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Article

Analysis of the Impact of Carbon Footprint on Economic Growth in Azerbaijan

Elchin Suleymanov ^{1,*}, Shaig Kazimov ² and Elvin Alirzayev ³

¹ National Observatory on Labor Market and Social Protection Affairs, Baku Engineering University, International Magistrate and Doctorate Center, Azerbaijan State University of Economics

² Azerbaijan State University of Economics (UNEC)

³ The Academy of the State Customs Committee of the Republic of Azerbaijan

* Correspondence: elchin.b.suleymanov@sosial.gov.az

Abstract: The increasing energy consumption and industrial activities that release carbon dioxide (CO₂) emissions into the atmosphere have become one of the most serious environmental issues of today. This article discusses the current status in Azerbaijan regarding the development of effective approaches to reduce carbon emissions and ensure sustainable development, and it proposes relevant strategies for managing the carbon footprint. By exploring the interrelationship between the economy and the environment, it aims to contribute to the formation of more effective policies for managing CO₂ emissions in Azerbaijan. According to the results of the econometric model established within the research for the period of 1990-2023, as the Azerbaijan economy grows, per capita CO₂ emissions tend to increase, which can be linked to rising industrial activity, energy consumption, and other factors driving economic growth. The presence of a positive long-term relationship between population growth and per capita CO₂ emissions can be attributed to higher overall energy consumption, increased demand for goods and services, and rising transportation needs. The strong correlation between economic growth and CO₂ emissions suggests that it may be too early to assert the validity of the Kuznets curve for Azerbaijan economy as a developing country.

Keywords: CO₂ emissions; energy consumption; Azerbaijani economy; Kuznets curve

2. Introduction

The management of carbon footprint is a crucial area in the fight against global climate change. The emissions of carbon dioxide (CO₂) released into the atmosphere due to increasing energy consumption and industrial activities have become one of the most serious environmental issues of our time. This problem requires particular attention in developing countries, where rapid economic growth further exacerbates its environmental impact. In Azerbaijan, significant changes in CO₂ emissions have been observed in recent years due to economic growth and increased industrial activities. Given that the country's energy consumption is primarily based on fossil fuels, carbon emissions are notably high. Therefore, the per capita CO₂ emissions in Azerbaijan represent an issue that should be analyzed from both ecological and economic perspectives.

The objective of this scientific article is to investigate how per capita CO₂ emissions in Azerbaijan are influenced by various economic and ecological factors through economic modeling. Our aim is to identify the key variables affecting CO₂ emissions and assess the scale of these impacts in relation to different sectors of the economy. Additionally, the findings from this analysis will aid in formulating recommendations for managing the country's carbon footprint. By employing econometric analyses, it is possible to more accurately identify the factors influencing per capita CO₂ emissions. Such analyses provide essential data for measuring the impact of energy consumption, economic growth, industrial production, the transportation sector, and other relevant variables on emissions. Furthermore, the information derived from this research will facilitate the development of

recommendations aimed at improving Azerbaijan's ecological policies and formulating strategies for reducing carbon emission.

3. Carbon Footprint: International Outlook

CO₂, a greenhouse gas, is the main driver of climate change and rising temperatures. As of 2022, the United States was the largest historical emitter, having released 427 billion metric tons of carbon dioxide (GtCO₂) into the atmosphere since the industrial revolution. This represents for almost a quarter of all historical CO₂ emissions from fossil fuels and industry. China is the second-largest contributor to historical emissions, with over 260 GtCO₂ released (Tiseo, 2023).

In 2023, fossil CO₂ made up 73.7% of total greenhouse gas (GHG) emissions, while methane (CH₄) contributed 18.9%, nitrous oxide (N₂O) accounted for 4.7%, and fluorinated gases (F-gases) represented 2.7%. Since 1990, global fossil CO₂ emissions have risen by 72.1% (EDGAR, 2024).

Since 1990, China's carbon dioxide emissions have increased more than five times, and by 2023, the country is responsible for about 34% of global CO₂ emissions. In contrast, CO₂ emissions in the United Kingdom have decreased by nearly 50% compared to 1990 levels. Although developed nations like the UK, the U.S., Japan, and Germany have seen overall reductions in emissions since 1990, developing regions have experienced dramatic increases. For instance, in India, emissions have surged nearly fivefold due to rapid economic growth, while Vietnam's emissions have skyrocketed by almost 2,000% (Tiseo, 2024a).

Since 1990, global carbon dioxide emissions from fossil fuels and industry have risen by more than 60%, totaling 37.15 billion metric tons (GtCO₂) in 2022 and reaching 53.0 billion metric tons CO₂eq in 2023. China is the largest emitter of global greenhouse gases, followed by the United States. While China was not always the leading emitter, its emissions have surged significantly due to rapid economic growth and industrialization in recent decades. Since 1990, CO₂ emissions in China have risen by over 4 times, whereas U.S. CO₂ emissions have decreased by 2.6%. Despite this changes, the U.S. continues to be the largest emitter of carbon historically. However, China was responsible for 30 percent of global greenhouse gas (GHG) emissions, making it the largest emitter in the world by a considerable margin for 2023. (Tiseo, 2024; 2024b), (EDGAR, 2024).

In 2023, China, US, EU-27, India, Russia, and Brazil continued to be the largest CO₂ emitters globally. Collectively, these countries represent 49.8% of the world's population, 63.2% of global GDP and 64.2% of global fossil fuel consumption, and 62.7% of global fossil CO₂ emissions (EDGAR, 2024).

Carbon footprints have a substantial effect on climate change. Greenhouse gas emissions in the atmosphere contribute to global warming. According to the World Meteorological Organization (WMO), the decade from 2011 to 2020 was the hottest on record. Between 1990 and 2005, carbon dioxide emissions rose by 31%. By 2008, these emissions had increased the Earth's radiative warming—an alteration in the planet's energy balance that leads to warming—by 35% compared to 1990 levels. (WMO, 2023).

The Paris Agreement as an international treaty concerning climate change was adopted by 196 parties at the UN Climate Change Conference (COP21) and came into effect on November 4, 2016. Its primary objective is to keep the global average temperature rise well below 2°C above pre-industrial levels and to strive to limit the increase to 1.5°C above those levels (UNCC, 2016).

The energy sector, being the primary contributor to global emissions, plays a crucial role in addressing the world's climate issues. Even with numerous promises and actions taken by governments to combat global warming, CO₂ emissions from energy and industry have risen by 60% since the United Nations Framework Convention on Climate Change was signed in 1992.

In the EU-27, between 1990 and 2021, net greenhouse gas (GHG) emissions, including those from international aviation, fell by 30%. Projections from EU Member States suggest that net emissions will be reduced by 48% by 2030 from 1990 level. However, there will still be a seven-percentage point shortfall from the 2030 target. The European Climate Law enshrines the objective from the European Green Deal for Europe sets a firm target for achieving climate neutrality by 2050 at the latest and mandates a reduction in net GHG emissions of at least 55% by 2030 compared to 1990 levels (EEA, 2023).

The COVID-19 pandemic led to a significant drop in global CO₂ emissions, decreasing by about 5.5% in 2020 due to lockdowns and other restrictions. Besides, the global recession in 2009 caused CO₂ levels to fall by nearly 2%, and the recession of the early 1980s also notably affected emissions. The most substantial annual reduction occurred at the end of the Second World War in 1945, when emissions dropped by 17% (Tiseo, 2024).

4. Carbon Footprint: Literature Review

In the literature, a significant number of studies have explored the relationship between CO₂ emissions and economic growth, specifically investigating how economic growth influences CO₂ emissions. An increase in population can lead to higher energy consumption, which in turn raises carbon emissions (Liddle, 2015). As countries strive to enhance their productive capacities, energy usage rises (Chindo and Abdul-Rahim, 2018), and this increase in energy consumption and urbanization level contributes to the growth of carbon emissions (Hossain, 2014; Begum et al., 2015).

In his article, “The Irreversible Momentum of Clean Energy,” former US President Obama emphasized the importance of “decoupling” energy sector emissions from economic growth. He highlighted that between 2008 and 2015 (during his presidency), CO₂ emissions from the energy sector decreased by 9.5% while the economy grew by over 10% (Obama, 2017).

In advanced economies, GDP growth has led to a peak in CO₂ emissions in 2007, followed by a decrease. For instance, in US, GDP has doubled since 1990, but CO₂ emissions are back to 1990 levels. Similarly, in the EU, the economy has expanded by 66%, while CO₂ emissions have dropped by 30% compared to 1990. This pattern is also observed in other advanced economies. As these economies represent more than half of global GDP and over a third of energy demand, decrease in CO₂ emissions in these regions is also evident. In contrast, emerging and developing economies like China and India show diverging trends. China’s economy has grown fourteenfold since 1990, but its CO₂ emissions are now five times higher than 1990 level. In India, GDP growth has exceeded CO₂ emissions growth by over 50%. Other emerging economies are also experiencing different trends in economic activity and emissions (IEA, 2024).

The research on the relationship between six key industrial sectors (agriculture, industry, construction, transportation, retail, and accommodation, along with other industries) and CO₂ emissions in China from 2000 to 2017 yielded intriguing findings. The share of agriculture, industry, and transportation in GDP shows a negative correlation with CO₂ emissions, while the share of construction, retail, and other industries in GDP is positively correlated with CO₂ emissions. This finding aligns with Xie and Liu’s (2019) analysis of China’s industrial sector, indicating a decoupling¹ between industrial economic growth and CO₂ emissions. The share of value added and GDP in the construction sector is positively correlated with carbon emissions. This can be linked with rapid pace of urbanization has further increased energy demand, making it a key contributor to the increase in carbon emissions. Regarding the impact of industry types on CO₂ emissions, a 1% increase in the share of value added to GDP from China’s agriculture, industry, construction, transportation, retail, and accommodation results in changes in total CO₂ emissions by -0.92%, 0.05%, 1.2%, 2.6%, 0.97%, and 0.098%, respectively.

Lee and Brahmasrene (2013) explored relationship among tourism, CO₂ emissions, economic growth, and FDI in EU countries between 1988 and 2009. The analysis showed that tourism, CO₂ emissions, and FDI significantly boost economic growth. Conversely, while economic growth significantly increases CO₂ emissions, tourism and FDI have a notable negative impact on CO₂ emissions. As resulted, 1% increase in tourism receipts boosts economic growth by 0.498% and reduces CO₂ emissions by 0.105%, indicating that tourism has a positive effect on economic growth while also contributing to a decrease in CO₂ emissions. Also, 1% increase in FDI inflows reduces CO₂

¹ Decoupling is when economic growth happens without increasing environmental harm or resource use, especially in terms of carbon emissions.

emissions by 0.017%. Conversely, a 1% increase in economic growth leads to a 0.199% rise in CO₂ emissions.

Dogru and others (2020) analyzed the effects of GDP, renewable energy consumption, and tourism receipts on CO₂ emissions in OECD countries. The results revealed that tourism development significantly reduces CO₂ emissions in Canada, Czechia, and Turkey, while it significantly increases CO₂ emissions in Italy, Luxembourg, and the Slovak Republic.

The Kyoto Protocol, effective since 2005, establishes legally binding targets for greenhouse gas (GHG) emissions specifically for industrialized countries. For policymakers to meet emission reduction targets, adjusting the industrial structure by limiting high CO₂-emitting sectors and expanding low-emission sectors is essential. However, this structural adjustment may slow economic growth and lead to macroeconomic losses. As Chang (2015) resulted, for China to cut CO₂ emissions from 5707.16 to 5452.12 million tonnes as of 2007, it would need to restructure its industries, which could reduce GDP by 82.59 billion Yuan (11.6 bn USD as of 2024).

The study by Osadume and University (2021) examined the relationship between economic growth and carbon emissions in selected West African countries from 1980 to 2019. They found that economic growth has a significant effect on carbon emissions, with a 1% increase in economic growth leading to a 3.11% increase in carbon emissions.

Saleem and others (2022) examined the dynamic relationships between non-renewable energy production, healthcare expenditures, and CO₂ emissions in 38 OECD countries from 2008 to 2018. Key findings included a positive response of fossil fuel energy production to healthcare expenditures and a bidirectional positive relationship between healthcare spending and CO₂ emissions.

Ramos-Meza and others (2023) finds a favorable bidirectional relationship between health spending and CO₂ emissions. The results show that increased energy production and consumption leads to pollution, therefore higher CO₂ emissions rise healthcare costs. However, energy consumption and healthcare expenditures positively influence environmental quality.

Grossman and Krueger (1991) examined how economic growth and environmental pollution interact within the framework of NAFTA. They explore the Environmental Kuznets Curve (EKC) hypothesis, which proposes that as a country's economy grows, environmental degradation initially increases but eventually decreases after reaching a certain level of income per capita as inverse U-shaped curve. They found that trade liberalization under NAFTA could result in increased pollution, especially in industries that are already highly polluting and have substantial production levels. In the short term, the boost in economic activity and industrial growth might worsen environmental degradation. Results also highlighted that, in the longer term, trade liberalization could improve environmental quality from increased efficiency, technological advancements, and the adoption of cleaner technologies as countries become wealthier and demand higher environmental standards.

Meadows, et al. (1972) explore the connection between economic growth and environmental limits. The authors analyzed how population growth, resource consumption, and industrial expansion interact with the Earth's finite resources. Their findings suggest that if these trends continue unchecked, the world will face economic and environmental collapse within the next century. The report highlights that economic growth is fundamentally constrained by environmental limits, such as the availability of resources and the planet's ability to absorb pollution. It advocates for a shift toward sustainable development, where resource use and economic activity are balanced with environmental conservation. The study emphasizes the need for policies that limit overconsumption and reduce environmental degradation, pointing to the long-term risks of ignoring ecological boundaries.

Chen and Huang (2014) investigate the nonlinear relationship between CO₂ emissions per capita and economic growth in various high-income and low-income countries from 1985 to 2012. Using a Panel Smooth Transition Regression (PSTR) model, the study examines how this relationship changes across different stages of economic development. The authors find that CO₂ emissions are not uniformly linked to economic growth; instead, the connection varies based on income levels and stages of development. In particular, the results indicate that high-income countries experience a decoupling effect, where economic growth leads to lower growth in CO₂ emissions. In contrast, in

lower-income nations, economic growth tends to significantly boost CO₂ emissions. The paper highlights the importance of targeted environmental policies, suggesting that as countries progress economically, they should adopt more sustainable practices to mitigate the environmental impact of growth. This nonlinear approach offers deeper insights into the complexities of the environment-economic growth nexus.

Dinda and Coondoo (2006) investigated the connection between GDP per capita and CO₂ emissions in 88 countries between 1960–1990 years. Their results suggest that, although there is evidence of long-term cointegration between CO₂ emissions and income, short-term cointegration is not observed. This indicates that while a stable, long-term relationship between economic growth and emissions may exist, the short-term dynamics do not always align with this equilibrium. For the regions where cointegration was found, the study notes different causal patterns, like Africa: There is bidirectional causality between income and emissions; Central America: Causality runs from income to emissions; Europe: The causality appears to run from emissions to income. The results suggest that countries may need to limit income growth to manage CO₂ emissions, especially if they lack access to cleaner technologies. They also note that economic openness affects emissions differently: it reduces CO₂ emissions in Western Europe but increases them in Africa and Central America.

However, in their early research Dinda and Coondoo (2002) investigated for same countries and time period, and findings did not strongly support the Environmental Kuznets Curve (EKC) hypothesis. Instead, they identified distinct causality patterns among different country groups, like developed countries (in North America, Western Europe, and Eastern Europe), causality was observed running from CO₂ emissions to income; developing countries (for Japan, Central and South America, and Oceania) causality ran from income to CO₂ emissions; and in Asia and Africa, causality was found to be bidirectional.

Lotfalipour et al. (2010) examined the causal relationships among economic growth, carbon emissions, and fossil fuel consumption in Iran from 1967 to 2007. Their study highlighted that, although economic growth and fuel consumption impact CO₂ emissions in the short term, these effects do not persist over the long term.

Hasanov, Bulut, and Suleymanov (2017) analyzed the relationship between energy consumption and economic growth in ten Eurasian oil-exporting countries. Their panel data analysis found that energy consumption significantly drives economic growth in these countries, with some showing a bidirectional relationship between energy use and economic expansion. Such economies heavily rely on oil and energy resources as the foundation for their development. The authors emphasize the need for policy measures to diversify energy sources, improve efficiency, and promote sustainability to support long-term growth while mitigating environmental impacts.

Hasanov, et al. (2019) explored the Environmental Kuznets Curve (EKC) hypothesis, finding that as Kazakhstan's economy grows, CO₂ emissions initially increase but eventually decrease after reaching a certain income level. The study underscores the need for effective environmental policies and cleaner technologies as the economy develops. The authors recommend strategies to balance economic growth with environmental protection, emphasizing sustainable development in a developing context.

Nordin and Sek (2019) analyzed the relationship between CO₂ emissions, energy consumption, and economic growth in 13 oil-importing and 11 oil-exporting countries using a panel data approach. They found that, for both oil-importing and oil-exporting countries, a strong relationship exists between energy consumption and economic growth. In many cases, increased energy consumption drives economic expansion. This relationship is particularly significant for oil-exporting countries where energy resources are a major economic driver. The study shows that higher energy consumption, especially from fossil fuels, leads to increased CO₂ emissions. This is particularly relevant for oil-exporting countries, where the extraction and use of oil heavily contribute to carbon emissions. Oil-importing countries also show increased emissions with economic growth, though they tend to rely on a more diverse range of energy sources. However, oil-exporting countries, due to their heavy reliance on oil production and exports, face higher environmental impacts. Oil-

importing countries may have more flexibility in transitioning to cleaner energy sources, though economic growth is still tied to energy consumption in both groups. The findings suggest that oil-exporting countries face a more significant challenge in balancing economic growth with environmental sustainability. They need to explore alternative energy sources and reduce their dependence on fossil fuels to mitigate CO2 emissions.

5. Econometric Assessment of Carbon Footprints in Azerbaijan: Methodology

Data and descriptive statistics: Carbon footprints in Azerbaijan by fields between 1990 and 2023 are depicted in Figure 1. According to the data, almost all types of carbon footprints have decreased since 1990. However, the clear and unknown reasons for this decrease have been investigated in many scientific materials (stagnation in the country’s economy and industry due to the collapse of the former Soviet Union, etc.). On the other hand, it is necessary to take into account that the reduction is misleading as a description. Because the data here represents the amount of carbon dioxide per capita, and since population growth and economic development do not develop with the same acceleration, the non-linearity in the impact of emissions into the atmosphere should be taken into account. As can be seen from the graph, although there was a drop in all directions of carbon dioxide emission in the 90s, a sharp increase in gasoline consumption is observed since 2000. A gradual increase is observed in the field of transport. At the same time, these increases have stabilized at a certain level since the 2000s.

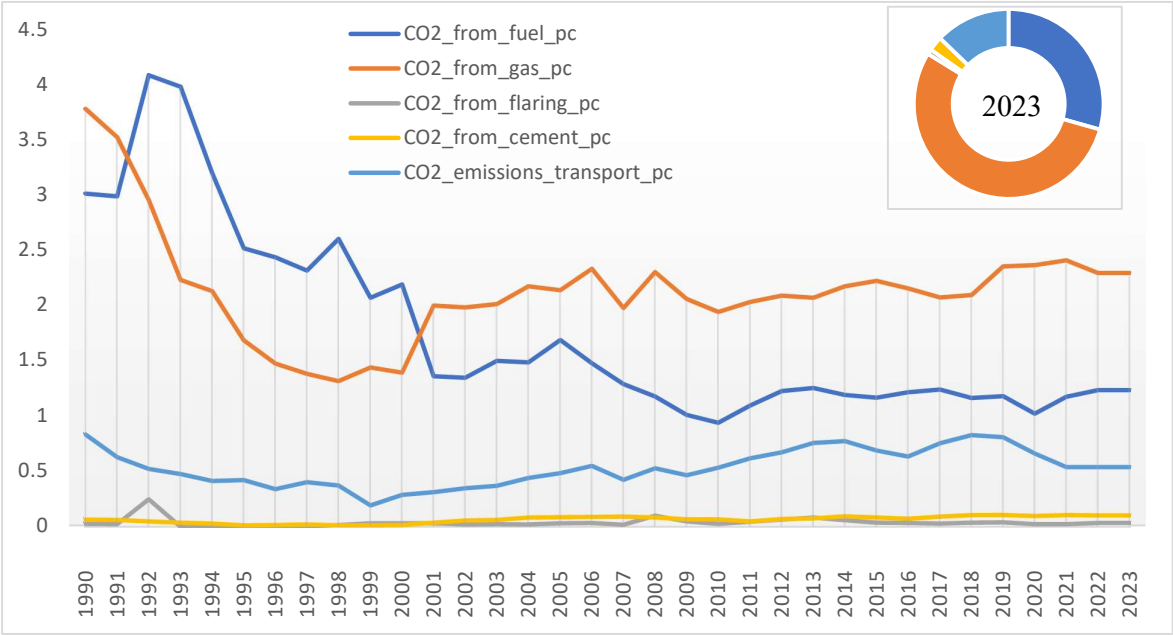


Figure 1. Azerbaijan CO2 footprint by sectors.

In Figure 1, the main share of the amount of carbon dioxide emissions in 2023 falls on the share of gasoline consumption, which makes 55%.

For the period 1990-2023 GDP rate, population change, total carbon dioxide emissions, per capita CO2 emissions from transportation, cement production, fuel and gasoline consumption, as well as per capita fossil fuel consumption, electricity from renewable energy resources (terawatt/hour), graphs of percentage of use of renewable resources in electricity production of the country are shown in Figure 2. First, let’s try to explain the trends in the graph in a coherent way. In general, the amount of carbon dioxide per person for the period 1990-2023 in the country was between 7-8 tons per year in the early 90s, but as a result of a dramatic decrease by 2010, it settled between 3-4 tons and by 2023 this stability has been maintained. Along with these time series, the population growth rate was 7 million in 1990. 10 million people in 2023. level with a stable trend. At the same time, the decrease in

the population growth rate has been observed more prominently in recent years. However, we cannot say the same for GDP per capita. Because, during this time series, there was a decline until 95, a gradual increase between 1995 and 2005, a dramatic increase between 2005 and 2010, and then stability until 2023. The graph shows a high acceleration of the GDP growth rate mainly between 1993-1997, and then in 2004-2006.

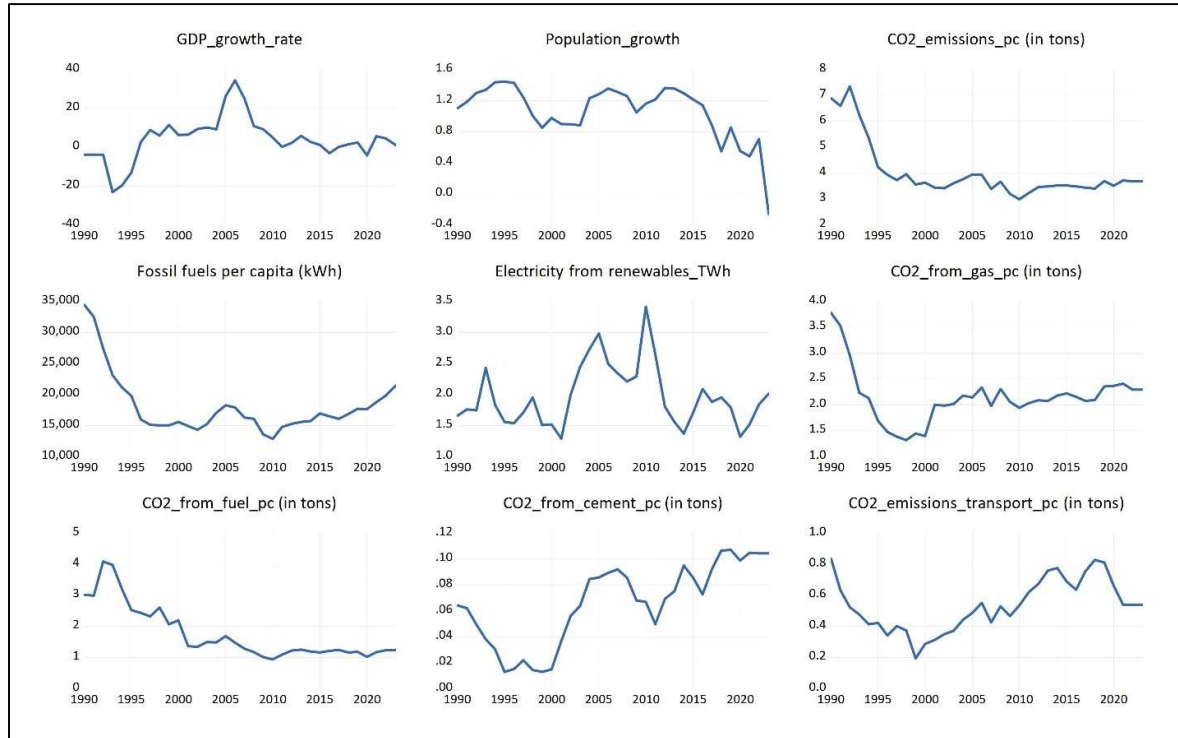


Figure 2. CO2 and other tendencies between 1990 and 2023.

Econometric analysis: To understand the relationship of carbon dioxide emissions by country to the country's gross domestic product, population change, and per capita fossil fuel consumption over the time series presented in the Data and descriptive statistics section of the study, the growth rate of gross domestic product per capita (as *GDPGH*) as a percentage, per capita carbon dioxide emissions (as *CO2PC*), population growth rate (as *POPGH*) and per capita fossil fuel consumption (kilowatt hours) (as *FOSS*) were used as variables. The natural logarithm of the *CO2PC* and *FOSS* variables used in the analysis was obtained and the others were kept original. To perform the cointegration analysis, we first check whether these variables are stationary. Stationarity is a measure of the robustness of a time series to a particular shock. In other words, if the time series is stationary, it will return to its previous level even if it is affected by any shock and shows an upward or downward trend for a certain period of time. In order to carry out the cointegration analysis, all the time series mentioned above must show stationarity at the same lag degree. That is, the null hypothesis for testing stationarity suggests that the time series has a unit root. A stationarity test is performed for this hypothesis within the framework of a predetermined significance criterion (α level). If we want to measure the stationarity of the time series Y_t then for the unit root test the following regression equation is constructed:

$$Y_t = pY_{t-1} + u_t \quad (1)$$

If the parameter ρ in this equation is statistically equal to 1, then the time series has a unit root and is not stationary. Equation (1) can also be expressed as follows:

$$[\Delta Y]_t = (p - 1) Y_{t-1} + u_t = \delta Y_{t-1} + u_t \quad (2)$$

Here, the parameter δ equal to 0 is investigated to check for stationarity. In this study, Augmented Dickey-Fuller, Phillips-Perron, Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests are

used to test for stationarity. Tables 1, 2, 3 and 4 below describe these results. For cointegration analysis, all variables must have stationarity at the same lag level. Table 1 describes the results of the ADF, Phillips-Perron and KPSS tests on the logarithm of carbon dioxide emissions per capita. The results of these tests, both in this table and in others, were checked according to the 5% significance level. As can be seen from Table 1, according to the Augmented Dickey-Fuller test, it was found that the time series on the difference from degree 1 does not contain a single root, that is, it is stationary. This result was also obtained in the Phillips-Perron test. However, according to the KPSS test, there is stationarity only in the original values of the time series.

Table 1. Unit Root Test of CO2 emissions per capita (CO2PC).

		Level			1st difference		
		Intercept	Intercept & Trend	None	Intercept	Intercept & Trend	None
ADF	t	-2.954021	-1.863301	-1.752988	-4.996442	-5.516533	-4.870561
	p	(0.0676)	(0.6505)	(0.0756)	(0.0003)*	(0.0004)*	(0.0000)*
Phillips-Perron	t	-3.358348	-1.750662	-1.752988	-4.996442	-5.586607	-4.866480
	p	(0.0201)*	(0.7054)	(0.0756)	(0.0003)*	(0.0004)*	(0.0000)*
KPSS	LM stat	0.473833*	0.169328*	-	0.401535	0.088744	-
	LM crit	0.463000	0.146000	-	0.463000	0.146000	-

* The significance level for all tests is 5%.

Table 2. Unit Root Test of Population Growth rate (POPGH).

		Level			1st difference		
		Intercept	Intercept & Trend	None	Intercept	Intercept & Trend	None
ADF	t	0.126502	-0.886014	-0.969255	-4.917985	-5.311521	-4.812110
	p	(0.9631)	(0.9458)	(0.2904)	(0.0004)*	(0.0008)*	(0.0000)*
Phillips-Perron	t	0.373326	-0.826182	-0.966817	-5.125394	-5.344690	-5.126759
	p	(0.9787)	(0.9527)	(0.2914)	(0.0002)*	(0.0007)*	(0.0000)*
KPSS	LM stat	0.389779	0.132822	-	0.348070	0.115364	-
	LM crit	0.463000	0.146000	-	0.463000	0.146000	-

* The significance level for all tests is 5%.

Table 3. Unit Root Test of GDP Growth Rate (GDPGH).

		Level			1st difference		
		Intercept	Intercept & Trend	None	Intercept	Intercept & Trend	None
ADF	t	-1.961510	-1.873430	-1.812933	-4.730110	-4.681350	-4.807541
	p	(0.3015)	(0.6454)	(0.0669)	(0.0006)*	(0.0037)*	(0.0000)*
Phillips-Perron	t	-2.061285	-1.914568	-1.915739	-4.728673	-5.099046	-4.837864
	p	(0.2608)	(0.6244)	(0.0539)	(0.0006)*	(0.0013)*	(0.0000)*
KPSS	LM stat	0.174450	0.152080*	-	0.159896	0.120303	-
	LM crit	0.463000	0.146000	-	0.463000	0.146000	-

* The significance level for all tests is 5%.

Table 4. Unit Root Test of Fossil Fuel use per capita (FOSS).

		Level			1st difference		
		Intercept	Intercept & Trend	None	Intercept	Intercept & Trend	None
ADF	t	-3.559267	-3.057327	-1.053065	-3.100454	-4.103805	-3.143778

Phillips-Perron	p	(0.0126)*	(0.1334)	(0.2578)	(0.0366)*	(0.0149)*	(0.0027)*
	t	-3.272940	-2.275362	-0.764131	-3.099765	-4.103805	-3.143778
	p	(0.0245)*	(0.4349)	(0.3776)	(0.0366)*	(0.0149)*	(0.0027)*
KPSS	LM stat	0.274653	0.173118*	-	0.528631*	0.089619	-
	LM crit	0.463000	0.146000	-	0.463000	0.146000	-

* The significance level for all tests is 5%.

Similarly, in tables 2, 3 and 4, according to the ADF, Phillips-Perron test, the results were obtained in the time series of population growth rate, gross domestic product growth rate and per capita fuel obtained from fossil soruces. In these time series, stationarity is also observed in the difference from the 1st degree.

According to the results of the stationarity test, the first preliminary Vector Auto Regression model (VAR model) is constructed to perform the cointegration test. To determine the number of lags, after building the model with a maximum of 2 lags by default, we perform a lag rate determination test in the VAR model and determine that the maximum required lag is 2. The stability of the autoregression was tested and the resulting modulus values were less than 1. According to the model, no serial correlation was observed in the time series. When checking the normality of the residuals, it was observed that there is no normal distribution in the data ($p = 0.0002$), but according to the Chi-square test, the time series of the residuals are homoscedastic ($p = 0.2181$).

According to the corresponding results in Tables 5 and 6 obtained from the cointegration analysis, there is at least one cointegration relationship among the most variables. With the cointegration relationship established, the next step is to estimate the Vector Error Correction Model (VECM). VECM allows to analyze how long-term (co-integrated) deviations are corrected over time. It involves using the correction coefficients given by the cointegration to model the short-term dynamics. Using the GDP growth rate, per capita fossil fuel and population growth rate in the VECM model to predict the amount of carbon dioxide emissions per capita, we obtain the following result:

$$\begin{aligned} Ln(CO2PC)(-1) = & 0.138 + 0.006 * GDPGH(-1) + 0.171 * POPGH(-1) - 0.173 * \\ & Ln(FOSS)(-1) \quad (3) \end{aligned}$$

(0.00201)

(0.08407)

(0.13625)

[2.81922]

[2.03280]

[-1.26828]

Table 5. Cointegration analysis (Unrestricted Cointegration Rank Test (Trace)).

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.668957	56.75869	47.85613	0.0059
At most 1	0.405870	22.48795	29.79707	0.2721
At most 2	0.168765	6.347567	15.49471	0.6544
At most 3	0.019721	0.617453	3.841465	0.4320

Table 6. Cointegration analysis (Unrestricted Cointegration Rank Test (Maximum Eigenvalue)).

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**

None *	0.668957	34.27074	27.58434	0.0060
At most 1	0.405870	16.14039	21.13162	0.2168
At most 2	0.168765	5.730115	14.26460	0.6481
At most 3	0.019721	0.617453	3.841465	0.4320

As can be seen from equation (3), all three variables, namely, GDP growth rate, population growth rate, and per capita energy from fossil resources have a positive effect on the growth of carbon dioxide per capita. The result of the error correction model is as follows:

$$\begin{aligned} D(LN(CO2PC)) = & -0.451 * ECT + 0.184 * D(LN(CO2PC(-1))) + 0.294 * \\ & D(LN(CO2PC(-2))) + 0.002 * D(GDPGH(-1)) + 0.003 * D(GDPGH(-2)) + 0.072 * \\ & D(POPGH(-1)) + 0.137 * D(POPGH(-2)) - 0.016 * D(LN(FOSS(-1))) - 0.363 * \\ & D(LN(FOSS(-2))) - 0.018 \end{aligned} \quad (4)$$

Equation (4) is the result of the error correction model. Here -0.451 lambda coefficient is the speed of error correction. Other parameters are short-term impact parameters (Table 8). Before the results of the table, we see that the error correction coefficient is -0.451368 and its t-statistic value is -4.57563. The fact that this coefficient is negative and statistically significant indicates that a 45.14% deviation from the long-term equilibrium is corrected in each period. This means that per capita carbon dioxide emissions will return to their regular trend relatively quickly.

Table 8. Vector Error Correction Model results.

Error Correction:	D(LN(CO2PC))				
	Coefficients	standard error t statistics			
CointEq1	-0.451368	-0.09865	[-4.57563]		R-squared: 0.680853
D(LN(CO2PC(-1)))	0.184074	-0.17355	[1.06062]		Adj. R-squared: 0.544075
D(LN(CO2PC(-2)))	0.294477	-0.17587	[1.67436]		Sum sq. resids: 0.064482
D(GDPGH(-1))	0.002158	-0.00161	[1.33696]		S.E. equation: 0.055413
D(GDPGH(-2))	0.003372	-0.00139	[2.43258]		F-statistic: 4.977818
D(POPGH(-1))	0.072188	-0.07797	[0.92588]		Log likelihood: 51.73102
D(POPGH(-2))	0.136825	-0.07617	[1.79627]		Akaike AIC: -2.692324
D(LN(FOSS(-1)))	-0.016275	-0.19728	[-0.08250]		Schwarz SC: -2.229748
D(LN(FOSS(-2)))	-0.363351	-0.20895	[-1.73893]		Mean dependent: -0.02236
C	-0.018151	-0.01054	[-1.72247]		S.D. dependent: 0.082066

6. Conclusion and Suggestions

The model shows a significant positive long-run relationship between GDP growth rate and per capita CO2 emissions. This means that CO2 emissions per capita tend to increase as the economy grows, suggesting that economic growth as measured by GDP can lead to higher emissions. This may be due to increased industrial activity, energy consumption and other factors accompanying economic expansion. The positive long-term relationship between population growth and per capita CO2 emissions means that as population increases, so do per capita CO2 emissions. This may be due to higher overall energy consumption, greater demand for goods and services, and increased transportation needs associated with a growing population. The model shows a weak and statistically insignificant negative long-run relationship between fossil fuel consumption and per capita CO2 emissions. This is somewhat counterintuitive, as fossil fuel consumption is generally expected to be positively related to CO2 emissions. A weak relationship may indicate that other factors, such as improvements in energy efficiency or the adoption of cleaner energy sources, are offsetting the effects of fossil fuel consumption on emissions. Because, in addition to traditional energy production in Azerbaijan, both hydropower production, which has been expanding since the time of the former

USSR, and alternative energy sources that have developed in the years of independence, have a certain share in energy production.

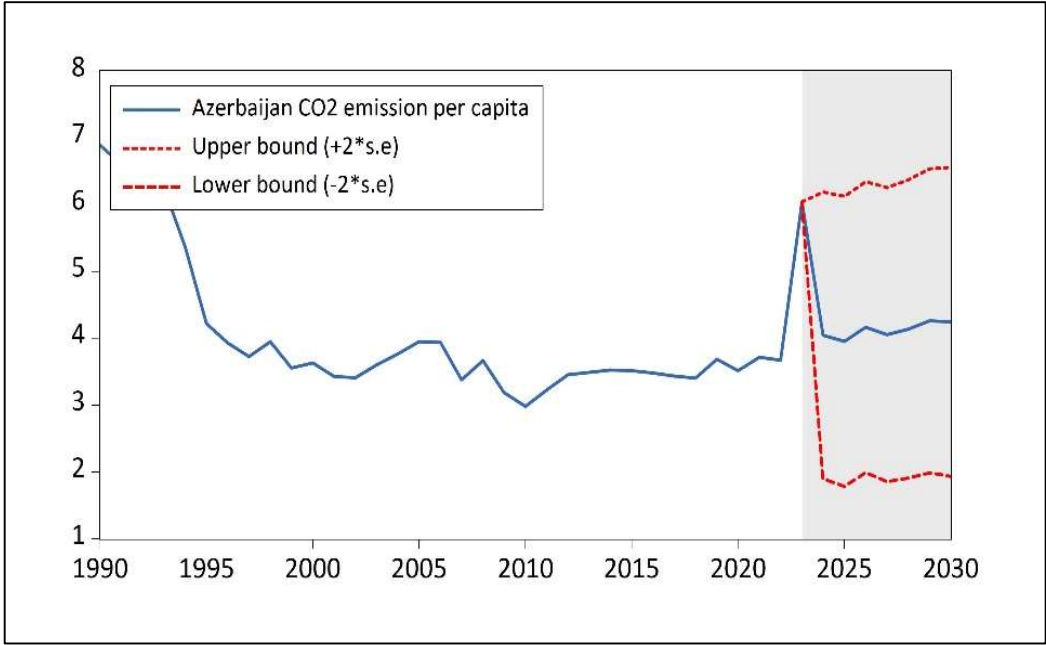


Figure 3. Azerbaijan CO2 emission per capita (including forecast).

A significant and negative error correction period for per capita CO2 emissions implies a relatively quick correction of deviations from long-term trends. This means that if CO2 emissions deviate from the level predicted by the long-term relationship (due to a shock or other factors), they will trend back about 45% over the period. This shows that per capita CO2 emissions respond to changes in key factors (GDP growth, population growth and fossil fuel consumption) and tend to stabilize over time. Similarly, a negative and significant error correction coefficient for fossil fuel consumption indicates rapid adjustment relative to the long-term trend. This indicates that fossil fuel consumption tends to return to the long-term trend after a deviation, reflecting the stability and persistence of fossil fuel consumption patterns. The error correction terms for GDP growth rate and population growth are not significant, indicating that these variables do not show a strong tendency to correct deviations from the long-term trend in the short term. This means that a wider range of factors affects GDP and population growth, and that it cannot respond quickly to short-term fluctuations in CO2 emissions or fossil fuel consumption.

The suggestions listed below are as follows:

- 1) The positive relationship between GDP growth and CO2 emissions indicates a trade-off between economic growth and environmental sustainability. Policymakers should consider strategies that decouple economic growth from CO2 emissions, including investing in green technologies, promoting energy efficiency and transitioning to renewable energy sources.
- 2) The positive association between population growth and CO2 emissions means that efforts to manage population growth or reduce its impact on emissions may be crucial to controlling CO2 levels. This can include urban planning, promoting sustainable living practices and improving public transport systems.
- 3) In the long term, the weak relationship between fossil fuel consumption and CO2 emissions suggests that energy policy should focus on improving energy efficiency and increasing the share of renewable energy in the energy mix. This can help reduce environmental impact without directly reducing fossil fuel consumption.

- 4) The quick reversion of CO₂ emissions and fossil fuel consumption to their own trend suggests that these variables are relatively stable and predictable in the long run. This stability can be used by policymakers to develop long-term strategies for reducing emissions.

The current study was driven by the absence of a detailed time series analysis on the relationship between CO₂ emissions and income in Azerbaijan. To ensure accurate estimates and avoid misleading policy implications, we began our analysis with a cubic functional form, as recommended by foundational studies in the Environmental Kuznets Curve (EKC) literature. To enhance the robustness of our findings, we employed five different methods and addressed issues related to small sample size bias. Our empirical analysis revealed a long-term relationship between CO₂ emissions and income. While a “U”-shaped relationship was observed, the turning point occurred beyond the 1992–2013 sample period, leading us to conclude that the impact of income on CO₂ emissions is consistently increasing in Azerbaijan. This suggests that the EKC does not apply to the country. This conclusion aligns with Azerbaijan’s socio-economic context as a developing, energy-rich economy, indicating that it will take considerable time for income levels to result in reduced CO₂ emissions. Our findings indicate a direct one-to-one relationship between these variables in the long run.

We hope this research will aid in developing effective CO₂ policies in Azerbaijan, highlighting the positive link between income and CO₂ emissions. This suggests that a focus on environmentally sustainable economic growth is essential moving forward. Specifically, if growth strategies prioritize heavy industries like oil, coal, and metals, pollution levels will likely rise. Therefore, fostering growth in service and technology sectors would be more beneficial. Additionally, policymakers should consider reducing reliance on fossil fuels and increasing the share of renewable energy in the energy mix. Implementing regulations such as a high carbon tax, carbon capture initiatives, and emissions trading schemes could also be valuable strategies for the Azerbaijan government.

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