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Does Qatar Face a Trade-off Between Economic Growth and CO_2 Emissions?

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Driven by the development of the oil and gas sector, Qatar has made remarkable economic achievements over the past few decades. However, Qatar's high dependence on fossil fuels has resulted in a rapid increase in its CO_2 emissions. As such, the country may be facing a trade-off between achieving continued economic growth and carbon emissions reductions. This study empirically analyzes the relationship between economic growth and carbon emissions in Qatar, using annual data of income and CO_2 emissions from 1970 to 2018. The analysis was conducted by employing the Environmental Kuznets Curve (EKC) framework and the Decoupling Index (DI) approach. The EKC was evaluated using the Fully Modified Ordinary Least Squares cointegration method. Additionally, a robustness check was conducted by Canonical Cointegrating Regression (CCR) cointegration method to confirm the results attained by FMOLS. The findings support the evidence of an N-shaped relationship and suggest that the country is currently undergoing expanding relative decoupling. Although findings show that Qatar's per capita emissions have been declining over the last few years, additional measures such as energy conservation, energy efficiency and renewable energy are required to allow cost-effective carbon emission reductions.

Keywords: Qatar, decoupling index, environmental kuznets curve, FMOLS, CCR, GDP, climate change, emissions

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INTRODUCTION

The linkage between economic growth and environmental degradation is very well discussed in the literature. The question we are still facing today is whether there is a tradeoff between sustaining economic growth and environmental protection, or whether it may be possible for the two to go hand in hand. A clear case of interconnection between economic development and environmental degradation is the use of fossil fuels, on which global economies still strongly rely (Shannak, 2022).

Worldwide, there is a heavy reliance on fossil fuels, in 2019, 81% of the energy that the world consumed was coming from fossil fuels, mainly oil, coal, and natural gas. Nearly 15 billion metric tons of fossil fuels are consumed every year (IEA, 2022). The 2015 Paris Agreement on Climate Change has raised global ambitions on tackling climate change through reducing unabated fossil fuels use. In this paper, we focus on a major fossil fuel producing country—Qatar—and we explore the question as to whether the country faces a tradeoff between its continued economic development and achieving environmental protection, which includes meeting increasingly stringent carbon emissions reduction targets.

Qatar has undergone a very rapid economic development over the last few decades, mainly driven by the exploitation of its vast hydrocarbon resources. According to the World Bank, Qatar is currently one of the richest countries in terms of GDP per capita, ranking among the top ten wealthy countries in the world. The country's economy is highly dependent on the oil and gas sector, which accounts for more than 50% of GDP, 85% of export earnings, and 70% of government revenues (MOFA, 2021). This reflects in per capita carbon emissions that in 2020 carbon dioxide emissions were among the highest in the world at 37 metric tons per person (the world average is about 10 metric tons per person) (IMF 2015, BP statistics, 2021).

Qatar is a signatory to the Paris Agreement and in 2021 it has updated its Nationally Determined Contribution to include for the first time a quantitative carbon emission reduction target (State of Qatar, 2021). The State of Qatar has also recently developed its first National Climate Change Action Plan and it is expected to be increasing its carbon emissions reduction ambitions further in the future. Yet, the question of how deep emission reductions can be achieved and the exent to which it involves a tradeoff between environmental protection and economic growth has received limited attention in the literature (see *Introduction* where the few studies focusing on Qatar are discussed).

The investigation of the interlinked relationship between economic growth and carbon emissions has been widely studied in the literature (Grossman and Krueger 1995; Al-Mulali and Ozturk, 2015; Apergis and Ozturk 2015), typically using two approaches: the environmental Kuznets curve (EKC) and the Decoupling Index (DI).

The first approach hypothesizes and tests a specific relationship between economic growth and environmental degradation. It uses several sets of indicators to explain how modern economic growth occurs at the cost of environmental degradation until average income arrives at a certain point throughout development (Grossman and Krueger, 1991). This behavior results in an inverted U-shape that explains the variation of CO_2 emissions alongside the increase in income and suggests that environmental degradation can be curbed by pursuing continued economic growth.

The second approach (DI) examines the ratio of the change rate of resources consumption to the change rate of economic scale over a period of time, and determines whether emissions growth rates are slower or faster than GDP growth. Combining these two approaches allows to gain complementary insights into the growth trajectories of CO_2 emissions and GDP, and understand which is growing faster than which.

The main goal of this study is to investigate the interlinked relationship between economic growth and CO_2 emissions in Qatar. To address this goal, the following research questions are considered:

(i) What is the shape of the relationship between economic growth and CO_2 emissions in Qatar?
(ii) How does the decoupling index behave in Qatar?
(iii) Is Qatar facing a trade-off between sustaining economic growth and reducing CO_2 emissions?

The rest of the paper is organized as follows: *Introduction* discusses the hydrocarbon-driven economic development of Qatar and efforts by the government to decouple it from its adverse effects on the environment; *Introduction* reviews existing literature on the topic; *Introduction* presents the data and functional specifications, while the methodology of the study is discussed in *Introduction*; *Introduction* presents the empirical findings, *Introduction* discusses these findings along with policy implications ans *Introduction* presents the conclusions of the study.

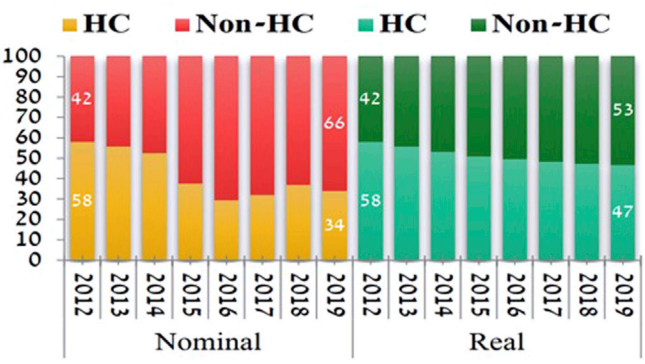

FIGURE 1 | Main economic sectors as a percentage of GDP (Source PSA, 2020). HC stands for Hydrocarbon.

ECONOMIC DEVELOPMENT AND CLIMATE CHANGE OBJECTIVES

Fossil fuel resources in Qatar are dominated by natural gas. In 1971, the world's third-largest offshore natural gas field was discovered however at the time this was still considered a second-rate energy resource. Initially, the market for Qatari gas was limited and Qatar was only able to trade it at a small scale and within close-distance markets (IEA, 2021). However, as the global gas market developed, Qatar became a major producer and exporter of natural gas and, to a lesser extent, of oil and oil products. Based on 2017 statistics, Qatar has 858 trillion cubic feet (Tcf) of proven gas reserves, ranking the country to be number three worldwide in terms of reserves. Qatar's gas reserves account for about 12% of the world's total natural gas reserves of 6,923 Tcf (Bp statistics, 2021).

In Qatar, the energy sector is the main source of revenues, with a 4% drop from 47% in 2019 to 45% in 2021 (IEA, 2021); see **Figure 1**.

In Qatar, domestic energy consumption per capita is around 15 tonne of oil equivalent (toe), including 15,100 kW h electricity, which results in Qatar being the fifth highest country in terms of electricity consumption per capita in the world (Enerdata, 2022). This figure is in itself very high and prompts the question: how much does such substantial electricity consumption, partly boosted by energy incentives, contribute to the total emissions of Qatar? Additionally, this consumption has been rising over the last decade at different rates,(i) rapidly between 2000 and 2013 with a growth rate exceeding 10% per year, 2) and slowly since 2013 with an average growth rate of 1.5% per year (**Figure 2**). It is

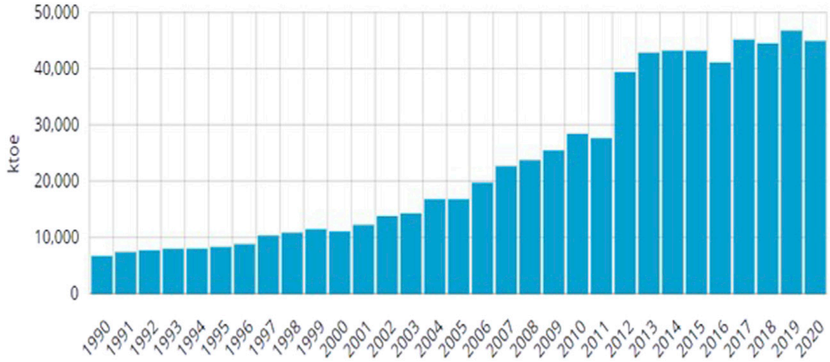

FIGURE 2 | Total energy consumption (ktoe) (Enerdata, 2022).

worth noting that in 2020, energy consumption reached 45 Mtoe, natural gas had the highest share of 81%, and oil 19% (Enerdata, 2022).

With this level of continuous growth in demand, the country has been working on expanding and upgrading its existing power generation capacity and at the same time introducing policies to reduce the per capita energy consumption to more sustainable levels. These actions are part of the Qatar National Vision 2030 focused on the diversification of the local economy towards a knowledge-based development, reducing national dependence on hydrocarbons, and on the development of the private sector (QNV, 2008). The Qatar National Vision 2030 is implemented through its National Development Strategies, the first covering the period 2011-2016 (NDS-1) and the second 2018-2022 (NDS-2), and intended to achieve economic expansion, promotion of human and social development, international cooperation, and environmental preservation goals. As part of the National Development Strategies, the State of Qatar set itself the target of enhancing its energy efficiency by 10% and reduce the per-capita electricity consumption by 8% through 2022, and that of deploying 200 MW of solar PV capacity by 2020 and 500 MW in the following few years.

In fulfilment of its obligations under the Paris Agreement on climate change, in 2021 Qatar has updated its National Determined Contribution by committing to reducing greenhouse gas emissions by at least 25% by 2030 relative to a business-as-usual scenario (State of Qatar, 2021), and has recently unveiled a national environment and climate change action plan. Under this plan, the country is also targeting to reduce groundwater extraction by 60%, reduce daily household water consumption by a third, and double desalination via reverse osmosis as well as prioritize high yield and sustainable agriculture production by driving more than 50% improvement in farmland productivity.

These initiative emphasizes the growing importance for the State of Qatar to accelerate the transition to a climate-resilient economy. Consequently, it is critical to investigate how CO_2 and economic growth relationship evolves in light of the implemented policy measures. According to the literature (Winkler et al., 2002, inter alia), analyzing the impact of economic growth on environmental degradation is particularly important for policy purpose particularly if the country witnesses significant economic growth as is the case of Qatar. Furthermore, investigating the relationship in the case of Qatar, a fossil fuel-rich developing country, would be a model for other similar countries in the Gulf region with similar environments, and thus may provide some understandings which are common across such kinds of economies. It is worth poininting that the economic growth-CO_2 emissions relationship has been investigated for several countries in the literature. Nevertheless, only a few time-series studies have included Qatar in their CO_2 analysis and, to the best of our knowledge, there is no time series study investigating this issue for Qatar using the proposed approach we are following in this study. Therefore, an empirical analysis is required to inform policy-makers and thereby help them design policy measures to meet climate change objectives as well as economic development targets.

The analysis of this study contributes to the existing literature in several ways. First, to the best of our knowledge, this is the first study that focuses on Qatar as a single country and analyzes the impact of income on environment degradation in terms of CO_2 emissions per capita by numerically estimating its effects in the long -run and verifies the N-shaped EKC relationship for Qatar along with DI calculations. Primarily, as in line with this study objective, the study adds value to the ongoing debate on sustaining economic growth along with curbing total emissions by empirically supporting the policy strategy that would result in meeting climate change objectives and reducing CO_2 emissions in Qatar. Moreover, numerical assessments conducted in the study are useful as they inform Qatari policymakers about a big role of economic development and technological progress that should be taken into consideration in designing long-term policy packages for the development of the country. Third, the study uses different estimation and robust test methods to confirm more vigorous results. This is crucial for formulating evidence-based policy recommendations.

The numerical evaluations and estimated specifications that this study offers can also be utilized for estimating and modeling future alternative development paths of the country under different policy options. Elasticity estimates inform policymakers with the weight and significance of each studied variable and its potential impact on carbon emissions. Accordingly, policymakers could use these numerical values to design effective policies with a clearer understanding of the overall impact. These empirical estimates would be useful to evaluate what role the different sectors can play in the future development of the whole Qatari economy. Such an evaluation would be vital when it comes to economic diversification away from dependence on oil, a key development strategy in Qatar National Vision 2030 that the country follows.

LITERATURE REVIEW

The available studies on carbon emission and economic development encompass two approaches: the first approach defines the relationship between emissions and economic growth and analyzes the drivers affecting them, while the second approach focuses on the growth of the economy without considering environmental degradation factors.

Concerning the first approach, Grossman and Krueger (1991), suggested an inverted U-shaped relationship between economic development and environmental quality, similar to the so-called Kuznets Curve (Kuznets and Simon, 1955). This relationship was described later by the Environmental Kuznets Curve (EKC), which is a hypothesized relationship between various indicators of environmental degradation and income per capita (Panayotou, 1993; Magazzino 2016; Magazzino, 2017; Xia et al., 2022). This relationship has received more attention these days as greenhouse gas emissions increase during the production process of most commodities. However, after a certain point, emissions or pollutants decline because of the followings (Lieb 2003): first, more strict environmental control policies are applied; second, one greenhouse gases emitter is substituted by another and thus reduced; third, technological enhancement that allows the production to increase at fewer emission rates of greenhouse gases.

The EKC hypothesis has been tested for different total and sectoral level environmental indicators, including CO_2 emissions. Using the EKC framework, Hartman and Kwon (2005) suggested whether road transportation in Britain was fit for the turning point or not. Abdallah et al. (2013) in their study in Tunisia verified that carbon emissions of conforming to the EKC specification. Azlina et al. (2014), Kharbach and Chfadi (2017), and Alshehry and Belloumi. (2017) confirmed the applicability of the EKC theory in road transportation considered such as financial development and trade openness (Satrovic 2019). Other researchers such as Ansari et al. (2020) applied ecological/material consumption footprint as an indicator of the anthropological burden on the ecosystem. They analyzed 37 Asian countries over the 1991–2017 period by employing pooled mean group, differenced panel generalized, panel co-integration, and dynamic ordinary least square methods. They concluded that the ecological footprint indicator proved the existence of EKC.

Similarly, Halliru et al. (2020) investigated the validity of the EKC theory over the period 1970 to 2017 by considering six West African countries. They applied the following factors as additional carbon emission determinants; human resources and bio-capacity. They concluded that a U-shaped relationship across the development of economy and CO_2 emissions are different from an inverted U-shaped EKC theory. Furthermore, Zhang et al. (2019) analyzed the EKC theory by applying evidence from 121 countries over a period from 1960 to 2014 on CO_2 emissions. They looked at emissions from industrial and building sectors and assessed the turning points for the economies where the EKC theory is established. They concluded that 95 out of 121 countries confirmed the EKC theory. Saqib and Benhmad (2021) have reviewed 101 academic papers released between 2006 and 2019. The main finding was that the EKC is valid. This association has been demonstrated to be a long-term one, and the type of econometric instruments utilized, or the type of data employed, is not deterministic.

On the other hand, some researchers argued that some other countries might not be subjected to the EKC hypothesis, and it is challenging to ensure the applicability of the EKC hypothesis between environment and carbon emissions (Huang et al., 2008). For example, Dogan and Inglesi-Lotz (2020) examined the EKC theory's feasibility for BRICST countries (Turkey, Russia, Brazil, China, India, South Africa). They concluded non-validity of the EKC theory and indicated that the structure and intensity of energy use are significant determining factors of ecological degradation, for the studied period 1980 to 2014. Nevertheless, until now, there is no consensus among scholars on the shape of the EKC curve due to different control variables.

Charfeddine et al., 2018 studied the energy consumption-economic growth nexus and the impact of income on the CO_2 emissions for Qatar during the period 1970–2014. Using the ARDL approach, the authors found strong evidence for cointegration between studied variables. furthermore, the results of the Granger causality tests showed that both energy consumption and electricity consumption cause economic growth in the case of Qatar. Charfeddine et al. (2018) is a valuable study with substantial contributions to the environmental/energy economics literature, with application to Qatar case. However, there are some nuances to investigate in addition to their work. First, the study period ends in 2014, which does not allow to see the impacts of the recent energy price reforms on CO_2 emissions. Second, they applied a second-order model specification for the analysis without testing-down, which might cause some estimation issues as discussed in *Literature Review*. Third, they have not performed elasticity analysis and have not calculated the turning points.

The second approach that has been applied in the literature and analyzes the relationship between economy and environment is a Decoupling Index, which is defined as a ratio of the change rate of resources consumption to the change rate of economic scale over a period of time. In general, the concept states that the total amounts of energy or materials used along with the growth in the economic volume continue to increase until a certain point where it drops, thus achieving economic growth. Tapio (2005) created a DI by employing the concept of elasticity. The author defined eight decoupling states that have been widely utilized to investigate the relations between economic growth and environmental degradation (Hasanov et al., 2021; Tarabusi and

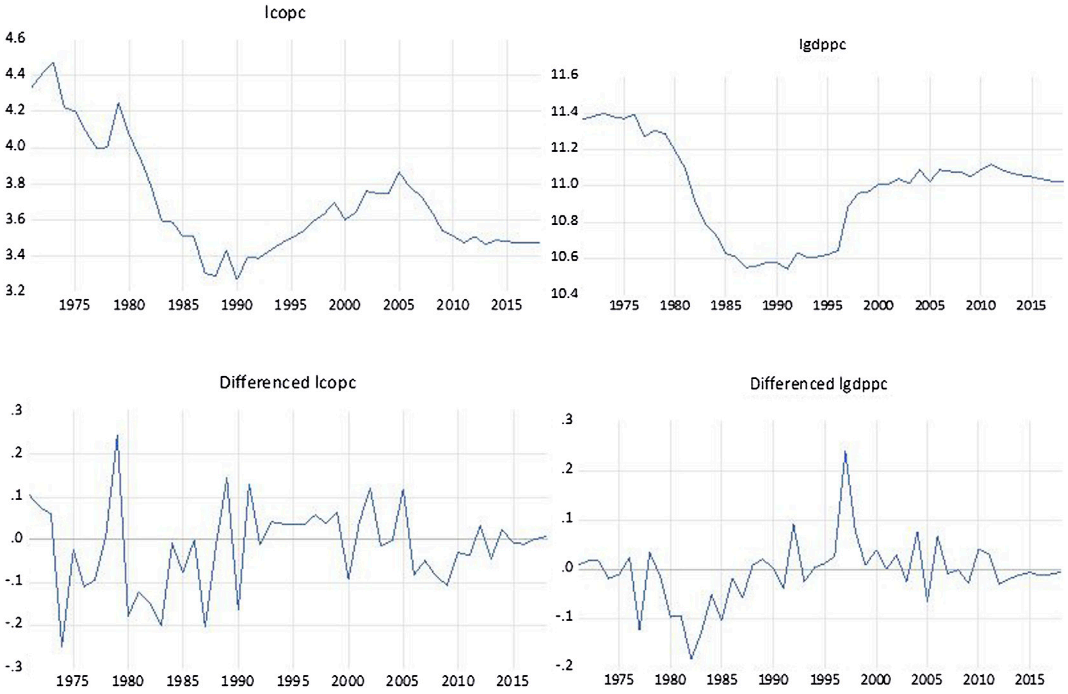

FIGURE 3 | Time profile of the variables. lcops stands for logarthim of carbon emission per capita and lgdppc stands for the logarithm of GDP per capita. The differenced lcopc and difference lgdppc correspond to the growth rates for the variables respectively.

Guranin, 2018; Dong et al., 2021). The developed DI prevents some unexpected scenarios where the indexes outcomes lead to huge differences across each other because of the use of a different base period (Cohen et al., 2018; Wang et al., 2018; Wu et al., 2018; Yang et al., 2018; Wang et al., 2019; Wang and Jiang, 2019). Some scholars have utilized decomposition analysis as a means to analyze the factors that affect the index (Zhao et al., 2016; Meng et al., 2018; Wang et al., 2018). For instance, Wang et al. (2019) studied the factors affecting the decoupling state, and they concluded that population and gross domestic production per capita inhibited decoupling, however, energy intensity increased decoupling. Similarly (Chen et al., 2017; Wu et al., 2018), found that the same factors inhibited the decoupling states.

Wang and Feng (2019) inserted the Shephard distance function to the Kaya identity to profoundly examine the embedded factors and technical efficiency influencing the decoupling index. Other researchers have employed the elastic property of the decoupling index. They used it to confirm that the inflection point of the EKC was the dividing point among the absolute decoupling and relative decoupling (Xia and Zhong, 2016; Song et al., 2019). Under this property and to better understand the decoupling state, scholars developed one-dimensional decoupling to two-dimensional decoupling. The decoupling and coupling states have started to appear consecutively, as proved by several studies (Wang, 2015; Wang and Tan, 2017; Dong et al., 2019; Huang et al., 2019; Yu et al., 2019; Zhang and Cheng, 2019; Derakhshannia et al., 2020; Zhang et al., 2020).

However, the index established by Tapio is capable to reflect the relationship between economic development and environmental degradation, yet it has some flaws. For instance, the Tapio decoupling index has shortcomings in investigating long-term relationships and is extremely vulnerable to short-term policies. However, decoupling emphasizes the trend of the decoupling process. That is to say, decoupling, not a random fluctuation or deviation in the short term, is a stable and continuous separation of environmental degradation from economic growth over a certain period. Thus, decoupling is not a short-term process. It is an adjustment process that requires a certain length of time and entails an economic cost (Dong et al., 2019).

DATA AND FUNCTIONAL SPECIFICATION

Data

The empirical analysis in this study was carried out using annual data covering the period 1970–2018, therefore covering 48 years. The span is chosen based on data availability. We used CO_2 emissions per capita as an indicator of environmental degradation as it represents more than 80% of the total global greenhouse gas emissions (World Bank, 2014). We used GDP per capita as an indicator to measure the effect of economic growth on environmental degradation (**Figure 3**). CO_2 emissions per capita data are measured in metric tons per capita and GDP is measured in constant 2015 U.S dollars per capita. CO_2 emissions data were retrieved from World Bank (WB, 2021), while GDP

TABLE 1 | Data statistics.

	Mean	Median	Minimum	Maximum	Standard Deviation
Lgdppc	10.99	11.04	10.54	11.40	0.27
Lcopc	3.71	3.6	3.27	4.47	0.31

Source: Estimation results.

data were retrieved from the macroeconomic indicators database of FAOSTAT (FAOSTAT, 2021). **Table 1** shows the descriptive statistics of the used data. The variables were transformed into their natural logarithms to decrease the heteroscedasticity phenomenon.

EKC Framework

As per the theoretical underpinning of the Environmental Kuznets Curve (EKC) hypothesis, economic growth could increase to a certain point but finally restraint CO_2 emissions as a premature agriculture based economy changes into a multifaceted industrialized one (Grossman and Krueger 1995; Apergis and Ozturk 2015).

An example of a typical EKC framework is shown in **Figure 4**. The framework is divided into four stages: scale effect, composition, technical effect, and technical obsolescence effect. The scale effect corresponds to preindustrial economy levels, in which small consumption of natural resources results in reducing environmental degradation levels. Following this stage and as the economy progresses, more consumption of natural resources occurs, but it exceeds the redevelopment rates. This developing stage results in environmental degradation and further deteriorates the quality of natural resources. This stage is known as a composition effect, where the government enforces more strict policies to reduce environmental degradation and to shift the current stage to the preindustrial stage.

Furthermore, advanced economies characterized with high income would allocate more resources to support research and development to reduce pressure caused by economic development on the environment. This stage corresponds to the technical effect stage where improvement to the overall quality of the environment becomes evident. The overall effects of all the above activities create a relationship between economic growth and environmental quality that takes the form of an inverted U-shaped relationship, which is known as the Environmental Kuznets (EKC) framework.

In addition to the inverted U-shaped relationship, various studies have stated an N-shaped relationship between economic growth and environmental degradation, which is the focus of our study. This indicates that at the early stages of economic development, the growth in the economy results in increasing the level of environmental degradation until the first turning point, and next a decrease in environmental degradation is experienced as the economy progresses until the second turning point. Beyond the second turning point, environmental degradation is back to increase. In general, an environmental correction occurs at this stage as the increase in incomes is directly related to environmental degradation. Moreover, policies at this stage should target clean energy resources and environmental regulations to avoid environmental degradation from escalating again. Additional investment in research and development is required to produce more efficient technologies that can improve environmental quality (Balsalobre and Alvarez 2016; Shahbaz and Sinha 2018).

To investigate this N-shaped relationship, numerous time-series studies consider GDP, GDP squared, or GDP cubic - after testing down - as independent variables in the same equation when analyzing the EKC framework. Following the standard practice, the following functional specification was developed to analyze the long-run relationship over the study period between the studied variables and CO_2 emissions in Qatar. The rationale behind applying the GDP cubic in the following **Eq 1** is that it contains an N-shaped curve as indicated by Shafik (1994) and Torras and Boyce (1998). If the enhancement in environmental condition after the threshold level of income is

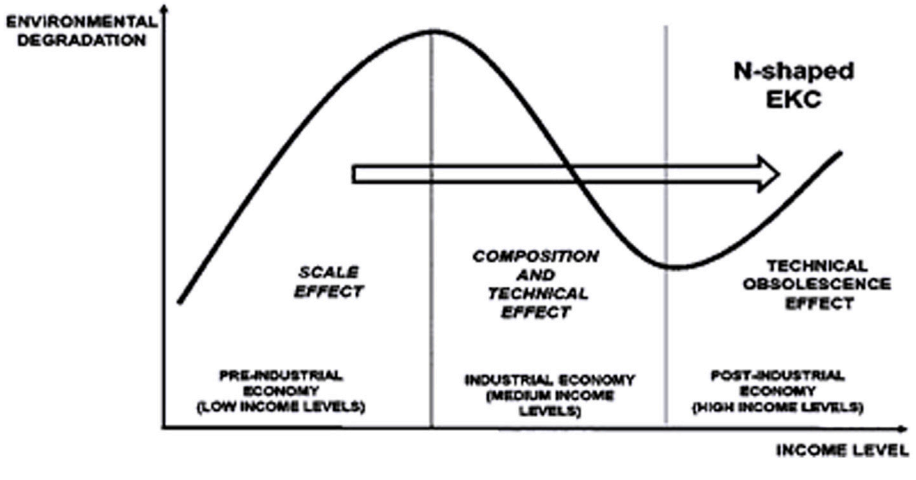

FIGURE 4 | The N-shaped EKC (adapted from Sinha et al., 2017).

observed to be temporary, then such a curve is detected. For this phenomenon to be valid an "inverted N shaped" relationship would be observed in the context of environmental efficiency.

$$emi = \beta_0 + \beta_1 gdp + \beta_2\, gdp^2 + \beta_3\, gdp^3 + u \tag{1}$$

Here, "emi" is the carbon emissions per capita, "gdp" is a gross domestic product per capita, u—error term, β0 is a constant term, β1, β2, and β3 are regression coefficients of the long-run relationship.

In the case of a linear function (without using gdp squared or gdp cubic), if $\beta\ 1 > 0$, the relationship between carbon emissions and GDP is linearly increasing. Any increase in incomes elasticity will lead to a proportional increase in carbon emissions. On the other hand, this income-CO_2 emissions relationship would be monotonically deceasing in case $\beta 1$ is < 0. It is worth noting, this relationship holds only if $\beta 1$ is significant.

The quadratic form of the EKC function-when using variables at level, but if we are using log variables, it depends on the scale of the variables (Hasanov et al., 2021)- is interpreted as follows: If $\beta 2 < 0$ and statistically significant, a classical inverted U-shaped EKC will be observed and If $\beta 2 > 0$ statistically significant, there will be a U-shaped relationship between environmental degradation and income.

The cubic form, which is the focus of this study can be interpreted as follows: If $\beta 3 > 0$ and statistically significant, there will be a cubic polynomial or N-shaped relationship between environmental deterioration and income. While, if $\beta 3 < 0$ and statistically significant, there will be an inverted N-shaped relationship between environmental degradation and economic growth. It is worth noting, in the case of the quadratic and cubic forms, the turning points should be within the sample size, so the chosen form is relevant (Hasanov and Shannak, 2020).

Following these conditions and assumptions, there could be a delinking relationship between income and CO_2 emissions. In other words, environmental degradation increases at the initial stage but at a decelerating rate, until it reaches a certain threshold. Following this stage, growth allows for enhancements in the environmental situation.

METHODOLOGY

After the transformation of the study variables and evaluation of the descriptive statistics, our next step was to utilize the algorithm for automated model selection (Autometrics) to detect structural breaks and outliers affecting the deterministic component of the estimation technique (Doornik, 2009). This option is available through OxMetrics software, which can manage non-orthogonal candidate regressors.

We also analyzed the stationarity of the series to determine if all variables are integrated in the same order. We followed the conventional procedures of the Augmented Dickey-Fuller (Dickey and Fuller, 1979) test for stationarity analysis, by considering a constant or a constant and a trend. The null hypothesis of the ADF test asserts the non-stationarity of the variable. To test the cointegration relationship between a dependent variable (*emi*) and independent variables (*gdp*); the Banerjee et al. (1993) test is used. For the two tests, the null hypothesis is the non-existence of the cointegration relationship.

After confirming that all variables are integrated in the same order, the long-run analysis and cointegration relations were investigated.

For cointegration analysis, all applied tests are conventional methods and very well documented in the literature, we opted to drop their description in this section. Pertaining the long-run estimations, the Fully Modified Ordinary Least Squares (FMOLS) (Phillips and Hansen, 1990) was employed.

The decoupling index was calculated using the OECD, 2020 method. First, the decoupling ratio was estimated between income and emissions as in the following equation (**Eq 2**):

$$Decoupling\ Ratio = \frac{\frac{CO2_t}{GDP_t}}{\frac{CO2_{t-1}}{GDP_{t-1}}} \tag{2}$$

Second, the calculated decoupling ratio was subtracted out of 1 (**Eq 3**). This can be interpreted as if the ratio is larger than 1, it implies the existence of coupling, while if it is smaller, it indicates the existence of decoupling.

$$Decoupling\ Index = \ 1 - \text{Decoupling Ratio} \tag{3}$$

Even though the EKC hypothesis suggests CO_2 emissions as a quadratic (inverted U-shaped) function of economic growth (Rauf et al., 2018; Işık et al., 2019), it does not state whether this relationship could hold or not. Thus, it is crucial to assess this issue that has largely remained not fully clarified in the literature. In particular and to address this literature gap, this study utilizes the CO_2 emission numbers of Qatar as a cubic function of economic development. Accordingly, if the estimated coefficients hold to the cubic term of the studied variables and are statistically significant, then it can be established that the EKC hypothesis is not likely to hold in the long-run for the studied country and during the study period. Moreover, we applied a cubic function of the polynomial model without control variables. The cubic form of a polynomial function is widely used to capture the future behavior of the income-environmental degradation relationship (Shafik 1994; Grossman and Krueger, 1995; Lieb 2003; Hasanov et al., 2021, inter alia). In the case of developing countries such as Qatar, a cubic form is recommended (general to specific approach) to capture different functional relationships (Shafik 1994; Lieb 2003; Hasanov et al., 2021, inter alia).

Lastly, the elasticity was estimated by calculating the first derivative of the developed model. Furthermore, the turning points for the cubic logarithmic specifications were calculated using the following formula with the raw units (Hasanov et al., 2021):

$$Y^{TP} = exp\left(\frac{-B_2 \pm \sqrt{B_{2-}^2\ 3B_1B_3}}{3B_3}\right) \tag{4}$$

Where Y^{TP} is the turning point, β2, and β3 are regression coefficients of the long-run relationship.

TABLE 2 | Unit root test results.

		At level			At first difference	
UNIT ROOT TEST TABLE (PP)		With Constant t-Statistic	With Constant & Trend t-Statistic		With Constant t-Statistic	With Constant & Trend t-Statistic
	Lemi	−1.6575 [n0]	−1.5124 [n0]	d (*Lemi*)	−6.8342 [***]	−6.9374 [***]
	Lgdp	−1.6248 [n0]	–-1.3903 [n0]	*d(Lgdp)*	−5.0696 [***]	−5.2268 [***]
UNIT ROOT TEST TABLE (ADF)		With Constant t-Statistic	With Constant & Trend t-Statistic		With Constant t-Statistic	Whith Constant & Trend t-Statistic
	Lemi	−1.6459 [n0]	−1.4681 [n0]	d (*Lemi*)	−6.8312 [***]	−6.9312 [***]
	Lgdp	−2.1159 [n0]	−1.9708 [n0]	*d(Lgdp)*	−2.7771 [*]	−5.0269 [***]

Notes (*)Significant at the 10% (**)Significant at the 5% (***) Significant at the 1%. and (n0) Not Significant.
**MacKinnon (1996) one-sided* p-*values.*
Source: Estimation results.

TABLE 3 | Grander Causality test results.

Null Hypothesis	F Statistics	*p*-Value	Whether to accept the Null Hypothesis
Lgdp does not Granger cause Lemi	3.33722	0.0452	Reject
Lemi does not Granger Cause Lgdp	1.10949	0.3392	Accept

EMPIRICAL ESTIMATION RESULTS

Unit Root Test

Following the methodology of time series modeling; first, the unit root properties of variables have been examined using ADF (Dickey and Fuller, 1979) test and we've also validated the results using Phillips–Perron (PP) test. The results of the ADF and PP tests are presented in **Table 2**.

As **Table 2** demonstrates all the variables are non-stationary at the level and they become stationary at differences. In other words, the studied variables follow integrated of order one, I 1) processes, and therefore any shock to these studied variables could have a permanent impact. Following this precondition test, the cointegration test can be performed.

Granger Causality Test

This test was performed to evaluate the internal causality and direction of time series before investigating the N-shaped relationship. This test should further provide evidence of whether there is a correlation among the selected variables. According to economic theory, there should be at least one causal relationship among variables to define a long-run relationship. As can be viewed from **Table 3** results, there is an existence of a cointegration relationship among the studied variables.

As a next step, the long-run estimations have been performed. The detailed estimation results from the FMOLS approach in the dynamic form are provided in the following subsection.

Long-Run Estimation Results

Table 4 below shows the long-run estimation results using FMOLS and CCR methods. All estimation coefficients have the expected sign and they are also significant.

We applied the CCR estimation technique to confirm the robustness of the results attained by the FMOLS. Indeed, the CCR method confirms the validity of the N-shaped relationship, which is reinforced by the existence of causalities from GDP, GDP of a square, and GDP cubic to CO_2 emissions.

Elasticity Estimates

The elasticity for the developed FMOLS estimation technique was calculated (by taking the first derivatives for the main specification equation) to monitor how GDP changes across the studied period and how it has been affecting CO_2 emissions (**Figure 5**).

In the case of cubic specification, using our estimation results, the elasticity equation would be as follows:

$$\eta = 840.47 - 156.02\, lgdppc + 7.23\, lgdppc^2 \tag{5}$$

Where η is the elasticity.

The intervention dummies selected by search algorithm (Autometrics) are the following ones: I_1976, T1_1977, T1_1978, T1_1987, T1_2004, T1_2008. The detected breaks in the late '70s and early 80s could be explained due to the energy crisis of the 1980s, which is known as the oil glut. This crisis had an enormous impact on GDP namely in oil-exporting countries and had a lasting impact over some years. While during the 2004 to 2008 period, the world witnessed a financial crisis that affected several sectors and oil prices peaked at high levels during the same period.

Turning Point

The turning point (TP) differs based on environmental indicators type and other factors such as social and political ones. In this study, the two turning points for a cubic form were calculated using **Eq 5**. The two found values for GDP per

TABLE 4 | FMOLS and CCR estimation results.

Method	Gdp	gdp2	gdp3	Intercept
	Coef. (Std. Er.)	Coef. (Std. Er.)	Coef. (Std. Er.)	Coef. (Std. Er.)
FMOLS	840.471***(253.16)	−78.01***(23.17)	2.41*** (23.17)	−3,014.9***(921)
CCR	797.608***(266.18)	−74.098***(24.36)	2.29***(0.74)	−2,858.3)***(969)

*Notes: The dependent variable is emi; Coef. and Std. Er. are coefficient and standard error; Standard errors are in parentheses; *, **, and *** indicate significance levels at 10, 5, and 1%.*
The used interventions dummies are: I1976, T1_1977, T1_1978, T1_1987, T1_2004, T1_2008.
I1 stands for impulse dummy, while T1 stands for break-in trend dummies.
Source: Estimation Results.

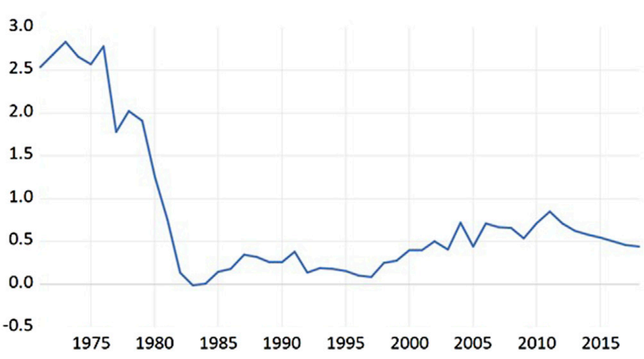

FIGURE 5 | Elasticity results using the FMOLS estimation technique.

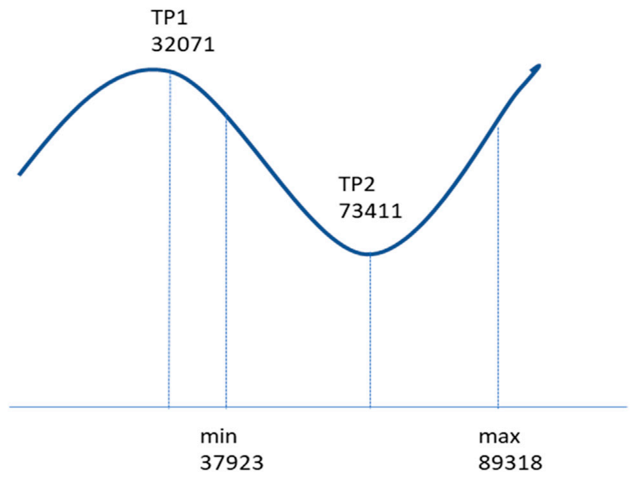

FIGURE 6 | Turning points of the studied logarithmic cubic specifications with GDP per capita range data.

capita are 32,071 and 73,411 in constant 2015 US$ (**Figure 6**). In other words, the smallest emissions that the country experienced during the study period correspond to these TPs. Furthermore, it is worth noting that the first turning point is less than the minimum gdp per capita data range, which implies theoretically that the cubic specification is not relevant for Qatar (**Figure 6**).

Decoupling (DI)

Based on the DI established by the OECD (2002), we estimated two-time intervals; first, covering the entire studied period (1970-2018), second, for 10 years intervals. It is crucial to estimate the DI for the full period to reveal the real evolution of the country. Although, given the number of years used in this study, the estimated DI for the entire period might exclude certain events. In other words, the global effect could adjust numerous partial effects in time. Therefore, and to determine if the studied variables have a linear behavior or if certain events cause significant changes in variables in the short periods, the estimation of DI over 10-year intervals becomes reasonable and crucial. The estimated DI covering the entire studied period resulted in a DI equal to 0.656. According to Yu et al. (2017), this estimated DI falls within the interval $0 < DI < 1$ which represents a relative decoupling effect or weak decoupling. This translates into growing CO_2 emissions as the economy grows, but at a slower rate. For the 10-year interval calculations, we noticed that in the first decade of this study, Qatar had a negative DI, which corresponds to the coupling effect, meaning CO_2 emissions increased as the economy grows but at a faster rate. Following this decade, the DI became positive, which translates into the economy starting to grow at a rate faster than the CO_2 emissions. Therefore, a relative decoupling or a weak decoupling effect is confirmed, which also corresponds to the result found in the index estimated for the entire period. It is worth noting that the DI approach supports the EKC framework analysis.

Discussion of Results and Policy Implications

This study applies the FMOLS approach to support empirical evidence for the EKC hypothesis in Qatar. The CCR technique was also applied as a robustness check to confirm the results found through the FMOLS estimation technique model. The results of the developed estimation technique confirmed an N-shaped relationship for Qatar. Furthermore, a decoupling index was also analyzed for two intervals (**Table 5**). The entire period intervals analysis indicates that Qatar had a relative decoupling. In other words, CO_2 emissions increase as the economy grows, but at a slower rate. Applying decoupling index by 10-year intervals showed a coupling effect for the period between (1970–1980), followed by relative decoupling for all the periods from 1980 to 2010. In the last period

TABLE 5 | DI results analysis.

Period	Decoupling Ratio	Decoupling Index	Decision
1970–2018	0.656	0.343	relative decoupling
1970–1980	1.000	0.000	no decoupling effect (coupling)
1980–1990	0.826	0.173	relative decoupling
1990–2000	0.908	0.091	relative decoupling
2000–2010	0.845	0.154	relative decoupling
2010–2018	1.032	−0.032	no decoupling effect (coupling)

between 2010 and 2018, we found a coupling effect (both CO_2 emissions and income are moving at the same rate).

By applying EKC and DI analysis, we can conclude that CO_2 emissions are triggered by economic development. Accordingly, both variables income and environmental degradation are simultaneously increasing. Moreover, the analysis supports and confirms a cubic polynomial or N-shaped relationship between environmental degradation and income in Qatar. This translates into the EKC framework that is not valid for the studied country. As an alternative, beyond a certain income level, increased income might once again lead to a positive relationship between economic growth and environmental degradation, as is typical of a cubic polynomial relationship (de Bruyn et al., 1998). Additionally, beyond the second turning point, the impact of GDP on emissions is getting weaker which results in CO_2 emissions increasing again faster than GDP. In other words, current policy measures might not be sufficient for CO_2 emissions to fall to the desired level and additional measures may be needed.

As **Figure 5** shows the elasticity for the period between 1970 and 1980 was greater than 1, which suggests that the emissions are more than proportionally affected by the change in GDP. While in the remaining period between 1981 and 2018, the calculated elasticity was less than 1, which implies that the demand is relatively insensitive to GDP or inelastic. In other words, when GDP increases, CO_2 emissions remain unchanged. These estimates are also following the DI analysis results. If emissions increase due to GDP growth this implies positive GDP elasticity, similar to the findings we have in **Figure 5** for the period between 1970 and 1982. Furthermore, if elasticity is greater than zero but less than 1, then emissions increase less fast than GDP, implying relative decoupling. In the case of absolute decoupling, the GDP elasticity has to turn negative, which is the case in the year 1983, meaning as GDP increases, emissions will drop.

Moreover, the elasticity analysis in **Figure 5** shows that a 1% change in GDP will result in a 2.5% change in CO_2 emissions in Qatar as in 1970. This trend has changed and dropped tremendously in the following years. Focusing on the last 10 years of the study period (2008—2018), a 1% change in GDP has resulted in 0.65 and 0.44% changes in CO_2 emission as in 2008 and 2018 respectively. This trajectory of a drop is very relevant to the country as several measures have been applied, namely over the last 10 years, to reduce emissions.

The confirmation of the N-shaped relationship for Qatar can be clarified by the growth of the economy and mainly over the last few decades which was also characterized by intensive energy use. Furthermore, Qatar faces a critical tradeoff between boosting economic development and balancing CO_2 emissions, as economic development has resulted in increased environmental degradation. Given the current 2030 vision, this trend is expected to alter in the long run. The country will witness additional growth in the economy, while CO_2 emissions are expected to fall.

All these programs combined should contribute positively to environmental degradation reduction and enhance the productivity of the sectors. Across the different sectors, energy efficiency measures should be developed, namely during economic growth periods. These measures could be applied and tailored to meet the specific requirements of each sector.

From a policy perspective, a clear understanding of variables and their causality is key to designing effective policies that tackle environmental degradation problems. Therefore, confirming the validity of the N-shaped along with the long-run relationship across the variables inform policymakers that the growth of the economy over the last decade has strong correlations with environmental degradation. Thus, strict policies that balance environmental degradation and economic development should be in place. The current vision of diversifying the economy is timely and well placed to reduce total emissions and enhance economic development.

Finally, the obtained estimates are consistent with the nature of the country. The high population growth accompanied by high economic growth rate increases incomes and leads to increased demand for different resources including energy ones, which in turn increases total CO_2 emissions. It should be noted that all the estimated coefficients across the estimation methods are very close to each other, indicating the robustness of the obtained results. Unfortunately, we are unable to compare the numerical values we obtained in this research with those from other studies as we could not find any prior econometric studies on this topic for Qatar employing the same methodology.

CONCLUSION

In this study, we investigate the relationship between carbon emissions and economic development in Qatar. Several cointegration methods are applied to investigate the long-run relationship between variables and carbon emissions. The investigation was based on testing the validity of the EKC hypothesis and analyzing the decoupling index over the study period. The methodology selected was FMOLS approach due to its capability to include dummies to monitor for events that might have happened over the 48 years considered in the study without impacting its findings, as well as allowing the separation of short and long-run estimates, which are vital for confirming the EKC hypothesis. Furthermore, a robustness check was performed to confirm the findings obtained with the main approach, the FMOLS, and the CCR estimation techniques were utilized. The Granger causality test was also completed. The results obtained with CCR are in accordance with the results of the FMOLS estimation technique.

The empirical analysis of the studied methods shows that there is an evidence of N-shaped relationship between income and environmental degradation over the study period. The results of the Granger causality test confirm that GDP causes CO_2 emissions, which verifies the results of the FMOLS estimation technique.

Regarding the DI approach, it has been estimated over two-time intervals, for the entire study period and over a 10-year interval to monitor the evolution of the DI approach, and for the whole period, to reflect the overall effect. For the 10-year interval calculations, we noticed that in the first decade of this study, Qatar had a negative DI, which corresponds to the coupling effect, meaning CO_2 emissions increased as the economy grows but at a faster rate. Following this decade, the DI became positive, which translates into the economy starting to grow at a rate faster than the CO_2 emissions. Therefore, a relative decoupling or a weak decoupling effect is confirmed, which also corresponds to the result found in the index estimated for the entire period. It is worth noting that the DI approach supports the EKC framework analysis.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

SS: Conceptualization, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing - original draft. MC: Writing - final draft and policy implications.

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