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Climate action and economic growth: Toward sustainable development in emerging economies

Mayis AZIZOV[1,a], Azerbaijan Zakaria BOULANOUAR[2,b*], Yusif SADILI[3,4,c], Azerbaijan Davud GULIYEV[4,d], Azerbaijan Tasnim AlGhussein[5,e], Abdulla Husain Jaffer Alhashmi[5,f]

[1]Department of Economics, Baku Engineering University

[2]Department of Economics & Finance, College of Business & Economics, UAE University, Al Ain, Abu Dhabi, UAE

[3]National Water and Energy Center, UAE University, Al Ain, Abu Dhabi, UAE

[4]Baku Engineering University

[5]UAE University, UAE

[a]mezizov@beu.edu.az, [b]zboulanouar@uaeu.ac.ae, [c]ysedili@std.beu.edu.az, [d]dguliyev@std.beu.edu.az, [e]202051083@uaeu.ac.ae, [f]202121496@uaeu.ac.ae

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Abstract. This study examines the long- and short-run effects of economic growth, trade openness, and renewable energy consumption on CO_2 emissions in Azerbaijan, Kazakhstan, and Russia, three fossil fuel-dependent emerging economies. Using annual data from 1990 to 2021 and applying an Autoregressive Distributed Lag (ARDL) framework, the analysis reveals consistent long-run relationships among the variables. Economic growth and trade are positively associated with emissions, while renewable energy consumption exerts a significant mitigating effect, strongest in Russia. The results highlight structural asymmetries in the decarbonization trajectories of these countries. Azerbaijan shows early signs of transition, whereas Kazakhstan's emissions remain tightly linked to energy-intensive growth. The findings underscore the need for tailored policy approaches to align economic development with climate goals in post-Soviet contexts. Emphasis on renewable deployment, institutional reform, and sustainable trade policy is critical for advancing low-carbon growth in resource-driven economies.

Introduction

Climate change has become an immediate global challenge, with rising emissions, extreme weather events, and energy market disruptions pressing nations to adopt sustainable growth models. For developing, resource-dependent economies, this presents a structural dilemma: how to sustain economic growth while reducing environmental harm. This tradeoff is especially pronounced in post-Soviet countries such as Azerbaijan, Kazakhstan, and Russia, where fossil fuel industries have historically driven GDP growth, trade expansion, and fiscal revenues.

In the past, environmental preservation was frequently seen as a barrier to economic advancement, suggesting a trade-off between environmental sustainability and economic growth. Recent theoretical and empirical research, however, casts doubt on this notion by showing that well-crafted climate policies can promote long-term growth, improve energy efficiency, and foster innovation (Acemoglu et al., 2012).

From an econometric perspective, the relationship between climate action and growth can be investigated by modeling economic growth as a function of both traditional growth determinants and climate-related variables, such as carbon emissions, consumption of renewable energy,

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environmental policy stringency, and green investment. Particularly in countries going through structural change, empirical data indicates that gains in energy efficiency and decreases in carbon intensity are frequently linked to stronger long-term growth rates (OECD, 2017).

These countries face mounting pressure to align their development pathways with global climate goals, including the Paris Agreement and the Sustainable Development Goals. Despite efforts to promote renewable energy, carbon emissions remain high due to persistent reliance on oil, gas, and coal. Institutional fragmentation, policy inertia, and limited green investment further complicate the transition.

This study explores the long- and short-run effects of GDP per capita, trade openness, and renewable energy consumption on territorial CO_2 emissions in the three countries from 1990 to 2021. By applying the ARDL cointegration framework, the paper provides empirical insights into the economic–environmental dynamics of each country and evaluates their progress toward sustainable development.

This study contributes to the literature by empirically investigating the impact of climate action on economic growth using an econometric model. By employing time-series methods and four key variables, the analysis aims to identify relationships between climate-related indicators and economic growth.

Literature review

The relationship between economic development and climate action has received sustained academic attention, especially in FF-rich developing countries. In the context of Azerbaijan, Kazakhstan, and Russia, the literature frequently underscores the inherent difficulty of decoupling economic growth from environmental degradation due to their historical reliance on extractive industries.

In Azerbaijan, the literature consistently highlights structural and institutional obstacles to low-carbon transition. Although the country has significant potential for solar and wind energy, its development trajectory remains dominated by oil exports and carbon-intensive infrastructure. Cholewa, Mammadov, and Nowaczek (2021) find that legal ambiguity, weak institutional coordination, and insufficient technological capacity have inhibited the growth of renewable energy. They point to the lack of stable regulatory environments as a core deterrent to long-term private investment, even as Azerbaijan aims for a 35–40% renewable share in electricity by 2030. Mammadli (2020) echoes these concerns, identifying fragmented regulation, poor infrastructure, and a lack of viable public-private partnerships as major roadblocks. The author further notes that Azerbaijan fell short of its goal to commission 420 MW of renewable capacity by 2020, largely due to the disconnect between policy intent and implementation mechanisms. Humbatova et al. (2024) provide econometric evidence using ARDL and DOLS methods, finding that GDP growth has a statistically weak or even negative impact on the development of hydro, solar, and wind energy. Meanwhile, the relationship between GDP and CO_2 emissions remains robustly positive, indicating that economic activity continues to drive environmental degradation.

Mukhtarov (2022) contributes to this debate by evaluating the implications of carbon pricing in Azerbaijan. His simulations show that the introduction of a \$40/tCO_2 carbon tax would reduce GDP by 1.1–1.8%, depreciate real incomes, and jeopardize competitiveness in energy-intensive sectors such as steel and fertilizers. This phenomenon, related to the "Dutch disease," underscores how FF wealth can induce currency overvaluation and harm non-oil export sectors. To counterbalance these risks, Mukhtarov recommends gradual price adjustments, green export certification schemes, and selective subsidies for low-carbon industries.

Kazakhstan shares many of Azerbaijan's structural limitations but also exhibits some distinctive dynamics. The country's economic growth remains tightly coupled with carbon emissions, particularly in industrial sectors such as mining and metallurgy. Tleppayev and Zeinolla (2023), using a Vector Error Correction Model, find that a 1% increase in energy consumption results in

approximately a 1.15% increase in CO_2 emissions, while GDP elasticity is around 0.8. This reinforces the argument that economic growth in Kazakhstan exacerbates environmental harm unless decoupled through structural reforms. Hasanov et al. (2019), applying the Environmental Kuznets Curve hypothesis, report a U-shaped relationship between income and emissions. They conclude that Kazakhstan has yet to reach the income threshold at which environmental degradation begins to decline, implying that policy interventions, not income growth alone, are necessary to improve environmental outcomes.

Kazakhstan's attempts at energy efficiency and legislative alignment with international climate standards have seen mixed results. Sydykova, Pashayeva, and Mammadov (2024) observe that while national energy efficiency laws have existed since 2013, enforcement remains limited due to financial constraints and a lack of trained personnel. Public awareness is also low, especially in the household and transport sectors. Despite Kazakhstan's "Green Economy" strategy and its Climate Roadmap 2050, Strielkowski et al. (2023) argue that policy implementation remains weak and mostly symbolic. This view is supported by evidence from the Russia Kazakhstan Azerbaijan Summary (2024), which indicates that FFs still dominate Kazakhstan's energy mix and account for over 65% of total emissions.

Russia presents a more complex case due to its geopolitical stature and extensive energy reserves. While national policy documents reflect an awareness of climate imperatives, their execution is widely considered inadequate. Strielkowski et al. (2023) analyze regional land use and development policies in Russia, identifying inconsistencies rooted in post-Soviet privatization, fragmented land ownership, and poor rural infrastructure. Kuzmin et al. (2023), in a bibliometric analysis, stress the centrality of human capital and institutional capacity in transitioning to a low-carbon economy. They argue that without investments in technical education, vocational training, and intersectoral coordination, Russia's energy transition will remain stalled.

Comparative research by Karaeva, Magaril, and Al-Kayiem (2023) highlights the institutional deficiencies of Russia's renewable energy policies. Unlike the European Union and the United States, which use feed-in tariffs and green certificates to promote renewables, Russia lacks strong fiscal or legal mechanisms to support such a shift. The country's renewable energy target, just 6% by 2035, is modest in comparison to the 45–80% targets set by Western economies. Moreover, FFs account for about 40% of Russia's federal budget and nearly 50% of total exports (Russia Kazakhstan Azerbaijan Summary, 2024), making decarbonization economically and politically sensitive.

Tarkhanova et al. (2020) further examine the role of green finance in Russia, concluding that the market is underdeveloped, lacking certification procedures for green bonds and offering weak incentives for sustainable investments. Climate risks are also largely absent from national development planning, especially in strategic regions like the Russian Arctic, where policy continues to prioritize extraction over adaptation.

In summary, the literature paints a coherent picture of the challenges facing Azerbaijan, Kazakhstan, and Russia. Common themes include FF dependency, institutional fragmentation, underinvestment in green technologies, and limited policy enforcement. While each country has articulated climate and energy strategies, their impact remains constrained by structural inertia. The studies reviewed here suggest that without systemic reforms, meaningful progress toward sustainable development and climate resilience will remain elusive.

Data and methodology

This study investigates the impact of economic growth, trade openness, and renewable energy consumption on territorial carbon emissions in three post-Soviet economies: Azerbaijan, Kazakhstan, and Russia. The analysis covers the period from 1990 to 2021 and uses annual data obtained from the World Bank's *World Development Indicators*. The analysis includes four key variables:

Territorial CO_2 emissions per capita (tCO_2/person): Carbon dioxide emissions generated within a country's territorial boundaries from fossil fuel combustion and industrial processes, divided by total population, expressed in metric tons per person. This serves as the dependent variable in our analysis.

GDP per capita (constant 2015 US$): Gross domestic product divided by midyear population and measured at constant 2015 prices to remove the effects of inflation.

Trade (% of GDP): The sum of exports and imports of goods and services expressed as a percentage of gross domestic product, indicating the degree of trade openness.

Renewable energy consumption (REC) (% of total final energy consumption): The share of renewable energy sources in total final energy consumption.

The dependent variable is territorial CO_2 emissions per capita (tCO_2/person), while the independent variables include GDP per capita (constant 2015 US$), trade as a percentage of GDP, and REC (Renewable energy consumption (% of total final energy consumption)). All variables are transformed into natural logarithmic form to facilitate elasticity interpretation and stabilize variance across time.

The empirical strategy is grounded in the Autoregressive Distributed Lag (ARDL) framework, which offers flexibility in handling variables with different orders of integration (I(0) or I(1)) and is suitable for small sample sizes. The ARDL bounds testing approach, developed by Pesaran and Shin (1999), is employed to examine long-run cointegration relationships among the variables. Prior to estimation, stationarity of each series is tested using the Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1981). Only variables integrated of order zero or one are admissible under the ARDL approach.

The general functional form of the estimated model is given as:

$$\ln(CO_{2t}) = \beta_0 + \beta_1 \ln(REC_t) + \beta_2 \ln(GDP_t) + \beta_3 \ln(Trade_t) + \varepsilon_t$$

where:
$\ln(CO_{2t})$: natural logarithm of territorial CO_2 emissions per capita
$\ln(REC_t)$: natural logarithm of renewable energy consumption
$\ln(GDP_t)$: natural logarithm of GDP per capita
$\ln(Trade_t)$: natural logarithm of trade as a percentage of GDP
β_0 : intercept
β_1, β_2, β_3: slope coefficients
ε_t: error term at time t

For Azerbaijan, a time trend variable is also included to account for structural shifts observed in the post-2000 period.

After verifying the integration properties of the variables, the ARDL model is estimated separately for each country using the Schwarz Information Criterion (SIC) to select optimal lag lengths. Diagnostic tests for serial correlation, heteroskedasticity, normality, and goodness-of-fit are also conducted to ensure model robustness. Finally, the cointegration test is performed using the bounds approach, and long-run as well as short-run coefficients are extracted and interpreted accordingly.

This methodology allows for the identification of both the short-term dynamics and long-term equilibrium relationships between economic activity, trade, renewable energy, and emissions in each country context.

Empirical results and discussion

The stationarity of all variables was tested using the ADF method. As shown in Table 1, all series, CO_2 emissions, GDP per capita, trade (% of GDP), and renewable energy consumption, were found

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to be non-stationary at level but stationary at first difference, i.e., I(1), confirming suitability for ARDL estimation.

Table1. *Unit-root tests results.*

Country	Variable	Level	Prob.*	1st difference	Prob.*	Result
Azerbaijan	REC	–2.601	0.103	–4.974 ***	0.004	I(1)
	GDP	–1.318	0.607	-3.395***	0.019	I(1)
	Trade	-3.480	0.015	–6.267 ***	0.000	I(1)
	tCO_2	–2.722	0.081	–4.735 ***	0.007	I(1)
Kazakhstan	REC	-2.035	0.271	-4.973***	0.004	I(1)
	GDP	-1.205	0.658	-2.759**	0.077	I(1)
	Trade	-3.196	0.030	-7.728***	0.000	I(1)
	tCO_2	-1.815	0.366	-2.649	0.164	I(1)
Russia	REC	-1.693	0.424	-9.230***	0.000	I(1)
	GDP	-1.303	0.614	-2.645*	0.095	I(1)
	Trade	-4.976	0.003	-15.235***	0.000	I(1)
	tCO_2	-2.402	0.149	-3.735***	0.008	I(1)

The ARDL bounds cointegration test results (Table 2) indicate the presence of long-run equilibrium relationships among the variables in all three countries. The F-statistics exceed the upper bounds critical values at the 10% level or better: Azerbaijan (8.23), Kazakhstan (4.19), and Russia (58.19), confirming cointegration in each case.

Table 2. *Cointegration test results*

Country Statistic	Azerbaijan	Kazakhstan	Russia
F statistic	8.2344***	4.1928*	58.1881***

Long-run coefficient estimates are presented in Table 3. Across all countries, GDP per capita shows a positive and statistically significant effect on emissions: 0.26 in Azerbaijan, 0.48 in Kazakhstan, and 0.15 in Russia, reflecting a common growth–emissions tradeoff. Similarly, trade openness contributes positively to emissions in all three, with a stronger effect in Azerbaijan (0.37) and Kazakhstan (0.36), and a marginal effect in Russia (0.008).

Table 3. *Estimation results*

Variable Country	GDP	REC	Trade	Trend
Azerbaijan	0.2646***	-0.4049***	0.3677***	-0.0225***
Kazakhstan	0.4784*	-0.2376*	0.3616*	-
Russia	0.1457***	-0.6976***	0.0078***	-

Renewable energy consumption has a negative effect on CO_2 emissions in all cases, suggesting its potential to offset environmental harm. Russia shows the strongest decarbonization response (−0.70), followed by Azerbaijan (−0.40) and Kazakhstan (−0.24). A time trend variable, included only for Azerbaijan, is also negative and significant (−0.022), indicating a slow structural decline in emissions over time.

Model diagnostics (Table 4) show no major violations: residuals are approximately normal, autocorrelation and heteroskedasticity are absent or minimal, and adjusted R^2 values are high, 0.92 (Azerbaijan), 0.99 (Kazakhstan), and 0.98 (Russia), confirming strong explanatory power.

Table 4. *Diagnostic tests' results*

	Normality	Serial Correlation	Heteroskedasticity	Adj R-squared
Azerbaijan	0.52	0.51	0.75	0.92
Kazakistan	0.19	0.11	0.85	0.99
Russia	0.85	0.61	0.88	0.98

Overall, the results support the view that renewable energy contributes significantly to emissions reduction, while economic growth and trade openness continue to elevate emissions. The varying magnitude of these effects reflects differences in national energy structures and policy effectiveness.

Conclusion

This study examined the long-run and short-run impacts of economic growth, trade openness, and renewable energy consumption on CO_2 emissions in Azerbaijan, Kazakhstan, and Russia from 1990 to 2021. Using the ARDL modeling framework, the results confirm the existence of stable long-run relationships among the variables in all three countries.

Across cases, GDP per capita and trade are found to exert a positive and statistically significant effect on emissions, reinforcing the environmental cost of growth and integration into global markets. In contrast, renewable energy consumption shows a consistent and significant negative effect on emissions, with the strongest impact observed in Russia.

The findings suggest that expanding renewable energy can serve as an effective tool for decarbonization in fossil fuel–dependent economies. However, policy effectiveness varies across contexts. Azerbaijan shows signs of gradual structural decline in emissions, while Kazakhstan's dependence on carbon-intensive sectors remains a critical challenge.

To achieve sustainable development, each country must strengthen renewable energy policy, improve institutional coordination, and adopt integrated strategies that align economic growth with long-term environmental goals..

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