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RESEARCH ARTICLE

How causality impacts the renewable energy, carbon emissions, and economic growth nexus in the South Caucasus Countries?

Azer Dilanchiev[1] · Muhammad Umair[2] · Muhammad Haroon[2]

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Abstract
Renewable energy is essential for boosting economic expansion and lowering carbon dioxide emission (CO_2) to achieve carbon neutrality. This study's objective is to investigate the relationship between the use of renewable energy, economic growth, and CO_2 for South Caucasus Countries. For analysis purposes, time series methods were applied on the panel data. Second-generation unit root and cointegration tests were used to test the cross-sectional dependence. Afterward, panel causality and panel VAR techniques were performed to examine the relationship between the variables. Based on feedback hypothesis, results of our causality analysis revealed a bidirectional causality relationship between growth and renewable energy consumption. Moreover, we revealed unidirectional causality from CO_2 to renewable energy and from growth to CO_2 emission. We also found that the effect of a shock in renewable energy on growth is increasing, and on CO_2, it is decreasing implying that renewable energy consumption will trigger growth and have a reducing effect on CO_2 emissions. We portrayed significant workable implications for policymakers, regulation bodies, companies, stakeholders, and managers. Results from this study should be extrapolated with caution since their applicability is limited to the South Caucasus Countries. In addition, the research heavily depends on summaries, which may obscure regional differences. In the future, researchers may want to dig deeper into the data and examine the subtle effect of renewable energy policy nationally. Moreover, including socio-economic aspects and technical improvements in the research might give a more thorough picture of the dynamics at play.

Keywords Renewable energy · CO_2 · South Caucasus Countries · PVAR · Causality analysis · Growth

Introduction

According to the United Nations Economic Commission for Europe (UNECE), in their most recent regional status report, renewables and energy efficiency present a chance for sustainable and independent energy suppliers in the South Caucasus region. Since 2018, the region has experienced an unheard-of increase in renewables. Compared to worldwide growth tendencies, public and private investments in renewable energy are still small throughout the focal nations. The region's nations require significant investments in renewable energy (Coskuner et al. 2020). Despite a global decline in risk appetite brought on by the conflict in Ukraine, the South Caucasus Countries (SSC) are considered as top destinations for renewable energy investments according to the European Bank of Reconstruction and Development (EBRD). The EBRD had previously committed more than 10 billion euros in the area and wished to maintain its involvement in the three former Soviet republics of the Caucasus as they recovered from the COVID-19 pandemic and war between Armenian and Azerbaijan forces over the Nagorno-Karabakh territory in 2020 (Mohsin et al. 2022). SSC has the potential to become a regional "green" energy powerhouse and contribute to Europe's energy security.

SCC is seen as one of the most viable energy supply options for Russia for the European continent, notwithstanding its tiny

Responsible Editor: Ilhan Ozturk

Azer Dilanchiev
adilanchiev@ibsu.edu.ge

Muhammad Umair
umair.economics.phd@gmail.com

Muhammad Haroon
haroonbaloch007.hb@gmail.com

[1] School of Business, International Black Sea University, Tbilisi, Georgia

[2] Department of Economics, Ghazi University, Dera Ghazi Khan, Pakistan

size and remote distance from the territory of the European Union (Shan et al. 2021). Thus, SCC's potential and initiatives to become a significant exporter of power produced from renewable resources come at a precious time. SCC's green energy exports are expected to contribute to European energy security significantly. As a result, current investments in SCC infrastructure expansion are especially crucial because, in a later stage, the same regional pipeline networks can be used to transport the green hydrogen that the EU will require to shift away from hydrocarbon energy sources. Countries aiming for economic growth must also emphasize the environment while achieving these goals. Interest in the concept of "low carbon and green growth" is increasing significantly yearly. More use of existing energy resources means an increase in greenhouse gases that cause climate change. It is linked to fossil fuels releasing copious amounts of carbon dioxide (CO_2) during combustion (Tang et al. 2023).

The analysis of carbon emissions in 2021 reveals that consumption of energy has been increased exponentially in the production lines if compared with previous years. Based on IEA's extensive energy and zone study, which used the latest public statistics as well as currently accessible resource and socioeconomic data, it was reported that carbon emissions have been raised from 6 to 36.3% gigatonnes (Gt) in 2020. This increase was greatly observed during 2020; however, when COVID hit the globe, the carbon emissions sufficiently reduced to 5.2% worldwide. Noticeably, increase in the energy consumption has reshuffled its state to an increasing point once global markets started normalizing. Moreover, unfavorable weather of South Caucasus Countries and energy market conditions enhanced the amount of coal burned reporting the huge gain in power generation of renewables. Particularly, after the Kyoto protocol was signed in 1997, a strong emphasis was placed on using renewable energy sources instead of fossil fuels. This protocol obliges developed countries to limit carbon dioxide emissions. At the Johannesburg summit held in 2002, the adverse effects of energy on the environment were pointed out. CO_2 emission has been accepted as the primarily responsible pollutant. To overcome this problem, all countries of the world have started to give more importance to renewable energy sources. Researchers also seem to focus on studies that empirically examine the causal relationship between renewable energy consumption, economic growth, and CO_2. The findings also differ due to the differences in the data used in these studies, the number of countries, the period, and the econometric method.

South Caucasus Countries (SCC) are developing countries that have not signed the Kyoto protocol. However, these countries also faced problems such as reducing pollutant emissions, improving energy use, and providing economic development, which developed countries face. South Caucasus region is a prosperous region in terms of renewable energy potential. Due to the SSC's solid renewable energy resource base, the potential market size attracts the attention of international investors and organizations that finance renewable energy production, and energy consumption in this region attracts attention. For sustainable energy supply in the SSC, various sources must produce energy. For example, natural gas and especially renewable energy sources should be given importance so that renewable energy sources reduce energy production costs and prevent environmental pollution. This study examines the relationship between renewable energy consumption, economic growth, and carbon dioxide emissions for SCC using annual data for the period 1990–2021. For this purpose, a 3-variable PVAR model was estimated using the Panel Vector Auto-Regression method. In addition, impulse response functions and variance decomposition analyses were performed to determine the effect of shocks between variables.

The research we conducted has several contributions in light of the aforementioned concerns. Our current research is focused on the nations belonging to the Southern Common Market in order to investigate the interrelationship among renewable energy usage, economic development, and carbon emissions. To the best of our current understanding, this research represents a novel examination of the Small Island Developing States (SIDS) that have not ratified the Kyoto protocol. Despite their non-participation in this international agreement, these nations have shown proactive efforts in addressing carbon emissions by adopting renewable energy sources and fostering economic development. Furthermore, a causality analysis was performed to examine the bi- and uni-directional causation among the variables utilized. Furthermore, we used the PVAR approach, impulse response function, and variance decomposition techniques to further investigate the magnitude of shocks across the variables. In conclusion, we have presented valuable findings that are relevant to both professionals and scholars in the area. These findings shed light on important aspects of the relationship between renewable energy consumption, carbon emissions, and economic development, with the ultimate goal of attaining carbon neutrality.

The findings from our research on causation indicate that there is a bidirectional causality between the increase and use of renewable energy, which aligns with the feedback hypothesis. Furthermore, our analysis uncovered a unidirectional causal relationship from carbon dioxide (CO_2) to renewable energy, as well as from economic development to CO_2 emissions. Additionally, our findings indicate that the impact of a renewable energy shock on economic development exhibits an upward trend, while its influence on CO_2 emissions displays a downward trend. This suggests that the adoption of renewable energy sources not only stimulates economic growth but also contributes to the mitigation of CO_2 emissions. We have shown substantial and practical consequences for policymakers, regulatory agencies, enterprises, stakeholders, and managers. Specifically, the research has examined the consequences for each nation within the South Caucasus Countries individually.

The rest of the study proceeds as follows: The "Literature review and theoretical background" section presents the literature review. The "Data and descriptive statistics" section explains data and variables. Meanwhile, the "Econometric techniques and empirical results" section describes the econometric method and estimations of results. Finally, the study concludes with some important implications.

Literature review and theoretical background

Literature review

The complex relationship between the adoption of renewable energy, the reduction of carbon emissions, and the promotion of economic growth has become a significant focus of investigation within the field of sustainable development discourse. The present research investigated the interrelationship among energy consumption, economic development, and carbon emissions in the South Caucasus region. The researchers used sophisticated econometric techniques to analyze the complex dynamics among the energy industry, the economy, and the environment (Croutzet and Dabbous 2021; De Keyser and Lijesen 2023; Kwilinski et al. 2023). The study conducted a panel causality analysis and identified the presence of bidirectional causation between energy use and economic growth. Moreover, research findings have shown the existence of a unidirectional causal link between energy use and carbon emissions. As previously said, the findings of the study emphasize the need of implementing energy-efficient strategies in order to address environmental degradation and promote economic growth. A study was done by the researchers to investigate the complex interplay between economic growth, energy consumption, and environmental degradation within the specific setting of Armenia. The research used the Ecological Kuznets Curve framework to reveal a curvilinear association between economic growth and environmental degradation, defined by an inverted U-shaped curve. The dynamics of this relationship are significantly influenced by energy use. This study presents empirical findings that support the idea that economic growth first amplifies environmental issues. Nevertheless, the adoption and execution of sustainability initiatives might potentially result in the detachment of economic expansion from the detrimental impact on the environment. To highlight the importance of understanding the dynamics and ramifications of these interconnections, the review is expected to include research that has examined the complicated linkages between real GDP, CO_2 emissions, and energy usage (Magazzino 2016). The findings point unequivocally to the fact that energy utilization is the primary driver of CO_2 releases, which has resulted in the rise of issues related to warming the planet. The E7 nations are under pressure to formulate efficient strategies for energy usage and ecological degradation due to rising greenhouse gases (Tong et al. 2020).

Numerous empirical studies have been conducted to examine the relationship between renewable energy consumption (REC), environmental factors such as CO_2 emissions, and economic growth. These studies can be categorized into three distinct strands of literature. The initial study centers on the impact of renewable energy sources on the advancement of economic growth. In the context of the United States, Ming et al. (2014) demonstrate the significance of renewable energy in fostering economic growth. In the study conducted by Wang et al. (2021), the author investigates the relationship between the economy and renewable energy within a panel of 27 European countries from 1997 to 2007. The findings of their study do not provide evidence supporting a direct correlation between economic growth and renewable energy consumption. Instead, their results support the neutrality hypothesis, suggesting no significant relationship exists between these two variables. This outcome can be attributed, at least in part, to the unequal and inadequate utilization of renewable energy sources in the countries under investigation.

The complex interplay of renewable energy, carbon emissions, and economic growth has received considerable scholarly and public interest owing to its significant implications for sustainable development and the mitigation of climate change. The nations of the South Caucasus, namely Armenia, Azerbaijan, and Georgia, possess a distinctive location that enables them to make valuable contributions to this ongoing discussion. This literature review aims to explore the current body of information, providing insights into the intricate relationship between renewable energy, carbon emissions, and economic development in the South Caucasus area. This study delves into the changing viewpoints, research methods, and policy consequences that underpin this complex association.

The relationship between the implementation of renewable energy sources and economic development has been a topic of contention. Historically, conventional economic frameworks have often prioritized a trade-off between the preservation of the environment and the attainment of economic well-being. Nevertheless, recent research has presented a counterargument, contending that renewable energy sources has the capacity to stimulate economic development while concurrently addressing the issue of carbon emissions. Investments in renewable energy have been shown to have a positive impact on the establishment of local employment opportunities, the improvement of energy security, and the promotion of technical advancements. As a result, these investments play a significant role in facilitating sustainable economic growth. In the context of the South Caucasus region, the incorporation of hydropower, solar, and wind energy sources is anticipated to have a significant impact on the diversification of energy portfolios and the stimulation of economic development.

The urgency to mitigate carbon emissions and address climate change has accelerated the shift towards renewable energy sources. Various research has shown evidence of a negative correlation between the implementation of renewable energy sources and the release of carbon emissions. The need for South Caucasus nations to mitigate their carbon emissions necessitates the use of renewable energy sources as a pivotal approach. The acceleration of this shift may be facilitated by the construction of resilient policy frameworks, conducive regulatory environments, and incentivization of investments in renewable energy. Moreover, the use of renewable energy resources has the potential to strengthen the region's ability to withstand and recover from external energy disruptions and geopolitical influences.

Gaining a comprehensive comprehension of the causal connections between renewable energy, carbon emissions, and economic development is of utmost importance in facilitating well-informed decision-making in the realm of policy. The direction of causality exhibits variability, spanning both unidirectional and bidirectional links, as well as the presence of feedback loops. While several studies emphasize the notion of "green growth," which proposes that the adoption of renewable energy leads to economic development while simultaneously mitigating carbon emissions, other perspectives advocate for the "growth-first" hypothesis, asserting that economic expansion takes precedence over the adoption of renewable energy. The distinctive socio-economic and geopolitical circumstances of the South Caucasus nations have the potential to shape the patterns of causation within this nexus.

Various methodological techniques are used in empirical studies that examine the correlation between renewable energy, carbon emissions, and economic development. These approaches include time-series econometric models, panel data analysis, and vector autoregression (VAR) models. Nevertheless, it is important to acknowledge that these methodologies do have some constraints. The South Caucasus area presents persistent issues in terms of data availability, quality, and harmonization. Furthermore, the presence of endogeneity and omitted variable biases may provide methodological constraints when attempting to accurately capture the underlying causal links within the given framework.

Theoretical background

Renewable energy, which increased worldwide in the 1990s, started to gain momentum towards the 2000s. In 2020, 19.8% of electricity was produced from renewable sources, primarily wind and hydro. By 2030, 35% is anticipated to have been reached. Most of the growth is anticipated to come from solar and wind energy.[1] Global renewable energy installed capacity raised to 9% in 2021. In addition, to meet the Net Zero Scenario, renewable power generation needs to keep growing by more than 12% annually throughout the years 2022–2030. Despite unprecedented increases in renewable capacity, power growth fell far short of the Net Zero Scenario milestone in 2021. All renewable technologies will need to be deployed much more quickly around the globe.[2] The SCC have agreed to reduce carbon footprint in their states in response to the worst consequences suffered by the climate change dynamics and Paris Accord 2016. Realizing that aim will require substituting renewable energy for high-emitting fuels. To accomplish the Paris agenda, Armenia, Azerbaijan, and Georgia must re-evaluate their energy policies and make significant adjustments to their energy mix.

The South Caucasus' most recent policies and developments regarding renewable energy are summarized in this special issue (Zaman and Moemen 2017). Although the growth of renewable energy has great potential in each of the three states, there are numerous political, financial, technological, and social obstacles that prevent the region from quickly and effectively implementing renewable energy policies. Since in our study, we will focus on the relationship between renewable energy consumption, economic growth, and CO_2 for SCC; the change in these variables between the years 1990–2021 has been examined. In Fig. 1, GDP values for selected SCC are discussed.

According to Fig. 1, it is seen that Armenia, Azerbaijan, and Georgia were larger in terms of scale and speed of GDP in the years 2003–2007. Due to the increase in the oil price, Azerbaijan achieved the highest level of GDP per capita in these years. Renewable energy consumption for these countries is shown in Fig. 2. According to Fig. 2, Georgia is the highest renewable energy consumption compared to other countries. Renewable energy consumption has increased since 1994, while in Armenia, there was a decline in renewable energy consumption in this year. On the other hand, it is seen that consumption of renewable energy is at a low level in Azerbaijan due to other alternatives available to Azerbaijan. The CO_2 emission rates, which are the biggest environmental pollutant among the greenhouse gases that cause climate change for these countries, are discussed in Fig. 3.

According to Fig. 3, starting from the independence of the SSC countries, which were almost at the same time, there was a huge decline in GDP, which was linked with the decline in CO_2 emission. Later, although the level of CO_2

[1] Please refer to: https://www.c2es.org/content/renewable-energy/

[2] Please refer to: https://www.iea.org/reports/renewable-electricity

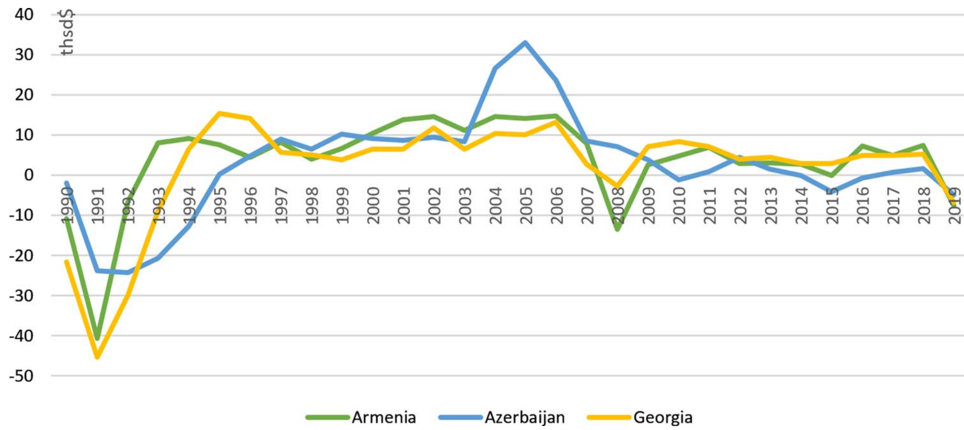

Fig. 1 GDP per capita in SCC Source: World Bank Data

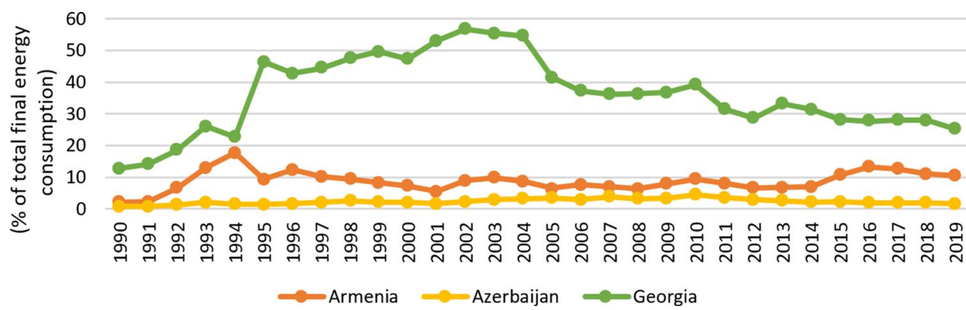

Fig. 2 Renewable energy consumption in SCC Source: World Bank Data

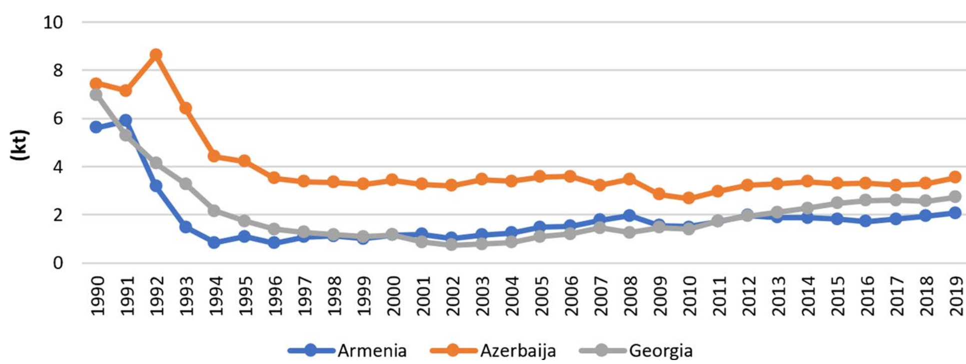

Fig. 3 CO_2 emission (kt) in SCC Source: World Bank Data

emission in these countries is almost the same in the relevant period, in Azerbaijan, it is relatively higher than in other countries, which is linked with the rapid growth of GDP in Azerbaijan. It is possible to observe that the trend of CO_2 per capita is almost the same in the SCC. Furthermore, the study conducted by Pao and Fu (2013) examines the correlation between gross domestic product (GDP), renewable energy consumption (REC), and energy consumption. The findings of the vector error correction model (VECM) indicate the presence of bidirectional causality between gross domestic product (GDP) and renewable energy consumption (REC). Additionally, a unidirectional causality is observed from economic growth to REC and energy consumption (EC) in the long term. In a similar vein, the research outcomes also indicate the significance of GDP in furnishing the necessary resources for achieving sustainable development, as well as highlighting the economic self-sufficiency of Brazil in terms of energy. Hence, the study conducted by Zhou and Li (2022) examines the correlation between renewable energy consumption (REC) and the economic growth of China. The findings of the Granger causality analysis indicate the presence of a bidirectional causal relationship between REC and Chinese economic growth in the long term. However, no empirical support exists for long-term or short-term causality between CO_2 emissions and REC. Modisha et al. (2019) investigates the relationship between economic growth, carbon dioxide (CO_2) emissions, and renewable energy consumption (REC) within the context of the Portuguese economy. The Gaussian mixture model (GMM) analysis findings indicate a statistically significant positive association among the three variables. The Granger causality test reveals a unidirectional causal relationship, indicating causality from renewable energy consumption (REC) to economic growth. In their study, Balsalobre-Lorente et al. (2021) investigate the relationship between renewable energy consumption (REC) and economic growth in Pakistan. They employ the VECM Granger causality technique to analyze this connection. The researchers' findings unveil a reciprocal relationship between the two variables. Ulucak et al. (2020) analyzed the interplay between economic growth, renewable energy consumption (REC), energy consumption, gross fixed capital formation, globalization, trade openness, and urbanization in the context of Iran. The findings indicate that there exists co-integration among all variables, implying the presence of long-term associations between them. Furthermore, the Granger causality test reveals a bidirectional causal relationship between renewable energy consumption (REC), globalization, foreign direct investment (FD), and actual gross domestic product (GDP).

The second study emphasizes examining the effects of renewable energy sources on the overall state of the environment. The scholarly investigations examining the relationship between renewable energy consumption (REC) and carbon dioxide (CO_2) emissions have yielded varying outcomes. Bai et al. (2020) analyzes two empirical models that examine the relationship between renewable energy consumption (REC) and income in a panel of emerging economies. The study reveals a positive and statistically significant effect of per capita GDP growth on per capita REC. In the context of these economies, it has been observed that a 1% increase in GDP per capita leads to an approximate 3.5% increase in per capita renewable energy consumption (REC) over the long term. According to Tola and Lonis (2021), empirical evidence suggests that in the context of European and Eurasian countries, non-renewable energy (NRE) exhibits an adverse effect on gross domestic product (GDP) growth while concurrently contributing to elevated levels of carbon dioxide (CO_2) emissions. The impact of renewable energy (RE) on the economic growth rate, as measured by gross domestic product (GDP), is beneficial.

Furthermore, Payne (2012) examines the relationship between renewable energy consumption (REC), real gross domestic product (GDP), and carbon dioxide (CO_2) emissions. The study demonstrates that implementing renewable energy legislation and policies since 1978 has substantially and positively impacted REC. The findings indicate that carbon dioxide (CO_2) emissions have influenced the renewable energy capacity (REC) favorably. In a separate investigation, Li et al. (2021) employs an autoregressive approach known as structural vector autoregression (SVAR) to analyze the relationship between renewable energy consumption (REC), real gross domestic product (GDP), and carbon dioxide (CO_2) emissions. The results of their study demonstrate that the rise in renewable energy (RE) is associated with a reduction in per capita carbon dioxide (CO_2) emissions.

The third objective of this study centers on conducting a comprehensive review of existing literature about the interplay between renewable energy consumption (REC), economic growth, and environmental quality. In their study, Gyamfi et al. (2018) investigate the correlation between carbon dioxide (CO_2) emissions, the consumption of nuclear and renewable energy, and the real gross domestic product (GDP) within the context of the United States. The findings of the Granger causality analysis indicate the presence of a one-way causal relationship between nuclear energy to CO_2 emissions. However, no significant association between REC and CO2 emissions is observed. Ding et al. (2023) examines the correlation between carbon dioxide (CO_2) emissions, renewable energy consumption (REC), real gross domestic product (GDP), and population density within the G7 countries. The study reveals that GDP, REC, and population density are significant factors contributing to CO_2 emissions.

Furthermore, the empirical study by Siagian et al. (2017) investigates the influence of income on emissions within emerging economies from 1990 to 2013. The findings indicate a direct correlation between income levels and carbon dioxide (CO_2) emissions. A divergence exists among models regarding endorsing the Environmental Kuznets Curve (EKC) hypothesis, which postulates a curvilinear association between income levels and environmental deterioration, characterized by an inverted U-shaped pattern. U.S. Energy Information Administration (2014) conducted a study investigating the causal relationships between emissions, renewable energy consumption (REC), and economic growth in 16 Asian countries. The findings of their study indicate the presence of bidirectional causality between renewable energy consumption (REC), gross domestic product (GDP), and emissions in the long term. The relationship between oil prices, renewable energy consumption (REC), carbon dioxide (CO_2) emissions, and gross domestic product (GDP) within the member countries of the Organisation for Economic Co-operation and Development (OECD) has been analysed. The empirical findings indicate a quadratic relationship between emissions and economic growth in the long run, thus supporting the hypothesis of the Environmental Kuznets Curve (EKC). The findings of Granger's causality analysis indicate the presence of a reciprocal association between emissions and renewable energy consumption (REC) in both the short term and long term. In a recent study conducted, it was discovered that the impact of REC plays a significant role in elucidating the degree of sustainable development observed in the countries under examination. Reducing CO_2 emissions relies heavily on the augmentation of human capital, rendering it a crucial factor in REC.

Aragon-Briceño et al. (2022) conducted a study that specifically investigated the potential of renewable energy

Table 1 Source of data

Variable	Abbreviation	Definition	Source
Renewable energy	REC	% of total final energy consumption	World Bank Data
Economic growth	GDPPC	GDP per capita	World Bank Data
Environmental quality	CO2	CO_2 emission(kt)	World Bank Data

in the South Caucasus region, particularly emphasizing Armenia. The authors analyzed the interrelationships among renewable energy consumption, economic growth, and CO_2 emissions. The study employed an autoregressive distributed lag model to reveal a positive correlation between renewable energy consumption and economic growth. This observation highlights the capacity of renewable energy sources to foster economic growth while concurrently mitigating the carbon emissions associated with energy generation. Ramli et al. (2015) made significant contributions to the field of panel analysis by providing valuable insights into the causal dynamics between energy consumption, economic growth, and carbon emissions in the South Caucasus Countries. The results of their study revealed a one-way causal relationship, with energy consumption having a causal effect on economic growth and economic growth having a causal effect on carbon emissions. The significance of these causal connections underscores the necessity for well-designed policy frameworks that enable the shift towards sustainable energy systems while upholding economic progress. The study conducted by involved a comprehensive investigation into the interrelationships among carbon emissions, energy consumption, and economic growth in the context of Armenia. The multivariate analysis conducted in their study provided empirical evidence supporting the substantial influence of economic growth and energy consumption on carbon emissions. The reciprocal nature of this relationship underscores the notion that achieving economic prosperity requires careful oversight of energy resources to mitigate the adverse effects of high carbon emissions. In summary, the studies mentioned above collectively emphasize the complex interconnections between adopting renewable energy, reducing carbon emissions, and promoting economic growth in the South Caucasus Countries. The findings underscore the significance of customized policy interventions that facilitate the shift towards renewable energy sources, promoting economic expansion while mitigating environmental deterioration. The studies presented provide valuable empirical insights that can serve as foundational knowledge for the development of sustainable strategies in the South Caucasus region and beyond.

Despite the helpful insights offered by previous studies, there still needs to be significant gaps in our understanding of the connection between renewable energy, economic development, and carbon emissions in the South Caucasus Countries:

1. The available research may only partially represent the specific socioeconomic and geopolitical circumstances of the South Caucasus area since it mainly focuses on industrialized states.
2. The quality and relevance of conclusions may be constrained by the absence of research using sophisticated econometric methodologies adapted to the complexities of the South Caucasus panel data.
3. Since renewable energy adoption in the South Caucasus may vary significantly from worldwide trends, in-depth studies of regional policy frameworks and socioeconomic aspects are required. Recent events and policy shifts in the area may need to be adequately captured by the time frame of previous research, calling for an updated study.
4. The interplay between renewable energy, economic development, and carbon emissions, as well as the feedback loops and nonlinear dynamics that may exist there, is mostly uncharted.

Future studies should fill these knowledge gaps to comprehend sustainable development in the South Caucasus better.

Data and descriptive statistics

In this study, the relationship between renewable energy consumption, economic growth, and carbon dioxide emissions for three South Caucasus countries (Armenia, Azerbaijan, and Georgia) using annual data for the period 1990–2021 was examined. Information on the data used in the application is summarized in Table 1. In addition, the logarithmic forms of the variables were examined in the study.

While examining Table 2, it is seen that while the panel average value of carbon emission per capita is 2.599 tons, the country with the highest average annual carbon emission per capita in the panel is Azerbaijan, and in the Armenia and Georgia are almost the same level average annual carbon emission per capita (1.819 and 1.892). While the panel standard deviation of the annual average carbon emission value per capita has a high value with 1460 tons, Azerbaijan is the country with the largest standard deviation of the

Table 2 Descriptive statistics

	Statistic	RE	EQ	GDPPC
Armenia	Mean	8.749	1.819	3.722
	St. Dev.	3.184	1.173	11.065
	Min	2.118	0.814	−40.744
	Max	17.763	5.902	14.695
Azerbaijan	Mean	2.324	3.917	2.760
	St. Dev.	0.869	1.460	12.663
	Min	0.722	2.685	−24.257
	Max	4.45	8.617	33.030
Georgia	Mean	36.824	1.892	2.600
	St. Dev.	11.454	1.037	12.504
	Min	14.119	0.744	−45.325
	Max	56.760	5,275	15.310
Panel	Mean	15.698	2.599	2.758
	St. Dev.	16.338	1.628	12.180
	Min	0.722	0.744	−45.325
	Max	56.760	8.617	33.030

annual carbon emission per capita; it is seen that the country with the smallest standard deviation is Georgia. Descriptive statistics of other variables are shown in Table 2.

Econometric techniques and empirical results

Econometric techniques

The study focused on the dynamic causality between economic growth, renewable energy consumption, and environmental quality. The PVAR model was estimated with the Generalized Method of Moments (GMM), and impulse-response and variance decomposition analysis were performed. Here, firstly, stationarity states and integration levels were determined for the series examined by panel unit root and panel cointegration analysis, and the existence of a long-term relationship between the variables was investigated.

Based on the traditional EKC hypothesis and following the works of Apergis and Payne, Pao and Tsai who used carbon emission as a determinant factor following model was developed:

$$CO2 = f(RE, GDPPC) \tag{1}$$

Based on the function (1) model can be written as:

$$LnCO2_{it} = \alpha_{it} + \alpha_{1t} LnRE_{it} + \alpha_{2t} LnGDPPC_{it} + e_{it} \tag{2}$$

This model is an extended version of EKC model with energy consumption. To better interpret the annual changes, the natural logarithm of all variables was taken. In the model, $i = 1,...,N$ represents each country in units. $t = 1,...,T$ represents the time period. In the model, α_{it} variable takes a positive value since per capita income is expected to move in the same direction as carbon emissions, and α_{1t} have negative values because income reduces carbon emissions when it reaches a certain point in the long run. It is expected that the α_{2t} value will take a positive value since its energy consumption is obtained from fossil-based fuels that increase carbon emissions to a large extent. Finally, the error term e_{it} is assumed to be independent, zero mean, and constant variance.

Cross-dependency and stationarity analysis

In the context of panel data analysis, it is common practice to assess the presence of unit roots using two distinct test frameworks. The unit root tests for determining the stationarity of variables may be categorized into two generations. The primary distinction between these two cohorts is in the existence of cross-sectional dependency, which refers to the connection seen among individual units. When cross-sectional dependency is not present, researchers often use first-generation testing. However, in cases when cross-sectional reliance exists, second-generation tests are utilized to determine which generation unit root tests should be examined. Therefore, it is important to first assess the presence of cross-sectional dependence. The consideration of cross-sectional dependency between the series has a considerable impact on the obtained findings. The CD (cross-section dependence) test, which is extensively suggested and used, is a prominent method employed in the examination of cross-section dependence. The measurement of the CD test is determined using the following formula:

$$CD = \sqrt{\frac{1}{N(N-1)} \sum_{i=j}^{N-1} \sum_{i=j+1}^{N} \left(Tp_{ij}^2 - 1 \right) \sim N(0,1)} \tag{3}$$

where ρij is the simple correlation coefficient between the residuals obtained from the least squares estimation of each equation. Pesaran et al. (2004) CD test results are summarized in Table 3.

According to the results summarized in Table 3, it is seen that the basic hypothesis was rejected at the 1% significance level for all variables. Accordingly, it was decided that there is a cross-section dependency. In this case, unit root analyses of the series can be examined with the CADF (Cross-Sectionally Augmented Dickey Fuller) test developed by Su et al. (2021), which is one of the second-generation tests that considers the cross-sectional dependence. The CADF test uses the familiar ADF regression extended with delayed cross-section averages. As a result of his Monte

Table 3 CD test results

Variables	*T* statistics	*P* value
LnCO2	30.11	0.000
LnRE	32.44	0.000
LnGDPPC	18.23	0.000

Alternative hypothesis: cross-sectional dependence

Table 4 Unit root test results

Variables	*T*-bar statistics	*z*-bar statistics	*P* value
	Level (constant and trend)		
LnCO2	−2.732**	−4.610**	0.032
LnRE	−2.474	−0.776	0.177
LnGDPPC	−2.272	−0.125	0.306
First Difference (constant and trend)			
LnCO2	−3.660***	−4.610***	0.000
LnRE	−3.605***	−4.404***	0.000
LnGDPPC	−3.017***	−2.205***	0.004

The deterministic specification of tests includes constant and trend. The basic hypothesis is that there is a unit root; the series is not stationary. *** and ** indicate significance according to 1% and 5% critical values, respectively. Critical values are based on the paper of Pesaran (2007)

Carlo studies, Pesaran (2007) revealed that the CADF test is valid in both T>N and N>T cases.

The CADF regression equation can be written as $\Delta Y_{it} = a_i + b_i Y_{i,t-1} + c_i Y_{t-1} + d_i \Delta Y_t + \epsilon_{it}$. Here, $\Delta Y_{it} = Y_{it} - Y_{i,t-1}$ and $Y_t = N^{-1}\sum_{i=1}^{N} Y_{it}, Y_t$, in the whole cross section, represent the mean of observations (N) over time (T). As in the classical ADF test, the equation is expanded in the presence of autocorrelation. In this test, the unit root hypothesis is tested depending on the estimated t ratio of b_i in the CADF regression model. The *t* ratio is denoted as t_i (*N*,) and each *i* of the panel and is obtained from each CADF model for the unit. The test statistic is calculated as $CIPS(N,T) = N^{-1}\sum_{i=1}^{N} t_i(N,T)$. The results of the Pesaran (2007) CADF unit root test for the variables we discussed are summarized in Table 4.

According to the results in Table 4, it is seen that all series analyzed are not stationary at the level of containing unit root (according to 1% significance level). All series are first-order stationary, that is, I(1). Co-integration analysis was performed to examine the existence of a long-term relationship between the variables whose integration levels were determined. In the study, panel cointegration tests, developed by the second generation cointegration test that allows cross-sectional dependency, were used. In case of cross-section dependency in the application of the test, the bootstrap probabilities must be calculated.

Table 5 Panel cointegration test result (Westerlund 2007)

Cointegration statistics	Test statistics		*P* values
Group average	*G*τ	−2.474	0.310
	*G*α	−3.215	1.000
Panel	*P*τ	−5.377	0.825
	*P*α	−7.368	0.808

The basic hypothesis: there is no cointegration. Regression includes constant and trend

Panel cointegration analysis

The panel cointegration test proposed by Westerlund (2007) consists of four test statistics. Two of these are test statistics based on group means (*G*τ and *G*α), and the other two are panel-based (*P*τ and *P*α). For the test, the delay (lags) and leading (leads) values must be determined. Westerlund (2007) used the method in determining these values in his original article. The purpose of the tests is to investigate the presence of cointegration by deciding whether each unit has its own error correction. Westerlund (2007) test results are given in Table 5.

When the results summarized in the table are examined, it is seen that the basic hypothesis of no cointegration by all four test statistics could not be rejected. According to these results, it was decided that there is no cointegration between the horizontal section units that make up the panel. Therefore, it can be said that the variables examined according to the results of the Westerlund (2007) test do not act together in the long run (Zhang et al. 2022). Panel Granger causality analysis was performed to examine the causality relationship between the variables. Analysis results are summarized in Table 6.

When Table 6 is examined, it is seen that there is a bidirectional relationship (GDPPC ↔ EQ) between growth and environmental quality. In addition, unidirectional (environmental quality → renewable energy, and renewable energy consumption → economic growth) causalities were found.

Panel VAR model

The PVAR model was estimated to see the relationship between growth, renewable energy consumption, and carbon dioxide emissions. In our study, PVAR analysis was handled in three parts. In the first part, the PVAR model was estimated with GMM to explain the relationship between the variables. Then, impulse response functions and variance decomposition analyses were performed to determine the effect of shocks between the variables. It is stated that

Table 6 Granger causality test results

Causality direction	$\chi 2$ test statistics	*P* values	Result
ΔLnCO2 →ΔLnGDPPC	4.5152	0.000	Granger Cause
ΔLnCO2 →ΔLnRE	2.3117	0.002	Granger Cause
ΔLnRE→ΔLnCO2	-0.691	0.489	Does not Granger Cause
ΔLnRE →ΔLnGDPPC	7.0514	0.0132	Granger Cause
ΔLnGDPPC →ΔLnRE	0.56017	0.5754	Does not Granger Cause
ΔLnGDPPC →ΔLnCO2	14.269	0.000	Granger Cause

The basic hypothesis : Granger is not the cause

Table 7 PVAR model estimates

	Δ $LnCO2_{t-1}$	Δ $LnRE_{t-1}$	Δ $LnGDPPC_{t-1}$	Δ $LnCO2_{t-2}$	Δ $LnRE_{t-2}$	Δ $LnGDPPC_{t-2}$
Δ$LnCO2_t$	−0.0141	−0.0108	−0.1517	0.0257	−0.0320	−0.0005
	(0.1161)	(−1,1614)	(−2.0086)	(0.3402)	(−1.1845)	(−0.0086)
Δ$LnRE_t$	0.1327	−0.0253	−0.2682	0.0164	0.0377	−0.3101
	(0.4435)	(−0.4465)	(−0.6445)	(0.0608)	(0.5305)	(−1.0168)
Δ$LnGDPPC_t$	0.2224	0.0105	−0.2674	−0.0145	0.0134	−0.1303
	(1.1106)	(1.0175)	(−1.4250)	(−0.2018)	(1.3750)	(−1.5157)

The three-variable PVAR model was estimated by the GMM method. The values given are the coefficients obtained as a result of the regression of the lags of the variables in the column and the variable in the row. Values in parentheses are *t* statistics. The lag length is 2 according to the AIC criterion

variance decomposition determines the most effective variable for macroeconomic size and can be considered as useful tool for policy ramifications (Wongsapai et al. 2016) and suggested removing fixed effects from the model by means of averaging. Since this process does not harm the externality relationship between the lagged values of the estimators and the transformed variables, the estimation of the PVAR model is made with the GMM approach, which uses the lags of the estimators as a tool variable. The two delayed PVAR models to be estimated in our study are defined as $Y_{it} = \Gamma_0 + \Gamma_1 Y_{it-1} + \Gamma_2 Y_{it-2} + \mu_i + \varepsilon_{it}$. Here, μ*i* is the unit effect and *Yit* is the vector of variables. In line with the explanations above, the estimations were estimated with GMM, which eliminates the fixed effects in the model, and the results are summarized in Table 7.

Key coefficients indicating lagged correlations between carbon dioxide emissions, renewable energy consumption, and economic growth are revealed by the PVAR model carried out using the Generalized Method of Moments (GMM). Significantly, a one-unit rise in delayed economic growth is related to a 0.1517-unit drop in current carbon emissions, as shown by the coefficient of −0.1517 for LnGDPPC at lag 1. The *t* statistics in parenthesis show the significance of these coefficients; for example, the value −2.0086 for LnGDPPC at lag 1 indicates a statistically significant effect. Moreover, the lag length of 2, calculated by the AIC criteria, emphasizes the inclusion of two earlier periods in the model. The findings provide light on the interplay between carbon emissions, renewable energy use, and economic development in the examined setting, as well as the impact of lagged factors.

The PVAR results provide information about the direction of the relationship between the variables used in the model. According to the results in Table 7, when the growth variable is considered as the dependent variable, the renewable energy variable takes a positive value at different lag lengths. In other words, the coefficients of the two lags 0.0105 and 0.0134, respectively, show that the impact of a shock in renewable energy on growth is positive. This result can be interpreted as renewable energy consumption will trigger growth. When carbon dioxide emission is considered as the dependent variable, it is observed that the effect of renewable energy on carbon dioxide emission is negative in both delays. In other words, the coefficients of −0.0108 and −0.0320, respectively, can be said to have a decreasing effect on the increase in renewable energy on carbon dioxide emissions.

The VAR approach also allows the use of impulse-response functions. Basically, impulse response function allows for the potential endogeneity in the data and in the variables which ultimately reflects 1% standard error shock in the variables determining endogeneity in the dataset (Akadiri and Adebayo 2022). Estimated action-response functions are given in Fig. 4. Impulse response functions are a practical way to see the behavior of the series under consideration against shocks. According to the results in Fig. 4, while the response of renewable energy to a one-unit

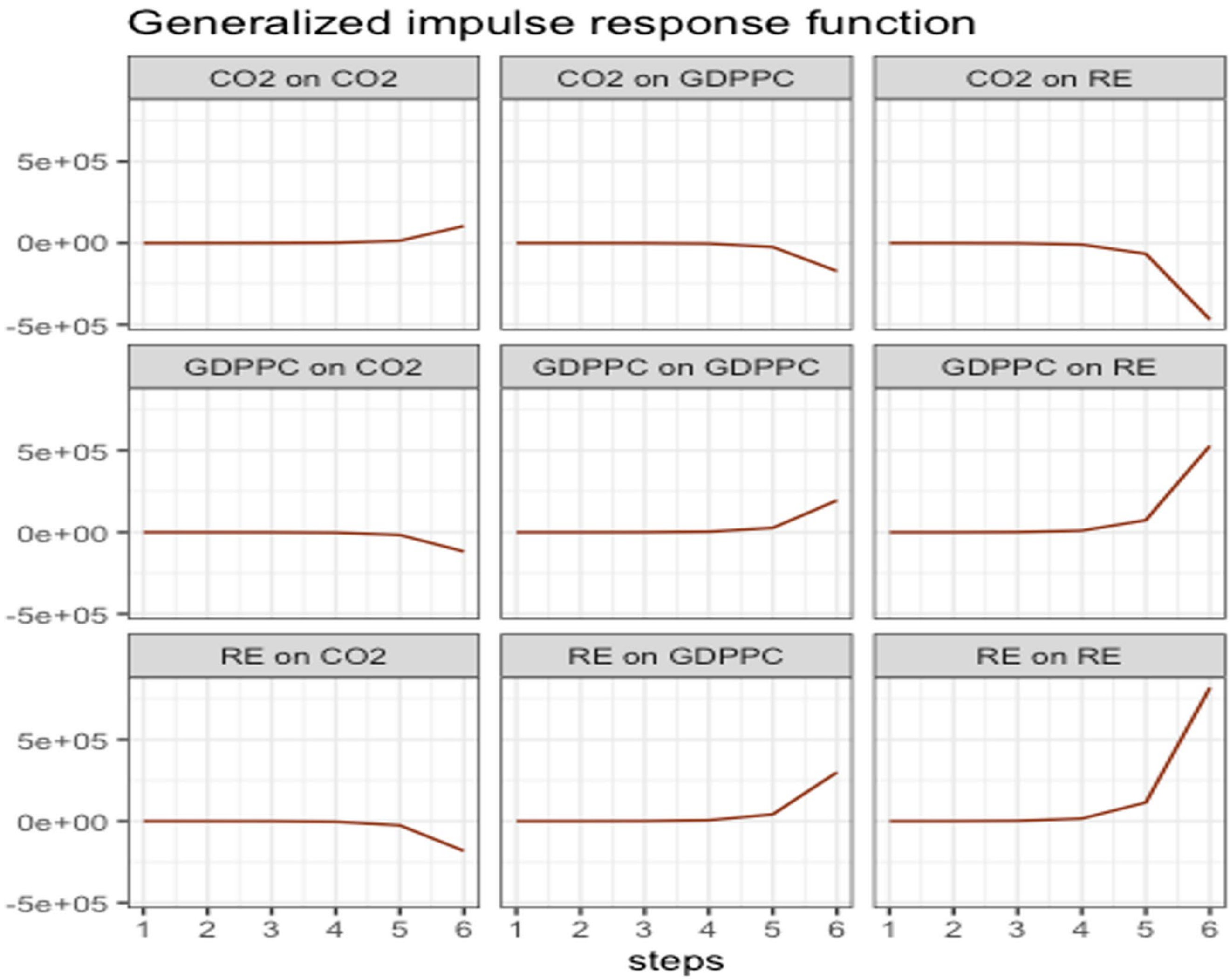

Fig. 4 Impulse-response function

shock occurring in the error term of the growth variable is negative, the response of carbon dioxide emissions is negative in the first periods and positive in the following periods. The response of both renewable energy and growth to a shock in carbon dioxide emissions is initially positive and then negative. The reaction of growth to a one-unit shock in renewable energy is negative at first, then positive in the following periods, and the reaction of carbon dioxide emissions is negative. In other words, it can be said that the increase in renewable energy consumption will have a reducing effect on carbon dioxide emissions.

Finally, variance decomposition analysis was performed in order to determine the sources of changes in the variance of the variables we discussed in the PVAR model. The variance decomposition obtained from the moving averages section of the VAR model expresses the sources of shocks in the variables themselves and in other variables as a percentage. It shows how many percent of a change that will occur in the variables examined is due to itself and what percent is due to other variables. It is asserted that variables act exogenously if maximum number of variables react to their own shocks. The variance decomposition analysis results are summarized in Table 8.

According to the variance decomposition results, approximately 88% of the renewable energy variations are explained by its historical values, while approximately 12% is determined by growth. 90% of the changes in growth are explained by itself, 2% by renewable energy, and 8% by carbon dioxide emissions. Finally, about 83% of the changes in CO_2 emissions are explained by their historical values, 8% by growth, and 7% by renewable energy. The second variable affecting growth was determined as carbon dioxide emissions, followed by renewable energy.

Discussion

The study's empirical findings provide insights into the interplay among economic growth, renewable energy consumption, and carbon dioxide emissions within the South Caucasus Countries. The econometric analysis utilized sophisticated methodologies, including the Panel Vector Autoregression (PVAR) model, impulse-response functions, and variance decomposition analysis. The findings provide significant insights into these pivotal variables' causal interdependencies and enduring relationships. The utilization of econometric methodologies in this research has facilitated a thorough comprehension of the intricate interconnections among economic growth, renewable energy utilization, and environmental sustainability. The PVAR model, estimated using the Generalized Method of Moments (GMM), revealed significant findings regarding the interconnections. Incorporating renewable energy consumption as an additional variable within the framework of the Extended Environmental Kuznets Curve (EKC) model has contributed to a more comprehensive understanding that considers both economic and environmental aspects (Abbasi et al. 2022).

Using panel unit root and panel cointegration analyses was crucial in determining the degree of integration among the variables. The presence of cross-sectional dependence was considered by employing the CD (cross-section dependence) test. This methodology facilitated a comprehensive evaluation of the stationarity of the series and significantly contributed to enhancing the precision of subsequent analyses. The utilization of the CADF (Cross-Sectionally Augmented Dickey-Fuller) test, which is a second-generation unit root test, allowed for the consideration of cross-sectional dependence and yielded additional understanding regarding the stationary nature of the variables (Zheng et al. 2023).

The findings derived from the panel cointegration analysis revealed the absence of a sustained association among the variables under investigation, thereby implying their lack of co-movement over time. As mentioned earlier, the result highlights the necessity of implementing specific policies that aim to tackle the interplay between economic growth, renewable energy consumption, and carbon dioxide emissions in the South Caucasus Countries (Adedoyin et al. 2023). The Granger causality analysis unveiled compelling causal connections among the variables. The study revealed a bidirectional causal relationship between economic growth and environmental quality, suggesting a mutually reinforcing association. The study identified unidirectional causal relationships between environmental quality and renewable energy consumption and between renewable energy consumption and economic growth. As mentioned earlier, the findings underscore the possibility of implementing policy interventions that capitalize on causal connections to bolster sustainability and foster economic development. This study recognizes the increasing significance of sustainable energy practices in influencing the correlation between economic growth and environmental quality by integrating renewable energy consumption into the conventional Environmental Kuznets Curve (EKC) model. Utilizing the PVAR model, in conjunction with GMM estimation, facilitates a comprehensive examination of the interplay between these variables throughout the temporal dimension (Shakeel et al. 2016).

The conducted panel unit root and cointegration analyses in this study address fundamental inquiries regarding stationarity and long-term relationships. Incorporating the assessment of cross-sectional dependence using the CD test enhances the precision of the derived conclusions. The CADF test, which incorporates the consideration of cross-sectional dependence, enhances the reliability of the findings in the context of potential endogeneity.

The Granger causality analysis offers valuable insights into the direction of influence among the variables. The existence of a bidirectional causal relationship between economic growth and environmental quality implies the presence of a feedback mechanism whereby economic prosperity has the potential to promote environmental preservation. Conversely, environmental preservation can contribute to economic growth. The presence of one-way causal relationships from environmental quality to renewable energy consumption and from renewable energy consumption to economic growth suggests potential opportunities for policy intervention. The results of this study indicate that the promotion of renewable energy consumption has the potential to reduce carbon emissions and stimulate economic growth.

Using impulse-response functions and variance decomposition analysis provides a dynamic outlook on the system's behavior in response to external shocks (Lee et al. 2023). The empirical evidence of the adverse consequences of renewable energy shocks on carbon dioxide emissions highlights the capacity of renewable energy adoption to facilitate the mitigation of carbon emissions, thereby supporting international endeavors to achieve sustainable development. It is imperative to recognize specific constraints within the scope of this study. The analysis uses a panel dataset, potentially leading to the omission of country-specific characteristics and peculiarities. Furthermore, the causality analysis captures the connections between variables, yet it needs to understand the underlying mechanisms that drive these relationships comprehensively. Additional investigation could delve into these mechanisms. The examination of impulse-response functions and variance decomposition analysis yielded additional insights regarding the dynamics of the variables' reactions to shocks. The correlation between renewable energy shocks and reducing carbon dioxide emissions is consistent with the worldwide necessity to shift towards sustainable energy sources to address environmental degradation (Mngumi et al. 2022).

Table 8 Impulse-response functions result

Variable	LnEQ	LnRE	LnGDPPC
LnCO2	0.7282	0.0831	0.0664
LnRE	0.0012	0.9875	0.0203
LnGDPPC	0.0641	0.0313	0.7822

The obtained variance decomposition results are based on impulse-response results. The percentage of changes in the variables in the row are explained in the columns. Results are for 6 periods ahead

The empirical analysis presented within this study highlights the intricate relationship between economic growth, renewable energy consumption, and carbon dioxide emissions in the South Caucasus Countries. The application of sophisticated econometric methodologies has resulted in significant findings regarding the causal connections, stationary patterns, and reactions to disturbances among these variables. The results emphasize the possibility of implementing strategic policy measures to stimulate economic growth while encouraging adopting sustainable energy practices and maintaining environmental quality within the region. This research makes a valuable contribution to the existing knowledge on sustainable development. It offers insights to inform policymakers in developing effective strategies for the South Caucasus Countries and other regions.

This study's Granger causality evaluation shows that GDP per capita growth and carbon dioxide levels are linked in both directions, indicating a mutually reinforcing cycle. According to the EKC theory, supported by this data, economic development and environmental deterioration have an inverse U-shaped connection (Adebayo et al. 2023). This two-way causation suggests that when economic growth improves, sustainability will also improve. This confirms that more developed countries can afford to invest in greener technology and environmental policies.

The research shows that there is a link, although a unidirectional one, between rising REC and rising GDP, as well as rising environmental quality. This result is by the prediction made by Shao et al. (2022), who states that individuals may be more likely to embrace renewable energy sources as they become more aware of the environmental effects of conventional energy sources. Based on these findings, switching to renewable energy sources directly contributes to a more prosperous economy. This research expands on earlier studies showing that renewable energy positively affects economic development (Hussain et al. 2023).

The Panel VAR model and impulse-response functions shed some light on the dynamic interactions between the variables. According to the model results, switching to renewable energy boosts economic growth. Sustainable development and green economies are rising worldwide, and our research supports such movements. Increased use of renewable energy sources may mitigate climate change and reduce carbon emissions because of the adverse impact renewable energy shocks have on carbon dioxide emissions. Shocks in the renewable energy sector are evidence of this.

With the aid of panel unit root and cointegration analysis, it may be feasible to acquire a better understanding of the stationarity and the long-term correlations among the variables. Without accounting for cointegration, the variables' behavior over time diverges. This study highlights the need for specialist and context-specific policies in the South Caucasus due to the intertwined nature of economic development, renewable energy use, and carbon dioxide emissions.

The variance decomposition analysis makes it possible to acquire a knowledge of the reasons for changes in the variables. Evidence of the path dependence inherent in energy decision-making may be seen in the prominence of historical values in explaining changes in the utilization of renewable energy sources. Another example of the self-reinforcing nature of economic development is the substantial impact growth has on itself. Policymakers may use the results to learn more about the causes affecting the variables.

This study fits in with and adds to others that have examined the relationship between economic development, renewable energy use, and ecological sustainability. Adding renewable energy consumption to the conventional EKC model broadens the picture and highlights the significance of clean energy for long-term sustainability (Umair et al. 2023). Consistent with the growing body of literature on the two-way effects of economic activity and environmental consequences, we show that economic expansion may have positive and negative effects on environmental quality.

Mentel et al. (2022) and Zhang et al. (2023) discovered comparable findings in their study, indicating that renewable energy helps economic growth, and environmental issues are crucial in determining energy choices. This study's results are in line with those of similar research. A complete picture of the temporal dynamics of the relevant variables is obtained when advanced econometric methods like the Panel VAR model, impulse-response functions, and variance decomposition are included in the analysis. As a consequence, we are better able to draw valuable conclusions from the data.

These results support the case for tailoring strategies to individual communities to advance sustainable development (Akadiri and Adebayo 2022; Yi et al. 2023). They also highlight the need to consider unique national features and local contexts when crafting policies. This study adds to the expanding body of work that aims to untangle the intertwined dynamics of economic development, renewable energy use, and environmental quality. It does this by shedding light on important issues for researchers and policymakers alike.

Conclusion and policy recommendations

In this study, the existence of a dynamic and causal relationship between renewable energy consumption, growth, and carbon dioxide emissions was investigated using annual data for the period of 1990–2021 for three South Caucasus Countries (Armenia, Azerbaijan, and Georgia). Time series methods applied for panel data were used in the study. Second-generation unit root and cointegration tests were used because of the cross-sectional dependence. Panel causality and panel VAR analysis were performed to examine the relationship between the variables.

According to the causality analysis results, a bidirectional causality was found between growth-renewable energy consumption. This result shows that the feedback hypothesis is valid between renewable energy consumption and growth. In addition, it has been observed that there is unidirectional causality from carbon dioxide emission to renewable energy and from growth to carbon dioxide emission.

When the results are evaluated in general, it is seen that the most important determinant of growth is itself when viewed from the point of view of the periods and countries. It has been found that the effect of a shock in renewable energy on growth is increasing, and on carbon dioxide emissions, it is decreasing. This result can be interpreted as renewable energy consumption will trigger growth. In addition, it can be said that the increase in renewable energy consumption will have a reducing effect on carbon dioxide emissions.

Policy recommendations

Renewable energy sources may improve the sustainability of the energy production by lowering reliance on outside players and CO_2 from imported petroleum products. Lowering reliance on imports from Russia in specifically may help to balance out the stark imbalance in their relationship. Massive intentions have not materialized into real projects; therefore, the advancement of renewable energy has been restricted thus far. Global attention in the growth of the renewables field in Armenia seems to have been effective; however, it has mainly been focused on the acquisition of already-existing hydroelectric plants. The reproduction of the Russian owned state companies' supremacy in the hydrocarbon and nuclear industries by private Russian enterprises in the renewables industry might diminish the entire look for provider rebalancing, even though it might theoretically help, and can guarantee the continuation of direct connections among two countries at diverse scales of the energy infrastructure. Currently, two projects have huge potential from the development of renewable energy perspective; they are the Voroton cascade that was built to produce hydroelectric power and provide irrigation water. Another project is Masrik solar project that offer a different—and more diversified—model for simultaneously growing the renewable energy sector reduce CO_2 emission at the same time chance to reduce reliance on Russia. The implication to prioritize the construction of renewable energy projects like the Voroton cascade and Masrik solar project is in line with SDG 7, the goal of which is to provide everyone with access to energy that is both cheap and clean. Armenia can help reduce carbon dioxide (CO_2) emissions and lessen its energy dependence on Russia by expanding its renewable energy industry.

Azerbaijan's goal is to cut GHG emissions by 35% from 1990 to 2030 in accordance with the Paris Agreement. The most recent official data on GHG emissions is from 2017, when emissions were 38% lower than they were in 1990 and 75% of all emissions came from the energy sector. By 2030, the Azerbaijani government wants to see a 30% rise in the proportion of renewable energy sources in the nation's total energy production. As part of ongoing reconstruction and rebuilding efforts, the Azerbaijani government has prioritized the creation of a green energy area in the Karabakh region. In the liberated areas, four hydroelectric power stations have already become functional, following with 5 more. Azerbaijan intends to completely convert the area into a green energy zone by 2050 and cut CO_2 emissions by 40%. Despite these ambitious plans, it is recommended that the banking sector should focus on making capital easily accessible for renewable projects and at the same time stimulate private domestic investors to invest in renewable energy. Another recommendation is to increase awareness among the public for expanding the use of renewables in Azerbaijan, where low domestic oil prices one of the main challenges on the transition for renewable energy. Azerbaijan's plan to reduce greenhouse gas emissions and boost the use of renewable energy sources is consistent with SDG 13, which calls for immediate action to tackle climate change. The establishment of a green energy zone and the subsequent transformation of freed regions into a green energy zone are both steps in the direction of environmental sustainability.

Georgia, the third state of SCC, bears substantial renewable potential in terms of hydropower and new plant construction to promote renewable energy consumption. It is worth noting that Georgia is considered as an ideal location for construction of these hydropower plants due to its geological vicinity and positioning on the globe as there are mountains along with vast flowing rivers. The rationale of using the renewable energy sources such as hydropower plants, ensures that these are naturally available resources which requires construction of dams to utilize the river flow efficiently. The main challenge for the Georgian government is to development of the standards regulating technical and safety issues in the process of creating infrastructure for renewable energy. The econometric findings obtained and the responses of the examined variables of the countries examined to each other over time can provide information for researchers and policy makers in terms of the implementation of appropriate alternative energy and environmental policies. Goal 7 (Affordable and Clean Energy): Georgia is working towards this goal by investing heavily in hydropower and building additional facilities—the country's energy transition benefits from using natural resources consistent with sustainable energy practices.

Goal 17: Working Together to Achieve the Goals Renewable energy initiatives in all three nations can only be realized with joint efforts. Rapid SDG advancement is possible by forming public-private partnerships and international alliances.

Making cash available for renewable projects, promoting private domestic investors in Azerbaijan, and setting standards for technical and safety concerns in Georgia are all suggestions in line with SDG 9, which focuses on industry, innovation, and infrastructure. This objective highlights the importance of sustainable industrialization and technological advancements in infrastructure development.

The green energy sector established in the Karabakh region is only one example of how Azerbaijan's rehabilitation efforts are helping to achieve Sustainable Development Goal 11 (Cities and Communities). This connects with the broader objective of making cities and human settlements inclusive, safe, resilient, and sustainable.

Goal 12 of the Sustainable Development Agenda supports responsible consumption and production; raising public awareness in Azerbaijan about increasing renewable energy usage contributes to this goal. More people learning about the need for sustainable energy practices may help solve problems caused by low domestic oil prices.

The South Caucasus nations may progress towards their energy objectives and contribute to the global agenda for sustainable development by adopting the suggested measures.

Limitations and future research directions

The interpretation of the study's findings should take into consideration various limitations that exist within the context. The initial concern pertains to the accuracy and comprehensiveness of the data, given its reliance on availability and quality from 1990 to 2021. The presence of inaccuracies in data collection and reporting, as well as the potential existence of missing data points, can introduce biases into the obtained results. Furthermore, it is essential to consider that the analysis conducted within a relatively limited time frame may fail to capture broader, more enduring trends and dynamics. Consequently, there is a possibility of overlooking significant changes that occur over extended periods. The study's scope may not include external factors such as geopolitical events, technological advancements, and policy changes, which have the potential to exert a substantial influence on the interplay between renewable energy consumption, economic growth, and carbon dioxide emissions. Moreover, the assumption of homogeneity in relationships across the South Caucasus Countries needs to consider each country's distinct characteristics and specific influences.

To overcome these limitations and propel the field forward, numerous avenues for future research become apparent. A more extensive analysis over an extended period would yield a more holistic perspective on the dynamic trends, policy ramifications, and intricate interconnections among the variables. A more comprehensive comprehension of the interrelationships can be achieved by incorporating supplementary factors such as energy prices, technological innovation, and policy measures. Examining studies focusing on individual countries within the South Caucasus region can provide valuable insights into unique dynamics that may not be apparent when using a generalized approach. Dynamic panel data models and qualitative research methods can be utilized to capture the delayed effects and offer a more comprehensive understanding of the underlying causal mechanisms. By exploring these avenues, researchers can enhance their comprehension of the interconnections among renewable energy, economic growth, and emissions. This process can contribute to developing efficient and contextually appropriate policy approaches for promoting sustainable development.

Author contribution All authors contributed to the study conception and design. Azer Dilanchiev: material preparation, data collection; Muhammad Haroon: analysis of the data. The first draft of the manuscript was written by Muhammad Umair. All authors commented on previous versions of the manuscript. And all authors read and approved the final manuscript.

Data availability The datasets used in this study are available from the corresponding author on reasonable request.

Declarations

Ethics approval No ethical approval was necessary for this study.

Consent to participate All participants in this study consent to participation.

Consent for publication All authors consent to this publication.

Competing interests The authors declare no competing interests.

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