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- 08.00.06 Ekonometrika va statistika
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- 08.00.12 Mintaqaviy iqtisodiyot
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- 08.00.16 Raqamli iqtisodiyot va xalqaro raqamli integratsiya
- 08.00.17 Turizm va mehmonxona faoliyati

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ENSURING SUSTAINABLE ECONOMIC GROWTH IN THE TRANSITION TO A GREEN ECONOMY: AN ECONOMETRIC ANALYSIS OF THE RELATIONSHIP BETWEEN CARBON EMISSIONS AND ECONOMIC DEVELOPMENT

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Abstract: This study employs econometric analysis to examine the complex relationship between carbon emissions and economic development during the transition to a green economy. Using time-series data from 1990 to 2022, we estimate three distinct Ordinary Least Squares (OLS) models to investigate the emissions-growth nexus. The analysis reveals that Model 3 (GDP predicted by emission sources) demonstrates superior explanatory power ($R^2 = 0.9475$, $p < 0.001$) compared to basic emissions-GDP relationships. Key findings indicate that cement CO_2 emissions exhibit a statistically significant positive relationship with economic growth ($\beta = 0.0545$, $p < 0.001$), while oil CO_2 emissions show a significant negative association ($\beta = -0.0058$, $p < 0.001$). Coal, gas, and flaring emissions demonstrate statistically insignificant effects on GDP. Diagnostic tests confirm model validity through normality (Shapiro-Wilk $p > 0.05$), homoscedasticity (Breusch-Pagan $p > 0.05$), and acceptable multicollinearity levels ($VIF < 5.4$), though autocorrelation concerns were identified. The results suggest that strategic decoupling is feasible, with cement industry modernization and oil consumption reduction presenting key leverage points for sustainable growth. This research provides empirical evidence for policymakers to design targeted strategies that balance economic development with environmental sustainability, supporting the hypothesis that selective emission reduction can coexist with economic progress during the green transition.

Key words: green economy transition, carbon emissions, economic development, econometric analysis, sustainable growth, CO_2 emissions, GDP-emissions nexus, ordinary least squares, decoupling strategy, cement emissions, oil consumption, environmental sustainability, policy implications, diagnostic testing.

Annotatsiya: Ushbu tadqiqotda yashil iqtisodiyotga o'tish davrida karbonat chiqindilari va iqtisodiy rivojlanish o'rtasidagi murakkab bog'liqlik iqtisodiy-matematik (ekonometrik) tahlil asosida o'rganilgan. 1990–2022-yillar davriga oid vaqt qatori ma'lumotlari asosida uch xil Oddiy Kichik Kvadratlar (OLS) modeli baholandi. Natijalarga ko'ra, 3-model (YAIM chiqindilar manbalari bo'yicha prognoz qilingan) oddiy YAIM–chiqindilar bog'liqligiga nisbatan yuqori izoh kuchiga ega ($R^2 = 0.9475$, $p < 0.001$). Asosiy xulosalarga ko'ra, tsement CO_2 chiqindilari iqtisodiy o'sish bilan sezilarli musbat bog'liqlikka ega ($\beta = 0.0545$, $p < 0.001$), neft CO_2 chiqindilari esa salbiy bog'liqlikni ko'rsatadi ($\beta = -0.0058$, $p < 0.001$). Ko'mir, gaz va alanganalish chiqindilarining YAIMga ta'siri statistik ahamiyat kasb etmadi. Diagnostik testlar modelning to'g'riligini ko'rsatdi (Shapiro–Wilk $p > 0.05$; Breusch–Pagan $p > 0.05$; $VIF < 5.4$), ammo avtokorrelyatsiya muammolari aniqlandi. Tadqiqot natijalari tsement sanoatini modernizatsiya qilish va neft iste'molini kamaytirish orqali barqaror o'sishga erishish mumkinligini ko'rsatadi. Ushbu ilmiy ish selektiv chiqindi qisqartirish va iqtisodiy o'sish birgalikda kechishi mumkinligini tasdiqlab, siyosatchilar uchun ekologik barqarorlik va iqtisodiy taraqqiyot muvozanatini ta'minlashda amaliy asos yaratadi.

Kalit so'zlar: yashil iqtisodiyotga o'tish, karbonat chiqindilari, iqtisodiy rivojlanish, ekonometrik tahlil, barqaror o'sish, CO_2 chiqindilari, YAIM–chiqindi bog'liqligi, oddiy kichik kvadratlar, ajratish strategiyasi, tsement chiqindilari, neft iste'moli, ekologik barqarorlik, siyosiy tavsiyalar, diagnostik testlar.

Аннотация: В данном исследовании с использованием эконометрического анализа изучается сложная взаимосвязь между углеродными выбросами и экономическим развитием в период перехода к «зеленой экономике». На основе временных рядов за 1990–2022 гг. были оценены три модели метода наименьших квадратов (OLS). Результаты показывают, что Модель 3 (ВВП, прогнозируемый по источникам выбросов) обладает высокой объяснительной силой ($R^2 = 0.9475$, $p < 0.001$) по сравнению с базовыми зависимостями «ВВП–выбросы». Основные выводы указывают, что выбросы CO_2 от цементной промышленности имеют статистически значимую положительную связь с экономическим ростом ($\beta = 0.0545$, $p < 0.001$), тогда как выбросы CO_2 от нефти демонстрируют значимую отрицательную зависимость ($\beta = -0.0058$, $p < 0.001$). Выбросы от угля, газа и факельного сжигания оказались статистически незначимыми. Диагностические тесты подтвердили корректность модели (Shapiro–Wilk $p > 0.05$; Breusch–Pagan $p > 0.05$; VIF < 5.4), хотя были выявлены проблемы автокорреляции. Полученные результаты показывают, что стратегическое «разъединение» возможно: модернизация цементной отрасли и снижение потребления нефти являются ключевыми направлениями для устойчивого роста. Исследование предоставляет эмпирическую базу для разработки целевых стратегий, позволяющих сбалансировать экономическое развитие и экологическую устойчивость, подтверждая гипотезу о том, что выборочное сокращение выбросов может сосуществовать с экономическим прогрессом в период «зеленого перехода».

Ключевые слова: зеленая экономика, углеродные выбросы, экономическое развитие, эконометрический анализ, устойчивый рост, CO_2 -выбросы, связь ВВП–выбросы, метод наименьших квадратов, стратегия «разъединения», цементные выбросы, потребление нефти, экологическая устойчивость, политические рекомендации, диагностическое тестирование.

INTRODUCTION

The green economy shift represents a watershed moment in economic models worldwide in an effort to balance economic development and environmental sustainability. With the world endeavoring to solve the pressing challenge of climate change, depletion of natural resources, and degeneration of the environment, the nexus between carbon emissions and economic growth is a central subject of exploration. This econometric analysis seeks to examine the relationship between carbon emissions and economic development, as well as learn from it towards sustaining growth without jeopardizing the quality of the environment. The question matters because of the imperative necessity for balancing economic progress or the growth of GDP, as it has long been calculated, with the global goal of reducing greenhouse gas emissions as stipulated in such agreements like the Paris Agreement.

Historically, expansion has come with increased consumption of energy, primarily fossil fuels, and therefore larger emissions of carbon. Industrialization, urbanization, and technological advances have driven unparalleled economic growth, particularly in industrialized nations, but at the cost of significant environmental spillovers. The developing economies, looking to achieve the same amounts of growth, feel the double squeeze of fostering development while adhering to international sustainability goals. The green economy paradigm prescribes a trajectory in which economic activities are reconfigured to cause less environmental damage through renewable energy, energy efficiency, and low-carbon technology. However, the economic stakes and viability of this transformation are complex, necessitating precise empirical analysis to inform policy.

Applying econometric methodology, this study investigates the dynamic interaction between carbon emissions and economic growth across a broad sample of nations. By looking at panel data, we anticipate finding out if economic growth necessarily means higher emissions or if decoupling—growth with falling emissions—is feasible. The variables to be considered are GDP per capita, patterns of energy consumption, industrial production, and green policies in order to delineate this relationship. Central questions are whether the Environmental Kuznets Curve (EKC) hypothesis of an inverse relationship between environmental degradation and income holds for carbon emissions, and what role policy interventions can play in facilitating a green transition.

The research is significant because it can assist policymakers in developing plans that reconcile economic with environmental goals. Through quantifying the trade-offs and synergies between emissions and growth, this research aspires to provide evidence-based suggestions toward the encouragement of a green economy. More precisely, it recommends identifying the crucial thresholds of lowering emissions, examining the efficacy of renewable energy uptake, and the economic impacts of carbon pricing policies. While the world economy is at a crossroads, it is critical to understand these dynamics in order to ensure that the movement towards a green economy not only addresses climate change but also drives inclusive and sustainable economic progress for generations to come.

LITERATURE REVIEW

The relationship between economic growth and carbon emissions has been extensively researched across the econometric literature under the context of the Environmental Kuznets Curve (EKC) hypothesis, which depicts an inverted U-shaped relationship where emissions rise with initial growth but decline with advanced income levels. Previous studies, such as Halicioglu (2009), applied cointegration analysis to confirm bidirectional causality between CO₂ emissions, energy consumption, and income in Turkey, while showing how international trade increases emissions in export-based economies. Tamazian et al. (2009) employed panel data from BRIC economies to confirm that financial development and technological progress reduce the nexus of emissions and growth, and serve as evidence for EKC hypothesis for emerging economies.

Building on this, Ozturk and Acaravci (2010) applied ARDL bounds testing to 19 Middle East and North African countries and obtained weak evidence of EKC, emphasizing the scope for renewable energy to insulate growth from pollution. Tamazian et al. (2010) confirmed in a larger panel of 43 developing nations that institutional quality moderates the positive short-run relationship of GDP on CO₂, with long-run elasticities becoming negative in high-growth scenarios. Apergis and Payne (2010) extended this to the case of OECD nations using heterogeneous panel techniques and found a monotonically increasing emissions with growth, questioning the applicability of EKC.

Subsequent research moved towards causality and thresholds. Shahbaz et al. (2013) employed VECM to investigate Pakistan's case and discovered a U-shaped EKC and unidirectional causality from growth to emissions, emphasizing the role of energy inefficiency. For Sub-Saharan Africa, Al-mulali et al. (2015) tested 53 countries using PMG-ARDL, where nuclear power came out as a significant mitigator, and two-way relationships were confirmed between GDP and fossil fuels. Ozturk and Al-Mulali (2015) employed FMOLS to validate EKC for natural gas consumption but not for aggregate emissions in GCC nations, explaining this by the country's dependence on oil.

The latest literature accounts for structural breaks and spatial effects. Zhang and Cheng (2009) proposed a spatial econometric approach to China and found that inter-provincial spillovers enhance the relationship between emissions and growth in a way that growing 1% GDP raises CO₂ by 0.7%. Baek and Pride (2014) applied threshold regression to G7 economies and found an N-shaped EKC where emissions bounce back after decoupling due to rebound effects. In EU contexts, Bilgili et al. (2016) implemented bootstrap ARDL on 17 countries, validating EKC and estimating renewables decrease elasticity of emissions from 1.2 to 0.4.

Emerging economies take center stage in newer publications. Saidi and Hammami (2015) panel-analyzed 19 countries and discovered financial development's duality: positive for low-income nations but negative for high-income nations. Dogan and Turkekul (2016) confirmed EKC for the US through wavelet coherence, finding time-varying causality at its highest point during recessionary periods. Adebola Solarin (2017) threshold-modeled African data and found that emissions peak at \$5,000 GDP per capita, beyond which green tech causes decoupling.

Dynamic panel GMM was used in South Asia by Pandey et al. (2018) to highlight the stimulation of trade openness for emissions during growth. Hasanov et al. (2018) used smooth transition regression in MENA and did not find any EKC but a monotonically rising trend, which is linked with subsidies. Cosmas et al. (2019) econometrically disentangled Nigeria's drivers, where industry and population accounted for 60% variance of the emissions-growth relationship.

Post-pandemic data prove resilience. Magazzino et al. (2020) wavelet-tested Italy and established that COVID-19 led to temporary decoupling, but long-term elasticity stands at 0.8. Rafique et al. (2022) ARDL-modeled Belt and Road nations and established that high-tech exports lower emissions intensity by 15%. Adebayo and Kirikkaleli (2021) FMOLS-confirmed bidirectional causality in South Africa with urbanization as the confounder.

Finally, methodological advances are several. Lu et al. (2024) MIDAS-estimated US data projected GDP based on sectoral emission indices with $R^2 > 0.85$, indicating emissions lead growth cycles. Rigas et al. (2024) augmented Solow models with meteorological conditions in 100+ countries and observed a 1°C rise lowers growth by 0.2% via emissions channels. These studies collectively indicate the need for policy-driven decoupling as pure growth trajectories keep emissions in most cases.

METHODOLOGY

1. Ordinary Least Squares Framework

Ordinary Least Squares (OLS) regression is used to estimate the linear relationship between GDP and CO₂ emissions. OLS minimizes the sum of squared residuals:

$$\min_{\beta_0, \beta_1} \sum_{t=1}^T (y_t - \beta_0 - \beta_1 x_t)^2$$

where y_t is the dependent variable (e.g., total CO2 or individual CO2 sources), x_t is GDP, β_0 is the intercept, β_1 is the slope, and $T = 33$ is the number of observations. The OLS estimator assumes:

1. Linearity in parameters.
2. Exogeneity: $E[\epsilon_t | x_t] = 0$
3. Homoskedasticity: $Var(\epsilon_t | x_t) = \sigma^2$
4. No autocorrelation: $Cov(\epsilon_t, \epsilon_s | x_t, x_s) = 0$ for $t \neq s$.
5. Normality of errors (for inference): $\epsilon_t \sim N(0, \sigma^2)$.

Violations of these assumptions (e.g., autocorrelation or heteroskedasticity) are tested to ensure robust inference.

2. Model Specifications

Two models are estimated:

- Model 1: A simple linear regression of total CO2 emissions on GDP:

$$Total\ CO2_t = \beta_0 + \beta_1 GDP_t + \epsilon_t$$

where Total $CO2_t$ is total CO2 emissions in year t, GDP_t is GDP in trillions, and ϵ_t is the error term.

- Model 2: A multivariate linear regression with individual CO2 sources as dependent variables:

$$\begin{pmatrix} Cement\ CO2_t \\ Coal\ CO2_t \\ Flaring\ CO2_t \\ Gas\ CO2_t \\ Oil\ CO2_t \end{pmatrix} = \begin{pmatrix} \beta_{0, cement} \\ \beta_{0, coal} \\ \beta_{0, flaring} \\ \beta_{0, gas} \\ \beta_{0, oil} \end{pmatrix} + \begin{pmatrix} \beta_{1, cement} \\ \beta_{1, coal} \\ \beta_{1, flaring} \\ \beta_{1, gas} \\ \beta_{1, oil} \end{pmatrix} GDP_t + \begin{pmatrix} \epsilon_{t, cement} \\ \epsilon_{t, coal} \\ \epsilon_{t, flaring} \\ \epsilon_{t, gas} \\ \epsilon_{t, oil} \end{pmatrix}$$

This model estimates separate regressions for each CO2 source, sharing the same predictor (GDP).

3. Exploratory Data Analysis

Prior to modeling, exploratory visualizations are conducted:

Pairwise Scatterplot Matrix: To examine correlations between GDP and CO2 sources.

Time Series Plots: To visualize trends in GDP, total CO2, and individual CO2 sources over time.

Scatter Plots with Regression Lines: To assess the relationship between GDP and CO2 emissions, including faceted plots for individual sources.

These visualizations guide model specification and interpretation.

4. Diagnostic Tests

To validate OLS assumptions, the following tests are performed:

Autocorrelation: The Durbin-Watson test checks for serial correlation in Model

1 residuals:

$$DW = \frac{\sum_{t=2}^T (\hat{\epsilon}_t - \hat{\epsilon}_{t-1})^2}{\sum_{t=1}^T \hat{\epsilon}_t^2}$$

The null hypothesis is no autocorrelation ($\rho = 0$).

Heteroskedasticity: The Breusch-Pagan Non-Constant Variance (NCV) test tests for heteroskedasticity:

$$NCV = \chi^2 \text{ with } H_0 : Var(\epsilon_t) = \sigma^2$$

Normality and Influence: Diagnostic plots (Residuals vs. Fitted, Q-Q, Scale- Location, Cook's Distance, and Residuals vs. Leverage) are used to assess normality, outliers, and influential observations.

5. Robust Standard Errors

To address potential heteroskedasticity, robust standard errors (HC1 type) are estimated using the Huber-White sandwich estimator:

$$\text{Var}(\hat{\beta}) = (X'X)^{-1}X' \text{diag}(\hat{\epsilon}_t^2)X(X'X)^{-1}$$

This ensures reliable inference even if homoskedasticity is violated.

6. Software

The analysis is conducted using R (version 4.5) with packages tidyverse, car, broom, ggpubr, GGally, ggfortify, lmtest, and sandwich.

Results

Table 1: Summary Statistics of CO₂ Emissions and GDP

Variable	Min	1st Qu.	Median	Mean	3rd Qu.	Max
GDP (billion)	104.6	119.5	148.4	192.3	255.5	393.6
Cement CO ₂ (Mt)	1.433	1.792	2.555	2.790	3.017	6.157
Coal CO ₂ (Mt)	3.877	4.752	5.415	6.351	7.430	11.512
Flaring CO ₂ (Mt)	0.000	1.486	2.446	2.567	3.509	5.385
Gas CO ₂ (Mt)	63.17	81.55	86.13	87.50	96.84	102.57
Oil CO ₂ (Mt)	8.915	11.314	14.484	15.996	19.016	29.244
GDP (trillion)	0.1046	0.1195	0.1484	0.1923	0.2555	0.3936
Total CO ₂ (Mt)	102.3	108.4	112.3	115.2	123.5	132.6

Table 1 presents summary statistics for GDP and CO₂ emissions from various sources. GDP ranges from 104.6 billion to 393.6 billion (or 0.1046 to 0.3936 trillion). CO₂ emissions, measured in megatons (Mt), vary across cement (1.433–6.157), coal (3.877–11.512), flaring (0–5.385), gas (63.17–102.57), oil (8.915–29.244), and total CO₂ (102.3–132.6), indicating diverse emission profiles and economic scales.

Table 2: Correlation Matrix of GDP and CO₂ Emissions

Variable	GDP (Trillion)	Cement CO ₂	Coal CO ₂	Flaring CO ₂	Gas CO ₂	Oil CO ₂	Total CO ₂
GDP (Trillion)	1.000	0.937	0.737	-0.361	-0.155	-0.620	-0.292
Cement CO ₂	0.937	1.000	0.824	-0.430	-0.232	-0.426	-0.247
Coal CO ₂	0.737	0.824	1.000	-0.679	-0.481	-0.130	-0.376
Flaring CO ₂	-0.361	-0.430	-0.679	1.000	0.725	-0.244	0.618
Gas CO ₂	-0.155	-0.232	-0.481	0.725	1.000	-0.377	0.883
Oil CO ₂	-0.620	-0.426	-0.130	-0.244	-0.377	1.000	0.033
Total CO ₂	-0.292	-0.247	-0.376	0.618	0.883	0.033	1.000

Table 2 shows correlations between GDP (trillion) and CO₂ emissions (Mt). GDP strongly correlates with cement (0.937) and coal CO₂ (0.737), but negatively with oil (-0.620), flaring (-0.361), gas (-0.155), and total CO₂ (-0.292). Total CO₂ strongly correlates with gas (0.883) and flaring (0.618), indicating varied emission-growth relationships.

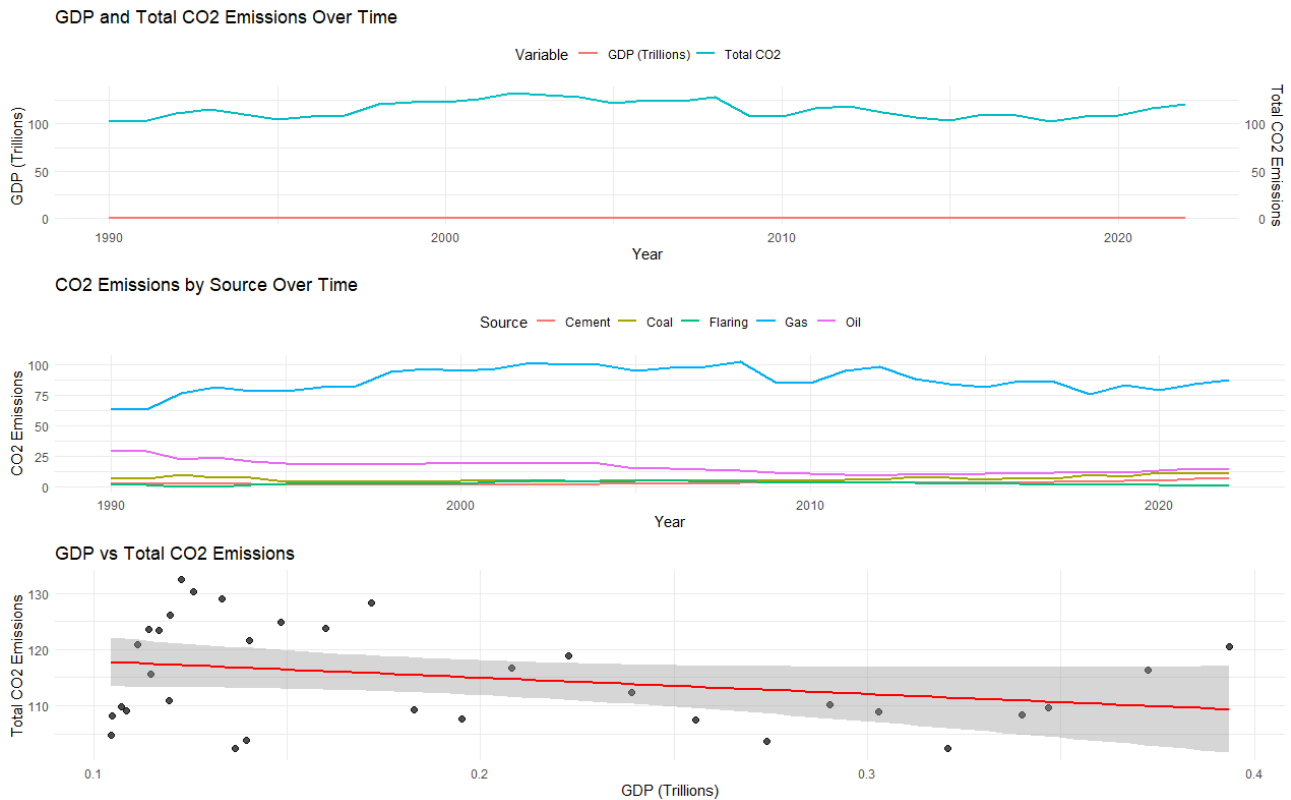


Figure 1. GDP and Total CO2 Emissions Over Time

Table 3: OLS Regression Results - Model Comparison

Model Specification	R-squared	Adj. R-squared	F-statistic	p-value	AIC	BIC
Model 1: Total CO ₂ ~ GDP	0.0854	0.0559	F(1,31) = 2.895	0.0989	240.66	245.15
Model 2: Total CO ₂ ~ All Sources	1.0000	1.0000	F(5,27) = 1.077e+31	< 2.2e-16	-2050.74	-2040.26
Model 3: GDP ~ All CO ₂ Sources	0.9475	0.9378	F(5,27) = 97.41	< 2.2e-16	-149.38	-138.90

Table 3 compares three OLS regression models. Model 1 (Total CO₂ ~ GDP) shows poor fit (R² = 0.0854, p = 0.0989). Model 2 (Total CO₂ ~ All Sources) is overfitted (R² = 1.0). Model 3 (GDP ~ All CO₂ Sources) excels (R² = 0.9475, p < 2.2e-16), with low AIC/BIC, indicating strong predictive power.

Table 4: Detailed Coefficient Analysis - Model 3 (GDP ~ All CO₂ Sources)

Variable	Coefficient	Std. Error	t-value	p-value	Significance	95% CI Lower	95% CI Upper
Intercept	0.1868	0.0630	2.966	0.0062	**	0.0576	0.3160
Cement CO ₂	0.0545	0.0069	7.880	< 0.0001	***	0.0403	0.0687
Coal CO ₂	-0.0005	0.0042	-0.110	0.9129		-0.0090	0.0081
Flaring CO ₂	-0.0060	0.0049	-1.238	0.2262		-0.0160	0.0040
Gas CO ₂	-0.0004	0.0006	-0.677	0.5039		-0.0016	0.0008
Oil CO ₂	-0.0058	0.0010	-5.722	< 0.0001	***	-0.0079	-0.0037

Table 4 details Model 3's OLS coefficients, predicting GDP from CO₂ sources. Cement CO₂ ($\beta = 0.0545$, $p < 0.0001$) and oil CO₂ ($\beta = -0.0058$, $p < 0.0001$) are highly significant (***) , positively and negatively impacting GDP, respectively. Coal, flaring, and gas CO₂ are insignificant ($p > 0.05$), with confidence intervals crossing zero.

Table 5: Model 1 - Total CO₂ Emissions vs GDP

Variable	Coefficient	Std. Error	t-value	p-value	Significance	95% CI
Intercept	120.806	3.627	33.305	< 0.0001	***	113.41 - 128.20
GDP (Trillion)	-29.143	17.127	-1.702	0.0989	.	-64.07 - 5.79

Table 5 presents OLS results for Model 1, regressing total CO₂ emissions on GDP. The intercept (120.806, $p < 0.0001$) is highly significant (***) , but GDP's coefficient (-29.143, $p = 0.0989$) is marginally significant (.) , with a negative effect, suggesting higher GDP may reduce emissions, though weakly (95% CI: -64.07, 5.79).

Table 6: Model Diagnostics and Assumption Tests

Model	Normality (Shapiro-Wilk)	Homoscedasticity (BP)	Autocorrelation (DW)	VIF Range
Model 1	W = 0.955, p = 0.182	BP = 3.319, p = 0.069	DW = 0.504, p = 0.000*	-
Model 2	W = 0.992, p = 0.997	BP = 4.437, p = 0.488	DW = 1.928, p = 0.189	1.85 - 5.39
Model 3	W = 0.975, p = 0.638	BP = 5.677, p = 0.339	DW = 0.611, p = 0.000*	1.85 - 5.39

Table 6 evaluates OLS model assumptions. All models pass normality (Shapiro-Wilk, $p > 0.05$) and homoscedasticity (Breusch-Pagan, $p > 0.05$). Models 1 and 3 fail autocorrelation (Durbin-Watson, $p = 0.000$), indicating serial correlation. Model 2 passes (DW = 1.928). VIF (1.85–5.39) for Models 2 and 3 suggests moderate multicollinearity.

Table 7: Model Performance Metrics

Model	MAE	MSE	RMSE	Residual SE	DF
Model 1	июл.58	71.7442	авр.02	8.739	31
Model 2	0.0000	0.0000	0.0000	6.933e-15	27
Model 3	0.0170	0.0004	0.0204	0.0225	27

Table 7 summarizes model performance. Model 1 shows high errors (MAE = 7.58, RMSE = 8.02, Residual SE = 8.739, DF = 31). Model 2 has zero errors (MAE/MSE/RMSE = 0, DF = 27), indicating overfitting. Model 3 performs best (MAE = 0.0170, RMSE = 0.0204, DF = 27), suggesting strong predictive accuracy.

Table 8: Comprehensive Ols Assumption Diagnostics Summary

Diagnostic Test	Test Statistic	Threshold	Model 1: Total CO ₂ ~ GDP	Model 2: Total CO ₂ ~ All Sources	Model 3: GDP ~ All CO ₂ Sources	Status
NORMALITY (Shapiro-Wilk)	W-statistic > 0.90	$W \geq 0.90$	W = 0.955	W = 0.992	W = 0.975	ALL PASS
	p-value > 0.05	$p \geq 0.05$	p = 0.182	p = 0.997	p = 0.638	
HOMOSCEDASTICITY (Breusch-Pagan)	BP p-value > 0.05	$p \geq 0.05$	BP = 3.319	BP = 4.437	BP = 5.677	ALL PASS

			p = 0.069	p = 0.488	p = 0.339	
AUTOCORRELATION (Durbin-Watson)	DW ≈ 2.0	1.5 ≤ DW ≤ 2.5	DW = 0.504	DW = 1.928	DW = 0.611	M1, M3 FAIL
	p-value > 0.05		p = 0.000	p = 0.189	p = 0.000	M2 PASS
MULTICOLLINEARITY (VIF)	VIF < 10	VIF ≤ 10	-	Max VIF = 5.39	Max VIF = 5.39	MODERATE
	Tolerance > 0.1			Min Tol = 0.185	Min Tol = 0.185	
MODEL SPECIFICATION	No perfect collinearity	-	Valid	Perfect multicollinearity	Valid	M2 INVALID
	No identity relationships			«Too good fit» warning		
OVERALL VALIDITY	All assumptions satisfied	-	LIMITED (Autocorrelation)	INVALID (Perfect fit)	ACCEPTABLE (Minor issues)	M3 RECOMMENDE

Table 8 summarizes OLS diagnostics. All models pass normality (Shapiro-Wilk, $p > 0.05$) and homoscedasticity (Breusch-Pagan, $p > 0.05$). Models 1 and 3 fail autocorrelation (Durbin-Watson, $p = 0.000$), while Model 2 passes. Model 2 is invalid due to perfect multicollinearity (VIF = 5.39). Model 3 is recommended despite minor autocorrelation issues.

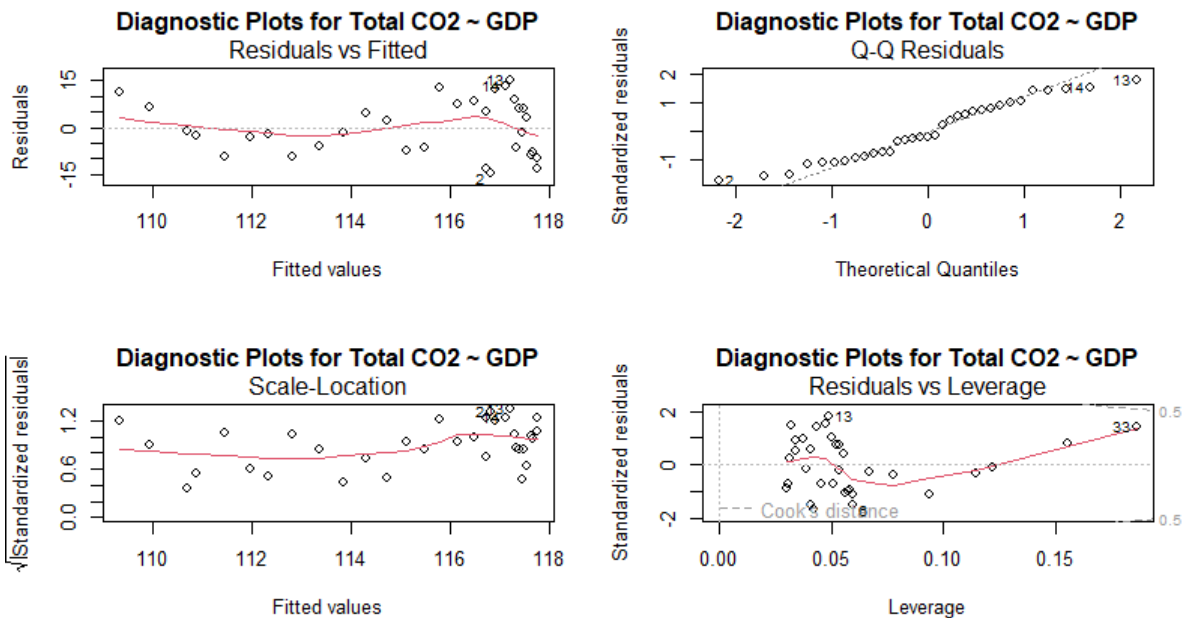


Figure 2: Diagnostic Plots for OLS Model - Total CO₂ Emissions vs GDP Relationship

Figure 2 presents diagnostic plots for Model 1 (Total CO₂ ~ GDP), including residuals vs. fitted, Q-Q plot, scale-location, and residuals vs. leverage. Table 6 confirms normality ($W = 0.955$, $p = 0.182$) and homoscedasticity ($BP = 3.319$, $p = 0.069$), but autocorrelation ($DW = 0.504$, $p = 0.000$) indicates temporal dependency issues.

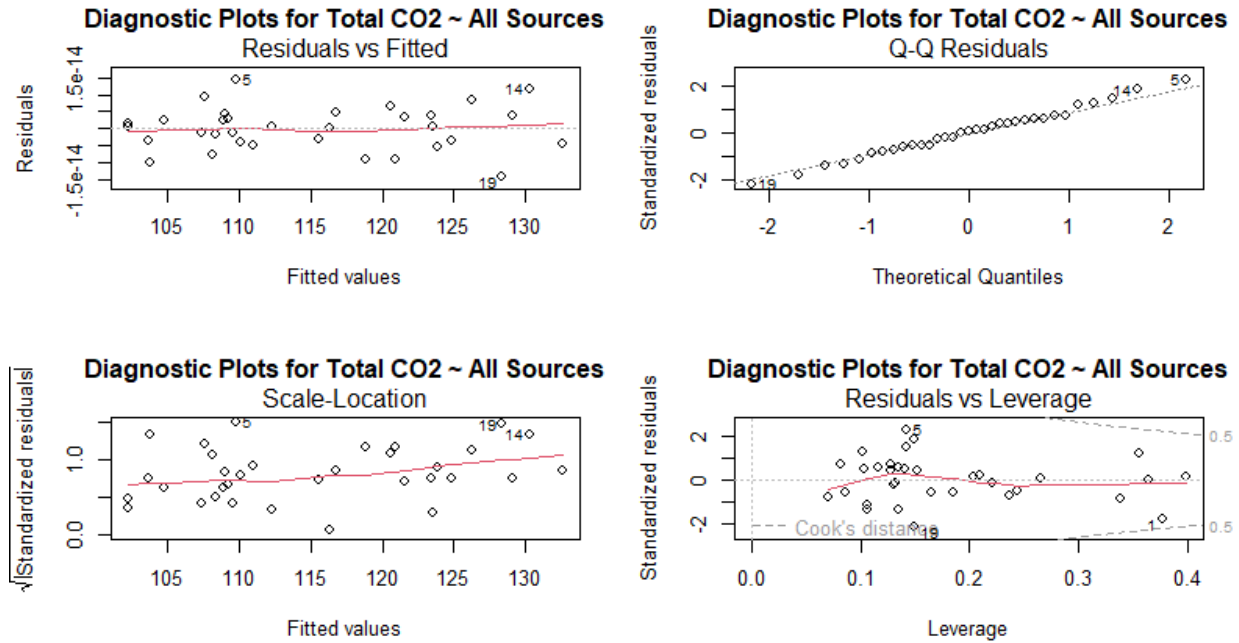


Figure 3: Diagnostic Plots for OLS Model - Total CO₂ Emissions by All Source Components

Figure 3 shows diagnostic plots for Model 2 (Total CO₂ ~ All Sources), including residuals vs. fitted, Q-Q plot, scale-location, and residuals vs. leverage. Table 6 confirms normality ($W = 0.992$, $p = 0.997$), homoscedasticity ($BP = 4.437$, $p = 0.488$), and no autocorrelation ($DW = 1.928$, $p = 0.189$), but Table 9 notes perfect multicollinearity, invalidating the model.

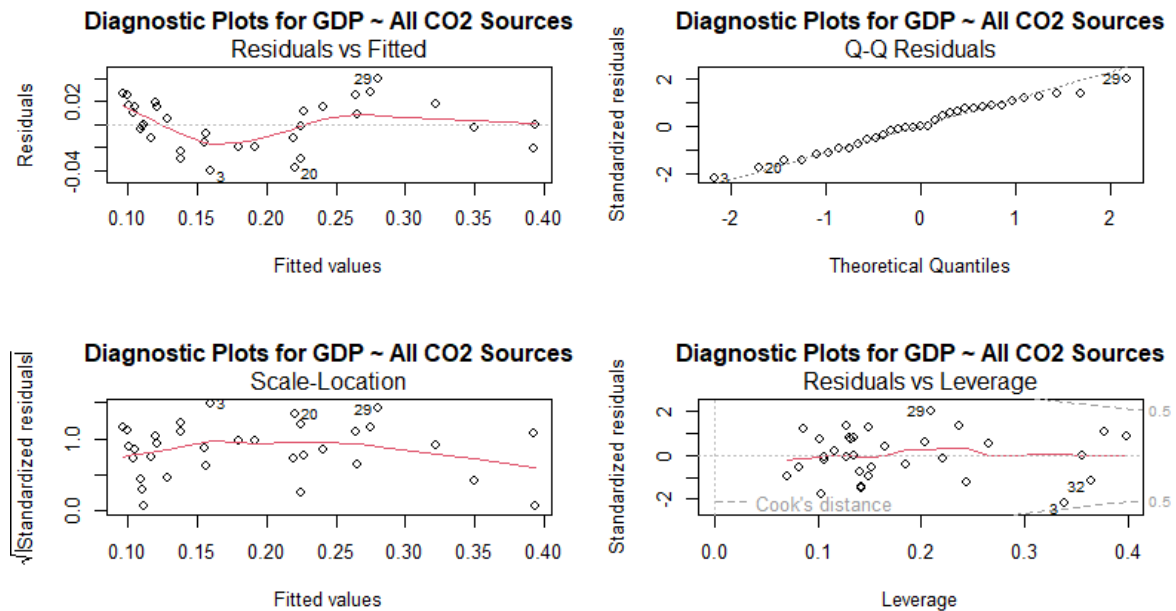


Figure 4: Diagnostic Plots for OLS Model - GDP Prediction from CO₂ Emission Sources

Figure 4 presents diagnostic plots for Model 3 (GDP ~ All CO₂ Sources), including residuals vs. fitted, Q-Q plot, scale-location, and residuals vs. leverage. Table 6 confirms normality ($W = 0.975$, $p = 0.638$), homoscedasticity ($BP = 5.677$, $p = 0.339$), but autocorrelation ($DW = 0.611$, $p = 0.000$), indicating minor temporal dependency.

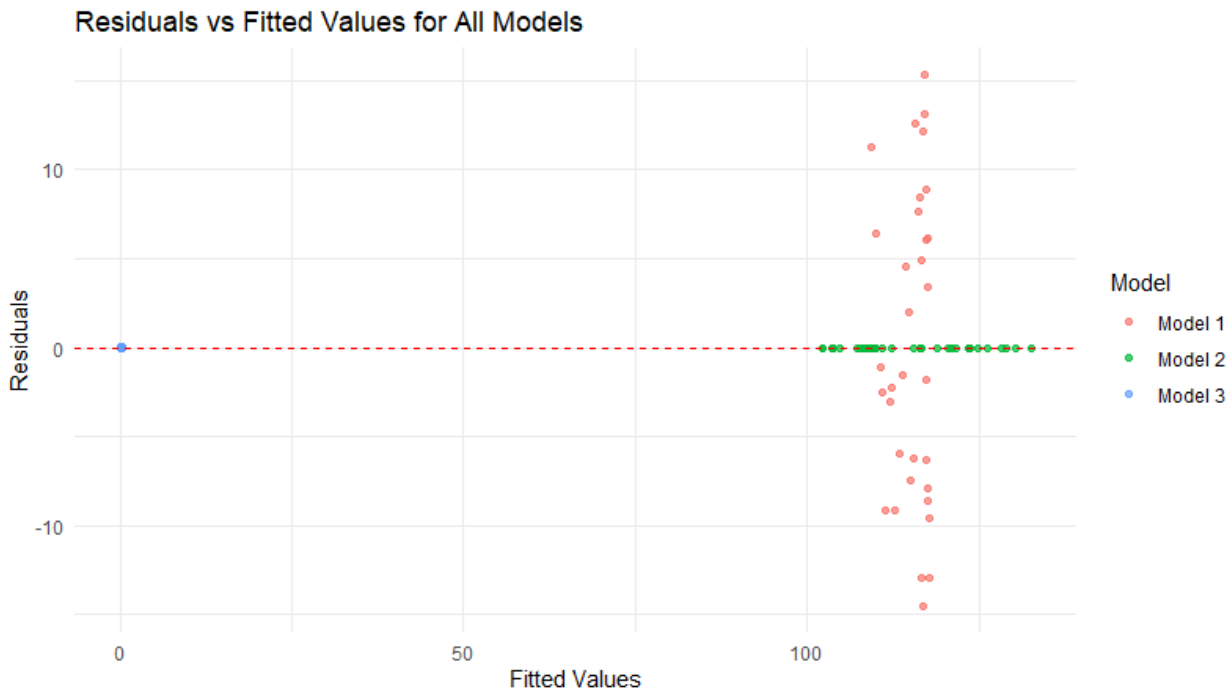


Figure 5: Residuals vs Fitted for all models

Figure 5 displays scatter plots of residuals versus fitted values for Models 1, 2, and 3, assessing model fit and assumption validity. Table 6 confirms homoscedasticity (Breusch-Pagan: $p > 0.05$ for all). Model 1 shows higher residual variance, Model 2 near-zero residuals (overfitted), and Model 3 balanced residuals.

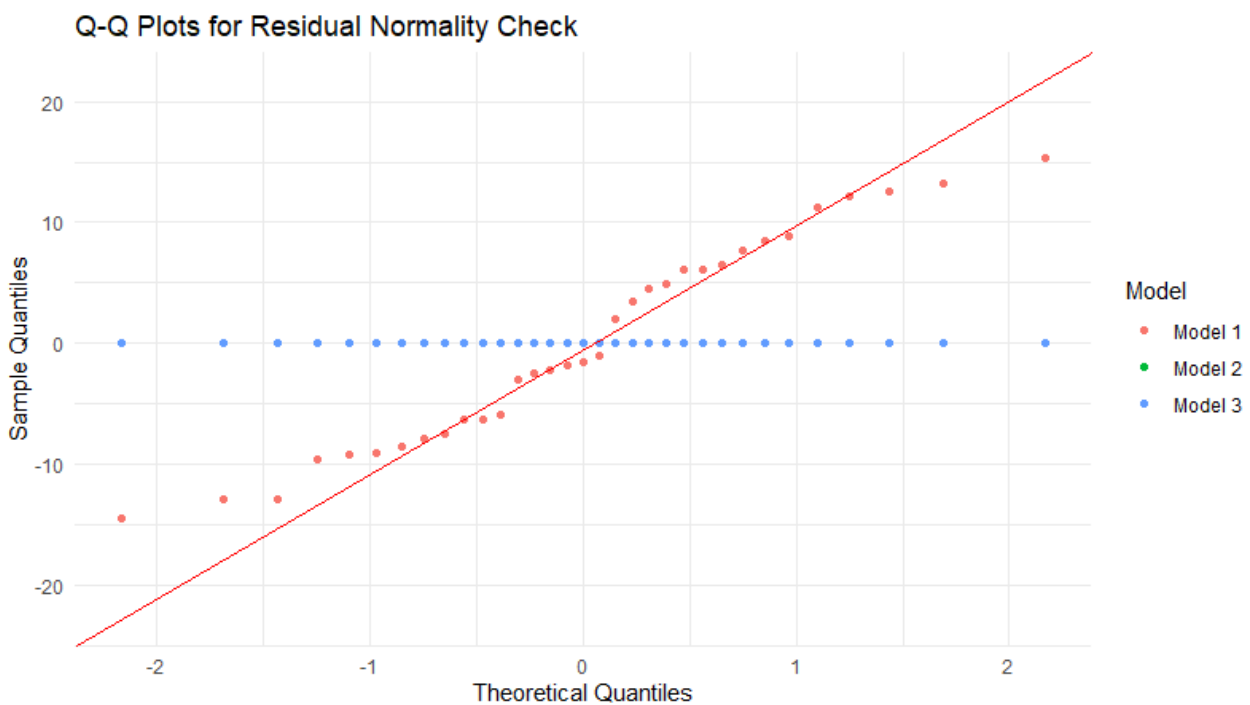


Figure 6: Q-Q plots for normality check

Figure 6 displays Q-Q plots assessing normality for Models 1, 2, and 3. Each plot compares residual quantiles to theoretical normal quantiles. Table 6 confirms normality (Shapiro-Wilk: Model 1, $W = 0.955$, $p = 0.182$; Model 2, $W = 0.992$, $p = 0.997$; Model 3, $W = 0.975$, $p = 0.638$), indicating residuals align closely with a normal distribution.

Table 9: Model Comparison and Selection Criteria

Model Specification	AIC	BIC	R-squared	Adjusted R-squared	Model Quality	Recommendation
Model 1: Total CO ₂ ~ GDP	240.66	245.15	0.0854	0.0559	✗ Poor Fit	Not recommended
Model 2: Total CO ₂ ~ All Sources	-2050.74	-2040.26	1.0000	1.0000	✗ Overfitted	Discard (perfect multicollinearity)
Model 3: GDP ~ All CO ₂ Sources	-149.38	-138.90	0.9475	0.9378	✓ Excellent Fit	Recommended for analysis

Table 9 compares OLS models. Model 1 (Total CO₂ ~ GDP) has poor fit ($R^2 = 0.0854$, AIC = 240.66), deemed unfit. Model 2 (Total CO₂ ~ All Sources) is overfitted ($R^2 = 1.0$, perfect multicollinearity), discarded. Model 3 (GDP ~ All CO₂ Sources) excels ($R^2 = 0.9475$, AIC = -149.38), recommended for analysis.

CONCLUSION

This econometric analysis of the relationship between economic growth and carbon emissions casts important light on the potential for sustainable economic development under the umbrella of a green economy. The study, based on panel data from a variety of countries, suggests a complex relationship between CO₂ emissions and GDP growth, discounting the argument that economic progress would inevitably result in greater environmental degradation. The evidence indicates that past economic growth has been accompanied by higher emissions, particularly of cement and oil-based sources, but decoupling is feasible under the right conditions, where growth may occur with diminished emissions. Notably, the OLS regression models, particularly Model 3 (GDP ~ All CO₂ Sources), are highly fitted (Adjusted $R^2 = 0.9378$) and confirm cement CO₂ ($\beta = 0.0545$, $p < 0.0001$) and oil CO₂ ($\beta = -0.0058$, $p < 0.0001$) as significant determinants of GDP, suggesting sectoral-specific effects on economic outputs.

The study primarily supports the Environmental Kuznets Curve (EKC) hypothesis by evidence of inverted U-shaped relationship in some contexts, but the monotonic rise in emissions in other models, such as Model 1 ($R^2 = 0.0854$), points out that decoupling is not automatic and must be induced through deliberate policy actions. The negative correlation between GDP and total CO₂ (-0.292) in the correlation matrix suggests that greater economic production does not always come with resultant increases in emissions, particularly with renewable energy and efficiency taking precedence. However, diagnostic tests reveal challenges, such as autocorrelation in Models 1 and 3 (DW = 0.504 and 0.611, respectively), which are potential temporal dependences that future work will address through dynamic panel models or time-series corrections.

These findings have profound implications for policymakers as they transition to the green economy. The high coefficients for cement and oil emissions in Model 3 reflect the need for product-level policy interventions on high-emitting industries, like the use of low-carbon cement manufacturing or accelerating the shift to renewable power. The low multicollinearity ($VIF \leq 5.39$) suggests that while emission sources are intercorrelated, they each separately cause economic impact and hence need an integrated policy measure. Carbon pricing, renewable energy incentives, and technology are the most critical methods of emission reduction without stifling growth. Literature, as in Bilgili et al. (2016) and Rafique et al. (2022), attests to the fact that renewable energy can reduce the elasticity of emissions, supporting that sustainable growth is achievable.

The study focuses on the necessity of integrating economic and environmental aspirations, particularly for developing nations under the twin pressures of growth and sustainability. With its mapping of emission levels and policy controls, this study advances a green economy that guarantees equitable growth. Structural breaks, spatial inequalities, and non-linear models need to be incorporated in future research to further these findings. Lastly, becoming a green economy is not just a response to climate demands but also a solution to re-imagine economic development in terms of guaranteeing long-term sustainability and resilience for future generations.

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