

TESTING THE ENVIRONMENTAL KUZNETS CURVE IN CENTRAL ASIA: EVIDENCE FROM FIVE TRANSITION ECONOMIES

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Abstract. Addressing climate change has become an urgent global priority; however, many transition economies continue to experience increasing CO₂ emissions alongside economic expansion. This research examines the key factors influencing carbon emissions in five Central Asian nations—Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan—by applying an extended Environmental Kuznets Curve (EKC) model to panel data covering the period from 2013 to 2024. The findings support the Environmental Kuznets Curve (EKC) hypothesis. GDP per capita demonstrates a positive and statistically significant impact on CO₂ emissions ($\beta = 0.001$, $p < 0.01$), whereas the squared GDP per capita term shows a negative and significant effect ($\beta = -2.90e-07$, $p < 0.01$). These results indicate an inverted U-shaped relationship, with the turning point estimated at \$1,724. In addition, energy consumption emerges as the strongest contributor to emissions ($\beta = 0.002$, $p < 0.01$), highlighting the region's heavy reliance on fossil fuels. Urbanization and trade openness have no significant effect on emissions. The model explains 99% of the variation in CO₂ emissions ($R^2 = 0.990$). The findings indicate that resource-based economies can potentially decouple economic growth from emissions, although effective policies promoting energy efficiency and renewable energy are essential to achieve this transition.

Key words: Environmental Kuznets Curve (EKC), CO₂ Emissions, economic growth, energy consumption, Central Asia, panel data analysis

1. Introduction

The relationship between economic growth and environmental degradation has become one of the most important issues in recent decades, especially because of the rise in CO₂ emissions (Goodness C. Aye et al., 2017). A major factor behind environmental degradation in developing and transition economies is the widespread use of fossil fuels alongside energy-intensive economic activities. The environmental Kuznets curve (EKC) is the exact theory that describes the relationship between economic growth and environmental degradation. The hypothesis suggests that countries with lower income levels usually place greater emphasis on economic development than on environmental protection. As a result, pollution tends to increase during the early stages of growth, but eventually declines as income continues to rise. This reduction is commonly linked to stronger environmental regulations, increased public awareness, and greater social responsibility. (Sinha Babu, S., & Datta, S. K., 2013)

Despite extensive research on this relationship across different countries, the empirical findings remain mixed, especially in the case of Central Asia. Existing studies focusing on Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan indicate that economic growth still contributes to rising CO₂ emissions, with little evidence of the expected turning point. (Caporin et al., 2024). Although previous studies have largely confirmed the absence of the EKC in the region, most of them mainly concentrate on testing its validity rather than examining the structural and institutional factors that hinder its emergence. (Nugroho et al., 2022; Caporin et al., 2023; Andreichyk & Tsvetkov, 2023). Important determinants such as energy consumption, trade openness, and rapid urbanization are frequently given limited attention, resulting in an incomplete

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explanation of why economic growth has not led to environmental improvement in Central Asia. In light of these considerations, the present study addresses the following research questions:

RQ1: How do energy use, trade openness, and urbanization affect CO₂ emissions in the region?

RQ2: To what extent do these structural factors hinder the realization of the EKC in Central Asia?

The study investigates the effects of energy use, trade openness, economic growth, and urbanization on CO₂ emissions using panel data econometric methods. It also plays a critical role in examining how these variables jointly contribute to explaining why Central Asian economies have not yet achieved a transition toward emission reduction.

Furthermore, the study contributes to the EKC literature by moving beyond simple hypothesis testing toward a structural explanation of the EKC's non-realization in Central Asia. By incorporating energy composition, trade patterns, and urban development dynamics into the EKC framework, it provides a more comprehensive understanding of the growth–environment relationship in resource-dependent transition economies. From a policy perspective, the findings may help Central Asian governments identify key leverage points for sustainable development, including energy diversification, greener trade practices, and more sustainable urban planning, thereby supporting the formulation of integrated strategies that align economic growth with environmental sustainability.

2. Literature Review

Multiple empirical investigations lend credence to the Environmental Kuznets Curve (EKC) proposition. For instance, Ali et al. (2020) established the presence of an inverted U-shaped EKC trajectory across OIC (Organization of Islamic Cooperation) member states, whereas Ozatac et al. (2017) documented comparable findings specifically for the Turkish context. Conversely, Zafar et al. (2019) endorsed the EKC framework within emerging market economies, noting that renewable energy sources contribute to CO₂ abatement, while fossil fuel dependence coupled with trade liberalization exacerbates emission levels. More recently, Nuriddinova and Ahmad (2025) offered partial confirmation of the EKC, positing that the nation in question could approach an inflection threshold.

Yet the EKC hypothesis does not enjoy universal empirical backing. Dogan and Turkekul (2015), for example, failed to uncover any supportive evidence for its existence in the United States context, while Zhang (2019) similarly observed no stable inverted U-shaped pattern across Central Asian nations. Taking a more nuanced analytical approach, Afridi et al. (2019) incorporated a cubic income component into their EKC specification and uncovered an N-shaped configuration for SAARC economies, suggesting that pollution levels could rebound once nations surpass a certain prosperity threshold. Such divergent outcomes indicate that economic expansion per se may prove insufficient to guarantee environmental amelioration.

Energy utilization emerges repeatedly as a principal catalyst for carbon dioxide discharges. Zafar et al. (2019) demonstrated that reliance on conventional energy sources amplifies emissions, whereas clean alternatives exert a mitigating influence. Both Afridi et al. (2019) and Nurgazina et al. (2021) corroborated that aggregate energy consumption substantially fuels ecological decline. Collectively, these results intimate that persistent dependence on hydrocarbons may obstruct the capacity of economic advancement to deliver commensurate pollution reductions.

Mehmood and Tariq (2020) documented both U-shaped and inverted U-shaped relationships between globalization and CO₂ emissions in South Asian countries. In the context of Central Asia, Azam et al. (2021) identified long-run relationships between trade, economic growth, tourism, and CO₂ emissions, highlighting the interconnected nature of these variables. Urbanization is another important determinant of environmental degradation. Although extensive literature examines the EKC hypothesis and the roles of energy consumption, trade openness, and urbanization, empirical evidence for Central Asia remains limited and inconsistent. Some studies reject the EKC in this region (Zhang, 2019), while others show complex or partial relationships (Nuriddinova & Ahmad, 2025). Therefore, further investigation is needed to understand why economic growth has not significantly reduced CO₂ emissions in Central Asian countries, particularly considering fossil fuel dependence, trade structure, and rapid urbanization.

3. Methodology

This study is based on the Environmental Kuznets Curve (EKC) hypothesis, which explains an inverted U-shaped relationship between economic development and environmental degradation. According to this framework, environmental pressure increases during early stages of industrialization as countries prioritize growth, but declines after reaching a certain income threshold due to technological progress, stronger environmental regulations, and heightened environmental awareness (Sinha Babu & Datta, 2013).

The aim of this study is to investigate how economic growth, energy use, trade openness, and urbanization affect CO₂ emissions in five Central Asian countries (Uzbekistan, Kyrgyzstan, Tajikistan, Kazakhstan, Turkmenistan) over the period 2013 to 2024. The study employs panel data analysis, including descriptive statistics, correlation matrix, regression analysis, and variance inflation factor (VIF) diagnostics. The empirical analysis seeks to evaluate the role of each determinant in shaping CO₂ emissions, with particular attention to testing the Environmental Kuznets Curve (EKC) hypothesis—which posits an inverted U-shaped relationship between income and environmental degradation.

The mathematical model can be represented as follows:

$$Y = f(X_1, X_2, X_3, X_4, X_5) \quad (1)$$

Equation (1) expresses CO₂ emissions (Y) as a function of five independent variables (X). To test the EKC hypothesis, the econometric model is formulated as:

$$CO2_{i,t} = \beta_0 + \beta_1 GDP_PC_{i,t} + \beta_2 GDP_PC^2_{i,t} + \beta_3 Energy_use_{i,t} + \beta_4 Urbanization_{i,t} + \beta_5 Trade_{i,t} + \mu_{i,t} \quad (2)$$

Where:

- **i** = country (the five selected Central Asian nations)
- **t** = year (2013–2024)
- **μ_{it}** = error term

In Equation (2), CO₂ refers to carbon dioxide emissions excluding LULUCF per capita (t CO₂e/capita). Following the EKC literature, the squared term of GDP per capita (GDP_PC²) is included to capture potential non-linearity in the income–emissions relationship. A positive coefficient for GDP_PC (β₁ > 0) combined with a negative coefficient for GDP_PC² (β₂ < 0) would confirm the inverted U-shaped EKC hypothesis.

All variables—GDP per capita (current US\$), energy use (kg of oil equivalent per capita), urbanization (urban population growth, annual %), and trade openness (trade as % of GDP)—are sourced from the World Bank's World Development Indicators. Table 1 provides a full description of the variables, their definitions, and data sources.

4. Results

Table 1 presents the pairwise correlation matrix. CO₂ emissions exhibits a very strong positive correlation with energy use ($r = 0.978$) and GDP per capita ($r = 0.912$), indicating higher economic output and energy consumption are closely associated with greater environmental degradation. The correlation between CO₂ and GDP_PC² is also strongly positive ($r = 0.787$), suggesting non-linear dynamics. GDP per capita and its squared term are highly correlated ($r = 0.962$), expected given their mechanical relationship—necessitating VIF analysis for multicollinearity. GDP per capita and energy use are strongly correlated ($r = 0.832$), reflecting the region's energy-dependent economic structure.

Urbanization shows weak positive correlations with all variables ($r = 0.270$ – 0.338). Trade openness displays negative correlations with all variables, particularly CO₂ ($r = -0.366$) and energy use ($r = -0.378$), indicating greater trade integration may be associated with lower emissions and energy consumption. Trade and urbanization are nearly uncorrelated ($r = -0.019$). These patterns support further regression analysis including GDP² to test EKC dynamics.

Table 1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Country id	60	3	1.426	1	5
YEAR	60	2018.5	3.481	2013	2024
CO2	60	6	5.059	.437	15.727
GDP_PC	60	4352.079	3815.121	788.71	14154.632
Energy use	60	1999.78	1609.558	288.395	5625.645
Urbanization	60	2.116	.4	1.161	3.057
Trade	60	67.672	27.043	28.735	134.027
GDP_PC2	60	33253153	49548467	622064.25	2.004e+08

Source: Developed by the author

Table 2 presents regression results with CO₂ emissions as the dependent variable. The model demonstrates excellent explanatory power ($R^2 = 0.990$), with the F-statistic (1056.30, $p < 0.01$) confirming overall significance.

GDP per capita exhibits a positive and significant effect ($\beta = 0.001$, $p < 0.01$), confirming economic growth contributes to environmental degradation. Critically, GDP_PC² is negative and significant ($\beta = -2.90\text{e-}07$, $p < 0.01$), providing strong empirical support for the Environmental Kuznets Curve (EKC) hypothesis—an inverted U-shaped relationship where emissions initially rise with income but decline after a turning point. The turning point is calculated as $-\beta_1/(2\beta_2) = -0.001/(2 \times -2.90\text{e-}07) \approx \$1,724$. Energy consumption shows the strongest positive impact ($\beta = 0.002$, $p < 0.01$), highlighting it as the primary emissions driver. Urbanization ($\beta = 0.287$, $p = 0.134$) and trade ($\beta = -0.004$, $p = 0.169$) are statistically insignificant. These findings validate the EKC framework for Central Asia and identify energy consumption as the critical policy lever.

Table 2: Linear regression

CO2	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
GDP_PC	.001	0	5.73	0	.001	.001	***
GDP_PC2	0	0	-2.90	.005	0	0	***
Energy_use	.002	0	15.27	0	.002	.002	***
Urbanization	.287	.189	1.52	.134	-.091	.666	
Trade	-.004	.003	-1.39	.169	-.009	.002	
Constant	-.949	.43	-2.21	.032	-1.811	-.086	**
Mean dependent var	6.000		SD dependent var	5.059			
R-squared	0.990		Number of obs	60			

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F-test	1056.299	Prob > F	0.000
Akaike crit. (AIC)	100.209	Bayesian crit. (BIC)	112.775

*** $p < .01$, ** $p < .05$, * $p < .1$
Source: Developed by the author

5. Discussion

The significant positive GDP coefficient combined with negative and significant GDP² ($\beta = -2.90e-07$, $p < 0.01$) confirms the Environmental Kuznets Curve hypothesis in Central Asia—emissions rise with growth initially but decline after a turning point (\$1,724). This aligns with Nuriddinova and Ahmad (2025) for Uzbekistan, Ozatac et al. (2017) for Turkey, and Zafar et al. (2019) for emerging economies. However, it contrasts with Caporin et al. (2024) who found only a linear relationship for Central Asia (1995–2018), and Zhang (2019) who reported a U-shaped relationship—suggesting EKC patterns may have emerged only recently in the region.

Energy consumption exhibits the strongest positive impact ($\beta = 0.002$, $p < 0.01$), identifying it as the dominant emissions driver. This is universally supported: Wang et al. (2020), Kozhagulov et al. (2025) , Zafar et al. (2019) , and Nurgazina et al. (2021) all confirm energy as the primary determinant of emissions across diverse contexts.

Urbanization ($p = 0.134$) and trade ($p = 0.169$) are statistically insignificant. The urbanization finding diverges from Verbic et al. (2021) and Zhang (2019) but aligns with Azam and Khan (2016) , suggesting context-dependent effects. The insignificant trade effect, despite negative correlation ($r = -0.366$), aligns with Nugroho et al. (2022) and Azam et al. (2021) who documented heterogeneous trade effects across Central Asia. It contrasts with Tcvetkov and Adambekova (2023) who found trade reduced emissions in SCO countries—likely reflecting Central Asia's resource-dominated trade composition where the "technique effect" has not yet overcome the "scale effect."

Conclusion

This study investigated the determinants of CO₂ emissions in five Central Asian countries from 2013 to 2024 within an extended Environmental Kuznets Curve (EKC) framework. The empirical results confirm the EKC hypothesis: GDP per capita has a positive and significant effect on emissions ($\beta = 0.001$, $p < 0.01$), while its squared term is negative and significant ($\beta = -2.90e-07$, $p < 0.01$), confirming an inverted U-shaped relationship with a turning point of approximately \$1,724. Energy consumption emerges as the dominant emissions driver ($\beta = 0.002$, $p < 0.01$), reflecting the region's fossil fuel dependence. Urbanization and trade openness are statistically insignificant. The model explains 99% of emissions variation. ($R^2 = 0.990$). This study provides the first empirical confirmation of the EKC hypothesis for all five Central Asian countries using recent data, reconciling divergent evidence where Caporin et al. (2024) found linear relationships and Zhang (2019) reported U-shaped patterns. The findings demonstrate that even resource-dependent economies can potentially achieve decoupling between growth and emissions. The dominant role of energy consumption confirms that without fundamental energy system changes, growth will continue generating environmental pressure. The relatively low turning point (\$1,724) indicates that Kazakhstan and Turkmenistan have surpassed this threshold yet emissions continue rising—implying income growth alone is insufficient; deliberate policy interventions are necessary to realize the EKC's predicted decline.

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