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Brief Communication

Do income and consumption growth cause CO_2 emissions in Qatar? Implications for climate policy

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Abstract
Qatar has experienced a remarkable surge in all four components of gross domestic product (GDP)—consumption, government spending, investment, and net exports as well as significant growth in population over the past thirty years. Despite a potential link between increasing production and consumption and a corresponding rise in CO_2 emissions in Qatar, there exists a significant gap in the literature addressing this linkage. Using sectoral data, this article investigates the long-term trends of GDP growth and expenditure and their nexus with CO_2 emissions in Qatar. Least square regression analysis (multiple regression approach) and Granger Causality tests have been used to examine the long-term association between GDP-expenditure and its components and CO_2 emission patterns. Additionally, the study discusses the environmental implications and the necessity for effective natural resource management in climate policy. Our analysis reveals consistent average annual increases in Qatar over the past three decades: 4.8% in total expenditure, 5.4% in GDP, 4% in government spending, 4.7% in household consumption, and 1.77% in CO_2 emissions. During this period, production- and consumption-based emissions surged by 700%, while consumption-based emissions rose by 500%. The energy sector alone accounts for 86% of Qatar's total CO_2 emissions. Significant Granger causality was found between CO_2 emissions and various economic growth and GDP components, suggesting a potential inverted U-shaped Kuznets Curve, indicating a possible decline in CO_2 emissions in future. However, achieving this decline in CO_2 emissions in accordance with UN SDG Goal 12 requires additional policy measures focussed on carbon capture and storage, circular economy practices, carbon pricing, and complementary climate policies. Specific policy actions include establishing CO_2 observatories, promoting clean energy initiatives, and engaging the private sector.

Keywords Income · Consumption · CO_2 emissions · Qatar · Climate mitigation · Policy tools

1 Introduction

Qatar's economy is one of the fastest growing in the Gulf region, with income levels projected to grow faster than the GCC regional average from 2024 to 2040. This economic prosperity has fuelled significant social, economic, and political transformation, as well as global integration. However, studies investigating the determinants of CO_2

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emissions have recognized both income and consumption growth can be major drivers of CO_2 emissions [1–3]. The country's rising incomes and continuing population growth have heightened the demand for energy, water, and food, leading to changing consumption patterns. Studies based on macro-level data confirm a positive correlation between income, consumption and CO_2 emissions [4, 5]. However, research based on the micro-level analysis suggests household energy demand varied significantly by household income. Household size, lifestyle and access to energy-efficient technologies may also influence energy demand across income groups [6].

Qatar's economic growth and the surge in energy consumption have contributed to environmental degradation. In the environmental economics literature, the relationship between economic growth and CO_2 emissions is often analyzed from the perspective of the Environmental Kuznets Curve (EKC) [5, 7]. The EKC hypothesis states that as a country's GDP per capita increases, CO_2 emissions initially increase but begin to decline after reaching a certain threshold level of economic development. This is attributed to four potential factors [7]: (i) energy consumption stimulates economic growth; (ii) economic growth in real sectors may drive energy consumption (the growth-led energy hypothesis), but the economy is not entirely energy, allowing for energy conservation policies without economic repercussions; (iii) the Granger causality test provides statistical evidence of consumer expenditure, government expenditure, economic activity Granger causing CO_2 emissions; (iv) on the other hand, the OLS regression does not provide statistical evidence of the relations between the selected variables.

While the standard EKC hypothesis suggests an inverted U-shaped relationship between economic growth and CO_2 emissions, different studies examining its validity have presented contradictory results. Some studies have found evidence supporting the EKC; others have not [7, 12]. However, there is a significant gap in studies addressing the linkage between production, consumption and the rise in CO_2 emissions in Qatar. In addition to the complex relationship between economic growth and energy consumption, many studies have examined the connection between economic growth, energy use, and carbon dioxide (CO_2) emissions [8, 9]. This relationship is often explored in a bivariate setting, looking at the direct association between economic growth and CO_2 emissions. However, recent studies have considered other potential determinants of CO_2 emissions, such as trade openness, to test the pollution haven hypothesis [10, 11]. Researchers attempted to include additional relevant variables in the estimation model for a more comprehensive understanding, such as urbanization, financial development index and renewable energy [12–17].

Understanding the association between economic growth, consumption, and CO_2 emissions is crucial for climate action policy in the Gulf states. Figure 1 provides a theoretical basis for assessing the long-term association between GDP and CO_2 emissions. Utilizing available macroeconomic data, including sectoral and carbon emissions data, this article aims to (a) investigate the long-term trends of GDP growth and expenditure in relation to CO_2 emissions in Qatar, (b) assess the extent to which economic growth variables influence CO_2 emissions and (c) suggest climate policy measures and actions to mitigate the impact of climate change due to economic growth and environmental pollution.

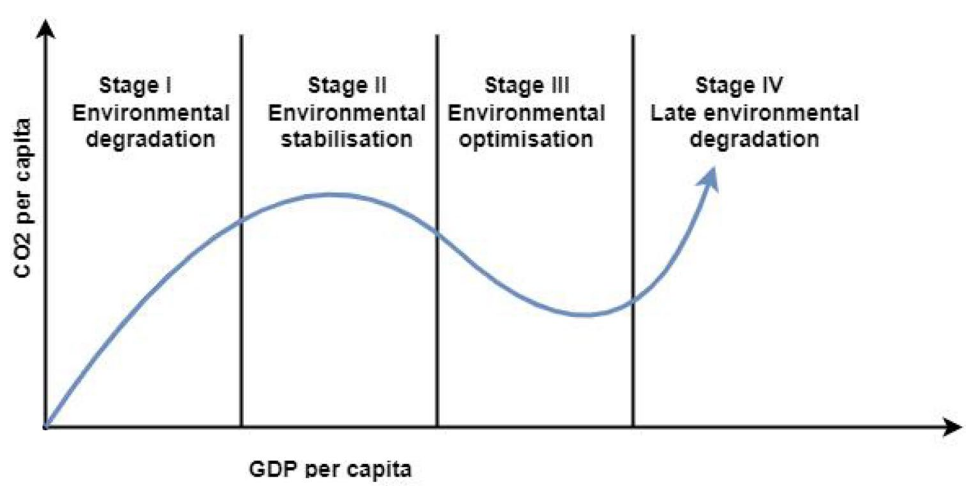

Fig. 1 Theoretical relationships between GDP and CO_2 emissions. Source: (Khalifa, A. 2019) NPRP9-232-5-026 technical report

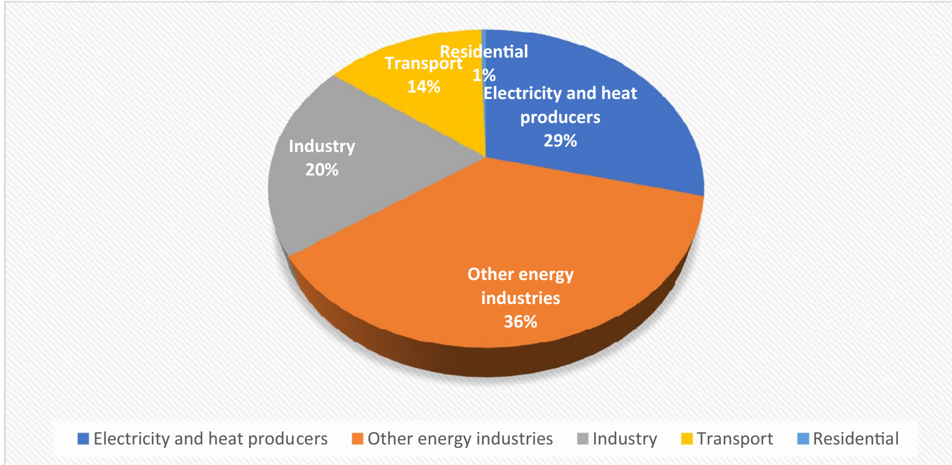

Fig. 2 CO_2 emissions by sub-sector in Qatar, 2021. Source: Computed by the authors based on available data published by IEA (2021)

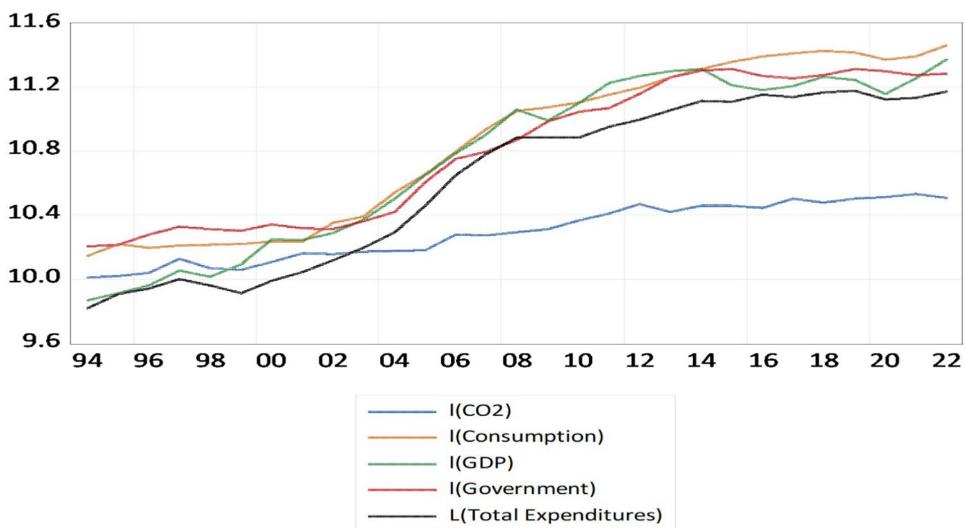

Fig. 3 Log of GDP, total, government, consumption expenditure and CO_2 emissions in Qatar, 1994–2022. Source: Figure generated by authors based on available data published in 2023

2 Data sources and methods

2.1 Data sources

Secondary macro-level data available for Qatar from the following sources are used for this analysis:

- GDP and consumption expenditure data sourced from World Bank National Accounts and OECD National Accounts. (Available online at: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD.
- Carbon emissions data are sourced from Climate Watch Historical GHG Emissions 2023. Washington, DC: World Resources Institute. Available online at: https://climatewatchdata.org/ghg-emissions.
- Global energy statistics sourced from International Energy Agency: Available online at: https://www.iea.org/data-and-statistics.

We conducted the analysis to generate the following results and outcomes: (i) percent share of CO_2 emissions by sub-sector in 2021 (Fig. 2), (ii) log-transformed GDP, total, government, consumption expenditure and CO_2 emissions in Qatar (Fig. 3), (iii) trends in GDP growth and production and consumption based CO_2 emissions during 1990–2022 (Fig. 4), (iv) least square regression analysis of the effects of change in GDP, Consumption and Expenditure on CO_2 emissions (Table 1) and (v) pairwise Granger Causality Tests to confirm causation and co-integration between CO_2 emissions and GDP, total expenditure, government expenditure and households consumption expenditure (Table 2). Cointegration

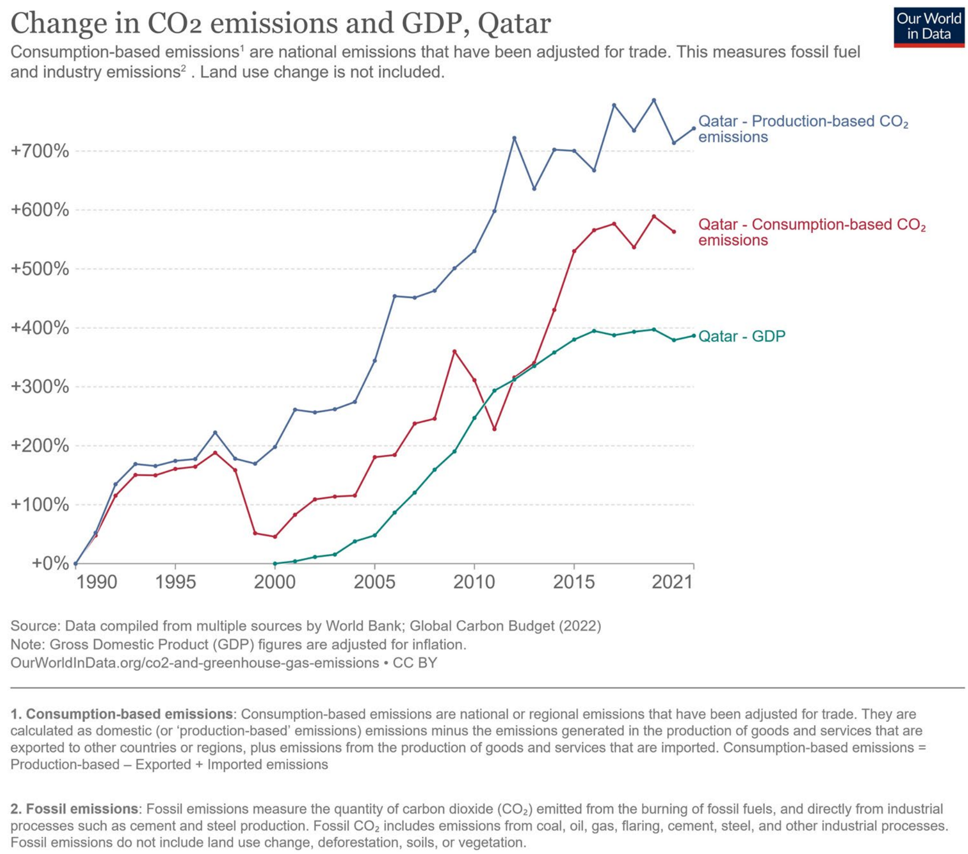

Fig. 4 Trends in GDP growth and production and consumption-based CO_2 emissions. Source: Hannah Ritchie, Max Roser and Pablo Rosado (2020)—"CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/co2-and-greenhouse-gas-emissions' https://ourworldindata.org/co2/country/qatar

Table 1 Least square regression analysis of the effects of change in GDP, consumption and expenditure on CO_2 emissions

Dependent Variable: CHANGE_L_CO2				
Method: Least Square Regression				
Sample (adjusted): 1995 2022				
Included observations: 28 after adjustments				
Variable	Coefficient	Std. Error	t-Statistic	Prob
C	1.261858	0.974176	1.295309	0.2081
CHANGE_L_GDP	0.094195	0.120572	0.781234	0.4426
CHANGE_L_CONSUMPTION	−0.370533	0.217991	-1.699766	0.1027
CHANGE_L_TOTAL_EXPENDITURES	0.294105	0.231814	1.268711	0.2172
CHANGE_L_GOVERNMENT	0.083962	0.158024	0.531323	0.6003
R-squared	0.197411	Mean of dependent variable		1.771416
Adjusted R-squared	0.057830	S.D. of dependent variable		3.723476
S.E. of regression	3.614209	Akaike information criterion		5.568056
Sum squared resid	300.4377	Schwarz criterion		5.805949
Log likelihood	−72.95278	Hannan-Quinn criterion		5.640782
F-statistic	1.414310	Durbin-Watson statistic		2.921656
Prob(F-statistic)	0.260767			

Table 2 Pairwise Granger Causality tests

Sample: 1994 2022
Included observations: 27

Lags: 2

Null hypothesis:	Obs	F-Statistic	Prob
L_CONSUMPTION does not Granger Cause L_CO2	27	5.13355	0.0148
L_CO2 does not Granger Cause L_CONSUMPTION		1.87929	0.1764
L_GDP does not Granger Cause L_CO2	27	3.59236	0.0447
L_CO2 does not Granger Cause L_GDP		0.44509	0.6464
L_GOVERNMENT does not Granger Cause L_CO2	27	3.91217	0.0352
L_CO2 does not Granger Cause L_GOVERNMENT		2.21562	0.1328
L_TOTAL_EXPENDITURES does not Granger Cause L_CO2	27	3.46515	0.0492
L_CO2 does not Granger Cause L_TOTAL_EXPENDITURES		0.27602	0.7614
L_GDP does not Granger Cause L_CONSUMPTION	27	3.31615	0.0551
L_CONSUMPTION does not Granger Cause L_GDP		0.36228	0.7002
L_GOVERNMENT does not Granger Cause L_CONSUMPTION	27	0.67861	0.5176
L_CONSUMPTION does not Granger Cause L_GOVERNMENT		12.0632	0.0003
L_TOTAL_EXPENDITURES does not Granger Cause L_CONSUMPTION	27	4.05948	0.0316
L_CONSUMPTION does not Granger Cause L_TOTAL_EXPENDITURES		1.43519	0.2595
L_GOVERNMENT does not Granger Cause L_GDP	27	0.65888	0.5273
L_GDP does not Granger Cause L_GOVERNMENT		6.68095	0.0054
L_TOTAL_EXPENDITURES does not Granger Cause L_GDP	27	0.12582	0.8824
L_GDP does not Granger Cause L_TOTAL_EXPENDITURES		2.04814	0.1529
L_TOTAL_EXPENDITURES does not Granger Cause L_GOVERNMENT	27	6.30600	0.0068
L_GOVERNMENT does not Granger Cause L_TOTAL_EXPENDITURES		0.82087	0.4531

tests are applied to time series data to determine long-run equilibrium relationships between non-stationary economic variables [18]. The Granger Causality test determines the direction of causality between variables. It involves estimating two regressions and checking for significant coefficients in the second to identify causality [19].

2.2 OLS regression model

We considered the OLS estimation of models of the form in Eq. 1.

$$Y_t = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \epsilon_t \tag{1}$$

where Y_t is the logarithmic value of CO_2 emissions (CHANGE_L_GDP), X_1 is the change in the logarithmic value of GDP (CHANGE_L_GDP), X_2 is the change in the logarithmic value of consumption (CHANGE_L_CONSUMPTION), X_3 is the change in the logarithmic value of total expenditure (CHANGE_L_TOTAL_EXPENDITURES) and X_4 is the change in the logarithmic value of government consumption (CHANGE_L_GOVERNMENT). Change in the logarithmic value is the. These steps are taken in order to have a stationary series.

2.3 Granger causality

As a bivariate concept, Granger causality means that lags of one variable improve our capacity to predict another variable. For example, if economic growth Granger-causes CO_2 emissions, then lags of economic growth have non-zero coefficients in the reduced-form CO_2 emissions. For example, if consumer expenditure Granger-causes CO_2 emissions, then lags of consumer expenditure have non-zero coefficients in the reduced-form CO_2 emissions. Mathematically, the relationship is expressed in Eq. 2.

$$Y_t = \beta_0 + \sum_{i=1}^{p} \beta_i \mu_{t-i} + \sum_{i=1}^{p} \delta_i Y_{t-1} + \epsilon_t \tag{2}$$

To test whether the economic activity or consumption expenditure Granger-causes CO_2 emissions in the economy, we can conduct the following hypothesis test:

$$\beta_1 = \beta_2 = \cdots = \beta_p \tag{3}$$

Hence, the null hypothesis: Granger causality H_0: economic growth or consumer expenditure do not Granger-cause CO_2 emissions.

In consideration of this, the F-test is used to reject the null hypothesis that economic growth or consumption expenditure and the rest of the variables Granger-cause CO_2 emissions.

3 Results

3.1 CO_2 emissions per sector in Qatar

The State of Qatar is a petroleum-based economy, with more than 83% of the government revenue derived from the energy sector, primarily oil and natural gas. As one of the strongest economies in the Gulf, Qatar implemented several large-scale infrastructure projects in the last decade in preparation for hosting the 2022 FIFA World Cup, all funded by oil and gas revenues. Qatar ranks high on per capita income, expenditure on cars, and energy consumption compared to the rest of the world [20]. This is evident in the high number of car ownerships per household, with a preference for large engines. Additionally, Qatar's annual household expenditure grew exponentially from QAR 25,391 in 2013 to 44,759 in 2022 [16]. According to IEA 2021 data (Fig. 2), the energy sector, including power generation, household utilities, oil and gas production and refining, accounted for 86% of Qatar's total CO_2 emissions. The transportation sector accounted for the remaining 14% of emissions. In addition, Qatar's population grew exponentially from around half a million in 1990 to around 2.7 million in 2023, another factor known to play a major role in driving up CO_2 emissions [21].

Three years after the Paris Climate Agreement, global CO_2 emissions from fossil fuels rose 2.7% in 2018. This increase widened the gap between current emissions and the trajectory needed to meet the agreement goals, with the CO_2 emissions gap estimated to be over 19 $GtCO_2$ in 2018. In response, Qatar has implemented several initiatives to reduce CO_2 emissions, including green building standards, renewable energy projects, and carbon capture and storage technologies, along with promoting extensive research and development activities in green energy solutions [9]. However, these efforts are challenged by the upsurge in economic activities, consumption, investment, and government expenditure. Additionally, population growth and the rising number of gasoline vehicles on the road have cumulatively contributed to unprecedented levels of emissions in Qatar.

3.2 Expenditure-based CO_2 emissions in Qatar

Figure 3 suggests evidence of the long-term relationship between CO_2 emissions and economic indicators. This is shown by the parallel trends in GDP, CO_2 emissions, total expenditure, government expenditure and consumption expenditure during 1994–2004. Additionally, Tables 1 and 2, respectively, present results of regression analysis of the co-integration test and Granger causality test. Least squares regression analysis was employed to quantify the relationships among changes in GDP, consumption, expenditure, and CO_2 emissions. The pairwise Granger causality test was conducted to investigate the directionality and co-integration between economic variables and CO_2 emissions. During 1994–2004, Granger causality tests confirm a statistical association between GDP, consumption and CO_2 emissions (Table 2). However, individual regression using stationary data revealed that a 1% change in GDP or total expenditure, government expenditure or consumption has a statistically insignificant effect on CO_2 emissions during this period. This suggests Qatar's CO_2 emissions have plateaued or have even begun to decline despite continuing economic growth. This also implies that further investigation using more detailed data is needed into the factors influencing CO_2 emissions in the context of Qatar's evolving economic landscape.

Regardless of the above results, studies support the hypothesis that national-level CO_2 emissions and economic activities are co-integrated (Tables 1, 2).[1] Fig. 4, based on world data, underlines this connection, indicating that the huge rise in CO_2 emissions in Qatar is driven by production and consumption over the past three decades of 1990–2021 [22]. Notably, production-based emissions have grown by 700%, while consumption-based emissions have increased by

500%. However, it is essential to note that CO_2 emissions for any country are more directly tied to consumption. Qatar ranks highly in per capita income, expenditure on cars, and energy consumption compared to the rest of the world.

Qatar's CO_2 emissions and total expenditure appear to have been linked before 2004, as shown in Fig. 3. However, this co-integration started to weaken after 2004, as indicated in Fig. 3 and Table 2. This deviation may be attributed to Qatar's extensive reliance on cleaner fossil fuels, particularly natural gas, as depicted in Fig. 2. The country's reliance on natural gas, rather than other fossil fuels, seems to be a key factor behind the divergence from the emissions-expenditure trend observed in other countries. During 1990–2021, while GDP rose by about 400% (Fig. 4), production-based CO_2 emissions have risen even faster than consumption-based CO_2 emissions. However, Fig. 3 also suggests that consumption-based emissions are steadily catching up to, and might even surpass, GDP growth in the long run. This trend highlights the need for further investigation of the underlying factors driving emissions in relation to economic growth and consumption patterns in Qatar.

A recent study by Afacan and Khalifa showed that CO_2 emissions increased alongside economic growth in Qatar [23]. Another study by the Arab Monetary Fund showed that GDP growth was positively and significantly related to CO_2 emissions in high-income Arab countries [24]. These trends suggest that both rising income and consumption levels have contributed to Qatar's substantial carbon footprint [21]. However, Qatar has the opportunity to leverage its higher economic growth to align with strict environmental policy regulations. Figure 3 shows a clear connection between CO_2 emissions and economic indicators up to 2004. However, this causation appears to have weakened between 2004 and 2022, likely due to a shift in Qatar's economy towards natural gas, a cleaner fuel than oil and coal.

The Granger causality test provides statistical evidence of consumer expenditure, government expenditure, and economic activity that causes CO_2 emissions. On the other hand, the OLS regression does not provide statistical evidence of the relations between the selected variables. Qatar is making efforts to promote a significant transition in consumption values and behaviour to reduce environmental pollution. The government of Qatar undertook several measures to improve environmental quality to align with Qatar National Vision (QNV2030), demonstrating its commitment to sustainability and economic growth [24]. As part of the policy strategy, the Government has identified 36 effective climate change adaptation measures, with over 300 initiatives planned to tackle environmental pollution and climate change issues [25]. These include (a) placing climate change at the forefront of its policy priorities, (b) setting up the new Ministry of Environment and Climate Change (MRCC) to promote sustainable development projects and achieve Qatar's goals in preserving the environment, promoting green growth, and limiting the effects of climate change, (c) launching major climate and environmental research programs, (d) implementing sustainable cities and green transport strategies and (e) promoting clean energy and digital transformation.

4 Conclusion and policy highlights

The research contributes to the ongoing discourse on the impact of economic growth on environmental pollution in Qatar. We explored strategies to achieve an inverted U-shaped Environmental Kuznets Curve (EKC), effectively reducing CO_2 emissions. Additionally, we examined policy measures and actions for Qatar to mitigate climate change and environmental pollution. Key economic factors influencing CO_2 emissions were identified, including GDP growth, household consumption and government expenditure, drawing on the 2019 NPRP9-232-5-026 technical report [7]. Our analysis of data from 1990 to 2022 revealed significant Granger causality and co-integration between CO_2 emissions and several economic factors, including GDP, total expenditure, government expenditure, and household consumption expenditure. The lack of statistical significance of regression coefficients suggests that Qatar might be nearing the peak of its CO_2 emissions curve. There is potential for an inverted U-shaped Kuznets curve, with a possible decline in CO_2 emissions. However, achieving this decline will require additional policy measures.

We recommend several technical and market tools based on our empirical work to reduce CO_2 emissions in Qatar and align with UN Sustainable Development Goal #12 on sustainable consumption and production patterns [8]. Our recommendations focus on resource efficiency and emission reduction. These include (1) implementing and scaling up carbon capture and storage (CCS), (2) adopting a comprehensive national strategy for circular economy at micro, meso and macro levels, (3) introducing and expanding carbon pricing mechanisms to incentivize emission reduction, and (4) implementing complementary climate policy mechanisms such as command and control regulations, incentives, pollution charges, marketable permits, removal of market barriers and the elimination of energy subsidies.

Qatar should continue advancing resource efficiency in both production and consumption to reduce CO_2 emissions. Specific policy actions include (a) establishing observatories to measure and monitor CO_2 levels, (b) implementing regulatory measures to promote clean energy and technology adoption, and (c) engaging the private sector in CO_2 reduction goals. These recommendations should be implemented through a comprehensive ecosystem integrating technology, institutions, behavioural change, regulations, and market tools. These steps are essential to mitigate climate change impact and ensure the well-being of current and future generations.

The limitation of this study is that it relied on secondary macroeconomic data available for Qatar. A more comprehensive and robust analysis will require detailed sectoral-level data over an extended period. Emissions profiles, resource use patterns, and technological characteristics of key industries in Qatar can also be evaluated. This approach will help identify sector-based policy tools to address Qatar's climate and sustainability challenges effectively.

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Author contributions AP and AK conceptualized, conducted analysis and prepared the first draft. HS assisted in diagrams and referencing. KG and MM contributed to reporting and revising the manuscript. All authors reviewed and approved the manuscript.

Data availability Data is provided within the manuscript as well as supplementary information. The data used in paper is publicly accessible secondary macro data sources. Diagrams and results used in this study generated by the authors based on secondary data sources or sourced from authors research papers and reports.

Declarations

Ethics approval and consent to participate This study is based on publicly accessible secondary macro data sources. Diagrams and results used in this study are generated by the authors based on secondary data sources or sourced from authors research papers and reports. Therefore, protocols related to consent to participate is not applicable.

Competing interests The authors declare no competing interests.

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