panel cointegration results were verified and aligned using the Johansen-Fisher (JF) panel cointegration test, as shown in Table 7.

According to the JF cointegration test results in Table 7, the null hypothesis (H0) that there is no cointegration between the variables should be rejected (Du & Zhang). These two tests confirm and guarantee that the variables have a long-term linear relationship, which is a sign of long-term panel cointegration (Hafeez & et al.).

The findings for long-run cointegration are presented in Table 5.7, following the Kao-based residual cointegration test as an additional test of cointegration (Wei & et al.). Using Kao-based statistics, we obtained a p-value of 5.952 ***, indicating that the two prior cointegration tests were successful and warrant further verification (Cheng).

Table 4: Unit root test

Regions	Methods	*CO2*	*ECON*	*GDPPC*	*GFC*	*FDEV*	*TROPS*	*URBN*
Full panel of	LLC	2.563	12.148	11.925	−4.340	7.842	−2.184 **	12.961

47 countries							
IPS	2.801	4.242	6.416	−4.162	9.218	−0.966	−0.150
ADF	80.662	60.327	60.133	146.992	38.392	104.548	122.581 **
PP	73.656	34.617	117.395 *	128.598	38.693	115.163 *	380.958 ***
1st Difference							
Full panel of 47 countries LLC	−36.90 ***	−31.11 ***	−149.7 ***	−38.36 ***	−25.1 ***	−33.410 ***	−6.354 ***
IPS	−31.31 ***	−22.44 ***	−52.55 ***	−32.15 ***	−25.4 ***	−33.010 ***	−4.671 ***
ADF	957.30 ***	776.28 ***	706.47 ***	838.42 ***	761.33 ***	970.871 ***	310.124 ***
PP	1031.750	884.77 ***	768.11 ***	979.89 ***	827.96 ***	1045.85 ***	546.27 ***

Note: *, **, and *** indicate that the statistics are significant at the 10%, 5%, and 1% levels, respectively.

Table 5: Pedroni panel cointegration test.

Alternative Hypothesis: Common Auto-Regressive (AR) coefficients				
Within-dimension				
Statistic		Prob.	Statistic	Prob.
Panel v-Statistic	1.96206	0.025 **	−3.8078	1.000
Panel rho-Statistic	3.7788	1.000	3.766	1.000
Panel PP-Statistic	−6.5950	0.000 ***	−6.4180	0.000 ***
Panel ADF-Statistic	−5.7340	0.000 ***	−6.4840	0.000 ***
Alternative hypothesis: Individual AR coefficients (between-dimension)				
Statistic		Prob.		
Group rho-Statistic	5.3726	1.000		
Group PP-Statistic	−9.1704	0.000 ***		
Group ADF-Statistic	−4.3975	0.000 ***		

Table 6: Johansen Fisher panel cointegration test, cointegration rank test

Hypothesized	**Fisher Statistics**		**Fisher Statistics**	
No. of CE (s)	(from trace test)	Prob.	(max-eigen test)	Prob.
None	1863.000	0.001 ***	1997.00	0.005 ***
At most 1	1156.000	0.003 ***	706.00	0.006 ***
At most 2	628.8	0.000 ***	356.2	0.004 ***
At most 3	361.5	0.008 ***	189.1	0.003 ***
At most 4	235.4	0.005 ***	143.3	0.002 ***
At most 5	167.7	0.004 ***	133.7	0.004 ***
At most 6	172.6	0.002 ***	172.5	0.006 ***

Table 7: Kao test for residual cointegration.

Null Hypothesis	**No Cointegration**
Kao t-Statistic	Probability
−6.852	0.002

Note: *** indicates that statistics are significant at a 1% level of significance, respectively.

4.4 Dynamic Panel Modeling

Panel estimates from the cointegration tests supported the long-term cointegration of the variables. For consistent results, it also recommends using fully modified OLS (FMOLS) (Apergis & Ozturk, 2015).To verify the intended linkages and evaluate the research hypothesis, DOLS and FMOLS were used (Xiao & et al.).

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According to the empirical assessment in Table 8, urbanization, gross fixed capital formation, energy consumption, and gross domestic product all have a positive and considerable impact on ecological conditions (a rise in CO2 emissions) (Farhani & et al.).

On the other hand, in the 47 BRI economies, trade openness has no negative impact on environmental conditions (Huang). We discovered using FMOLS that changes in ecological degradation (CO2 emissions) are correlated with changes in financial development, energy consumption, gross fixed capital formation, and urbanization, with correlation coefficients of (0.16259 ***), (0.040417 ***), (0.012342 ***), (0.005335 ***), and (0.030532 ***, respectively.

The environment is also negatively affected by commercial openness. The FMOLS estimates imply that the 47 BRI nations may have implemented some measures to limit reciprocal trade openness and its detrimental impact on ecological sustainability, while other estimates show hazardously rising compressions on environmental degradation for the 47 BRI economies (Atici).

Censured acts must be implemented, and governments must establish strong regulations to prevent ecological damage for the BRI to succeed (Jaunky, 2011). Overall, the findings of DOLS and FMOLS imply that the environmental sustainability of Energy consumption in 47 BRI nations poses a challenge to BRI initiatives, as they are primarily reliant on non-renewable energy sources, including gas, coal, and oil.

Is a higher economic growth rate—regardless of how it is attained—really important for any country? The sustainability of the environment has recently been negatively affected by developing, emerging, and low-income countries that have achieved high GDP levels.

The majority of the economies included in the BRI rely on outlay, but not necessarily green-intensive savings (Xu & Lin). Green investments may stimulate economic development without harming the environment if people are more aware of them. Urbanization should be managed in the interim to avoid affecting ecological sustainability or its position. Similar conclusions are reached by this (Dogan & Seker, 2016).

Table 8: DOLS and FMOLS estimation

Dependent Variable			**CO2 Emissions/Environmental Degradation**	
Panel-1			**Panel-2 (DOLS)**	
Independent	Coefficient	t-Statistic	Coefficient	t-Statistic
ECON	0.16259 ***	18.0931	0.112086 ***	6.7634
GDPPC	0.040417 ***	3.643503	0.038047 ***	2.67892
GFC	0.012342 ***	4.302308	0.015532 ***	4.59378
FDEV	0.005335 ***	4.18017	0.00362 ***	2.78995
TROPS	−0.00537 ***	−6.544434	−0.00553 ***	−5.47391
URBN	0.030532 ***	6.620429	0.039617 ***	7.17279
Observations	1669		1569	
R2	0.882718		0.987315	
Adjusted-R2	0.878944		0.970313	

Note: Author's estimates, where: FDEV stands for Financial Development; CO2 stands for Carbon Emissions; ECON is abbreviated for Energy Consumption; GDPPC stands for Gross Domestic Product Per Capita; The acronyms GFC stands for Gross Fixed Capital Formation, URBN for urban population, and TROPS for trade openness. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

4.5 Dumitrescu Hurlin Panel Heterogeneous Causality Test

The fundamental relationships among the study's variables were determined using a panel Granger causality test based on heterogeneity (Levin & Chu). Table 9 displays the findings of the panel Granger causation test. Divergent findings emerge from the heterogeneous causality test estimates across the 47 countries.

Except for trade openness, which has a one-way relationship with environmental quality, the causal estimates indicate bidirectional relationships between CO2 emissions (environmental quality) and the independent variables. A rise in regressors also significantly worsens environmental quality, according to the heterogeneous panel test (Pesaran).

Table 9: Pairwise Dumitrescu–Hurlin panel causality tests.

Null Hypothesis	W-Stat.	Zbar-Stat.	Prob.
ECON does not homogeneously cause CO2	2.5845	6.5894 ***	0.0000
CO2 does not homogeneously cause ECON	132.626	570.342 ***	0.0000
GDPPC does not homogeneously cause CO2	1.78912	3.14126 ***	0.0017
CO2 does not homogeneously cause GDPPC	17.4198	70.9029 ***	0.0000
GFC does not homogeneously cause CO2	2.16896	4.77437 ***	0.0000
CO2 does not homogeneously cause GFC	2.24507	5.10369 ***	0.0000
FDEV does not homogeneously cause CO2	1.79336	3.15877 ***	0.0016
CO2 does not homogeneously cause FDEV	4.65403	15.5583 ***	0.00000
TROPS does not homogeneously cause CO2	2.05119	4.27686 ***	0.0000
CO2 does not homogeneously cause TROPS	1.33402	1.16806	0.2428
URBN does not homogeneously cause CO2	2.0885	4.43914 ***	0.0000
CO2 does not homogeneously cause URBN	7.92282	29.7319 ***	0.0000
GDPPC does not homogeneously cause ECON	2.01748	4.13126 ***	0.0000
ECON does not homogeneously cause GDPPC	302.794	1308.05 ***	0.0000
GFC does not homogeneously cause ECON	2.0842	4.40761 ***	0.0000
ECON does not homogeneously cause GFC	5.09723	17.445 ***	0.0000

FDEV does not homogeneously cause ECON	2.3183	5.43411 ***	0.0000
ECON does not homogeneously cause FDEV	5.87297	20.8417 ***	0.0000
TROPS does not homogeneously cause ECON	2.01295	4.1111 ***	0.0000
ECON does not homogeneously cause TROPS	1.78924	3.14134 ***	0.0017
URBN does not homogeneously cause ECON	2.20207	4.93148 ***	0.0000
ECON does not homogeneously cause URBN	13.1911	52.5709 ***	0.0000
GFC does not homogeneously cause GDPPC	1.21968	0.66684	0.5049
GDPPC does not homogeneously cause GFC	4.4179	14.5056 ***	0.0000
FDEV does not homogeneously cause GDPPC	4.71034	15.8024 ***	0.0000
GDPPC does not homogeneously cause FDEV	2.31776	5.43178 ***	0.0000
TROPS does not homogeneously cause GDPPC	1.45646	1.69881 ***	0.0894
GDPPC does not homogeneously cause TROPS	3.0435	8.57836 ***	0.0000
URBN does not homogeneously cause GDPPC	8.48795	32.1818 ***	0.0000
GDPPC does not homogeneously cause URBN	26.2417	109.147 ***	0.0000
FDEV does not homogeneously cause GFC	1.77286	3.05957 ***	0.0022
GFC does not homogeneously cause FDEV	4.0814	13.0471 ***	0.0000
TROPS does not homogeneously cause GFC	3.14244	8.98575 ***	0.0000
GFC does not homogeneously cause TROPS	2.80657	7.53253 ***	0.0000

URBN does not homogeneously cause GFC	2.02434	4.14861 ***	0.0000
GFC does not homogeneously cause URBN	11.4119	44.7685 ***	0.0000
TROPS does not homogeneously cause FDEV	4.31992	14.1088 ***	0.0000
FDEV does not homogeneously cause TROPS	1.24132	0.76571	0.4438
URBN does not homogeneously cause FDEV	2.9404	8.1306 ***	0.0000
FDEV does not homogeneously cause URBN	14.1335	56.6468 ***	0.0000
URBN does not homogeneously cause TROPS	2.54725	6.42721 ***	0.0000
TROPS does not homogeneously cause URBN	27.2547	113.53 ***	0.0000

Note: Author's estimates, where FDEV stands for Financial development, GDPPC displays gross domestic product per capita, and CO2 stands for carbon emissions. The acronyms GFC, URBN, and TROPS stand for Gross Fixed Capital Formation, urban population, and trade openness, respectively. W-stat stands for the likelihood of Wald and Zbar statistics. Statistics are significant at the 10%, 5%, and 1% levels, respectively, indicated by *, **, and ***.

4.6 Country-Wise Long-Run Estimations

It lists the long-term statistical analyses of ecological deterioration focused on a specific economy. The results of every economy, from Yemen to Albania, demonstrate that economic expansion has a protective effect against environmental degradation (Hadri, 2000).

The BRI panel's participation by a few affluent economies has both positive and negative impacts on ecological quality, similar to the influence of energy consumption. Wealthier economies, predominantly reliant on renewable energy, experience diminishing ecological concerns (Lan-yue & et al., 2017). Conversely, numerous BRI economies, predominantly at lower levels of development, face challenges in allocating time and resources to environmental preservation and renewable energy initiatives (Pedroni).

Enhanced trade among BRI nations has the potential to promote environmental sustainability through the transfer of green investments and technologies. Consequently, in transnational urbanization efforts, governments should prioritize environmental protection measures (Dumitrescu & Hurlin).

4.7 Robustness Examination of the Dynamic Panel Models

Pooled regression, fixed-effect, and random-effect models were used to test the robustness of the DOLS and FMOLS estimates, as shown in Appendix 5. A. These three methods were used to address the standard endogeneity and heterogeneity issues. Except for trade openness, all factors under the DOLS and FMOLS approaches remained favorable and negatively impacted the environment's quality (Al-Mulali & et al.).

To control for endogeneity and serial correlation, a cross-check using pooled, random-effects, and fixed-effects models was suggested (York & et al.). Similar to the random-effect models, which used the aforementioned DOLS and FMOLS methodologies to yield robust findings, the linear OLS model produced mixed results with a fixed effect (Zhou & Wang).

The model fitness was consistent with the observed R-squared. Based on the "Hausman test," the fixed-effect model is the most appropriate for the current study (Zhou & et al.). According to the study's estimates, CO2 emissions are positively and significantly influenced by the core explanatory variables. However, trade openness generally has a detrimental effect on ecological sustainability(World Bank Group. World Development Indicators).

5. Conclusion:

The study examined the 47 economies that collectively made up the BRI from 1980 to 2022 to examine the relationships between financial development, economic growth, energy consumption, trade openness, urbanization, and environmental sustainability.

After using a series of four-unit root tests (LLC, ADF, IPS, and PP) to determine whether the dataset was stationary, we next used three cointegration tests to plot the cointegration relationships among the variables of interest.

The DOLS and FMOLS tests were used to assess cointegration for the entire panel of 47 BRI economies, and the pooled regression, fixed-effect, and random-effect models were used to evaluate robustness. Bidirectional links were found between CO2 emissions (environmental quality) and economic growth, energy consumption, urbanization, financial development, and gross fixed capital formation, except for trade openness.

Which only had a one-way relationship with environmental quality. A pairwise Granger causality test confirmed this. Moreover, the cross-country research revealed multi-dimensional estimators, suggesting various policy implications at the regional, state, and federal levels.

The DOLS, FMOLS, and Hsuan tests show that the regressors had positive and significant effects on environmental quality, except for trade openness, which negatively affected CO2 emissions. For this reason, it was proposed that countries improve their authority and implement country-specific policy recommendations to benefit from the BRI.

Comparative, long-term studies also found that growing economies were contributing to environmental degradation across all 47 countries, despite varying levels of evidence on the impact of energy use. The negative coefficient can be explained by the absence of industrialized countries in the 47 BRI full panel; these countries are more likely to rely on renewable energy sources.

Most BRI economies, however, are located in LDCs and emerging markets, which require additional time and resources to invest heavily in environmental protection and the development of domestic renewable energy sources (such as hydropower, wind power, biomass power, solar power, and waste-based renewable energy). As a result, in tandem with other BRI economies, the Chinese government should shift investment priorities away from coal-based facilities and towards renewable energy sources, such as solar, hydropower, wind, and biomass.

Trading green energy-based gadgets and technologies might help BRI economies advance ecological sustainability. Implementing options that also reduce environmental damage should be pursued to govern cross-country urbanization. The report also offers unified policy implications for the whole panel and for particular nations.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. https://databank.worldbank.org/reports.aspx

Ethics approval and consent

Ethics approval was not required. All participants provided informed consent for participation and publication of anonymized data.

Competing interests

The authors declare no competing interests.

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