

Abid, Mehdi

## Article

# How does renewable energy consumption affect environmental quality in Saudi Arabia? : evidence from quantile regressions

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## Kontakt/Contact

ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics  
Düsternbrooker Weg 120  
24105 Kiel (Germany)  
E-Mail: [rights\[at\]zbw.eu](mailto:rights[at]zbw.eu)  
<https://www.zbw.eu/>

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# How Does Renewable Energy Consumption Affect Environmental Quality in Saudi Arabia? Evidence from Quantile Regressions

Mehdi Abid\*

Department of Finance and Investment, Al Jouf University, Saudi Arabia. Email: [meabid@ju.edu.sa](mailto:meabid@ju.edu.sa)

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## ABSTRACT

This paper explores the relationship between renewable energy consumption, non-renewable energy, economic growth and urbanization on CO<sub>2</sub> emissions of Saudi Arabia during 1990–2019 period. Using the OLS method and the quantile approach developed by Powell (2022), the results prove that the consumption of renewable energy significantly reduces the level of CO<sub>2</sub> emissions; moreover, its impact increases with higher quantiles. On the other hand, non-renewable energy consumption increases CO<sub>2</sub> emissions, while its effect decreases with higher quantiles. The empirical results also confirm the validity of the EKC hypothesis for the case of Saudi Arabia. Policymakers should implement policies and regulations to promote the adoption and use of renewable energy to improve environmental quality.

**Keywords:** EKC Hypothesis, Renewable Energy, Non-renewable Energy, Saudi Arabia, Quantile Regression

**JEL Classifications:** F47, G15, G17, Q20, Q40

## 1. INTRODUCTION AND LITERATURE REVIEW

Like capital and labor, renewable energy is a factor of production and has a major place in economic, social, political and environmental aspects (International Energy Agency, 2014). While it is recognized that renewable energy has an influence on economic growth, the fact remains that its influence on the environment should not be overlooked. Today, one of the major environmental concerns is global warming caused by the accumulation of greenhouse gases. Indeed, the energy sector, based on the consumption of fossil fuels, being the main cause of these gases, has been undergoing structural changes for several years in terms of energy efficiency and the introduction of renewable energies (Alharthi et al., 2021; Dai et al., 2016; Spiegel-Feld et al., 2016; Adebayo and Demet, 2020; Shahbaz, 2018). Given the need to design efficient energy policies, the causal link between energy consumption and economic growth could be a decisive element. Indeed, in recent years, the debate on the causal link

between the consumption of renewable energies and environmental degradation closely followed by advances in econometric theory, energy economics and environmental economics has flowed a lot of ink (Aydoğan and Vardar, 2020; Salahuddin et al., 2015; Solarin and Ozturk, 2015; Saidi and Omri, 2020; Jebli et al., 2020; Ullah et al., 2020). It then becomes necessary to explore the link between renewable energy consumption and environmental degradation, as well as its potential determinants.

Saudi Arabia is particularly concerned: Saudi Arabia generated more electric power in the Middle East than any other country, with an estimated 362 terawatt hours in 2019, which was about the same as in 2018 (EIA, 2019). After increasing at an average annual rate of 6% between 2000 and 2015, growth in power generation declined significantly because population growth slowed, GDP growth slowed, energy efficiency and demand-side management measures were implemented, and electricity prices increased between 2016 and 2018 (APICORP, 2019). Power generation declined by 1% in 2020, according to data from BP Statistical Review of World Energy (2021), as a result of the economic

slowdown from the COVID19 pandemic. Residential power use rose because of the COVID-19-related lockdowns and restrictions, but electricity sales to the commercial and government sectors fell (SEC, 2020). Saudi Arabia fueled nearly all of its electricity generation with natural gas (61%) and crude oil (39%) in 2020, although the Saudi government plans to diversify fuels consumed for electricity output to increase available crude oil for export and to reduce its carbon emissions (BP Statistical Review of World Energy, 2021). The share of natural gas rose substantially over the past decade from 42% of total power generation in 2010 because of expanded natural gas-fired generation capacity that is supported by higher production (BP Statistical Review of World Energy, 2021). In 2019 and 2020, growth in natural gas production slowed substantially, which encouraged crude oil use in the power sector, particularly during the peak summer season. The Saudi government intends to replace most of the crude oil burn and diesel-fired power generators with natural gas and heavy fuel oil in the next few years (Reuters, 2021).

Several studies have confirmed the feedback causality between CO<sub>2</sub> emissions and renewable energy consumption. For example, Apergis et al. (2010) studied the causal relationship between renewable energy consumption and CO<sub>2</sub> emissions in 19 developed and developing countries. The authors used the VECM and ARDL techniques to study this relationship. The empirical results revealed a bidirectional causality between renewable energy consumption and CO<sub>2</sub> emissions. Sebri and Ben-Salha (2014) conducted a study on the causal relationship between renewable energy consumption and CO<sub>2</sub> emissions in BRICS economies. They used annual data from 1971 to 2010 and the VECM model to explore this causal relationship. The results revealed a bidirectional causality between CO<sub>2</sub> emissions and renewable energy consumption. The conclusions of the study by Attiaoui et al. (2017) corroborate those of Sebri and Ben-Salha (2014), who found a bidirectional causality between CO<sub>2</sub> emissions and renewable energy consumption.

Furthermore, Aydoğan and Vardar (2020) investigated the link between renewable energy consumption and CO<sub>2</sub> emissions in E7 countries. The authors used panel ARDL limit tests and the Granger causality technique to explore this interaction. The results revealed a two-way causality between renewable energy consumption and CO<sub>2</sub> emissions. However, in the case of Thailand, the study by Boontome et al. (2017) found no evidence of causality between renewable energy consumption and CO<sub>2</sub> emissions. Some studies have shown that renewable energies have a negative impact on CO<sub>2</sub> emissions. For example, Zoundi (2017) examined the interaction between CO<sub>2</sub> emissions and renewable energy use in 25 selected African economies by applying panel cointegration and ARDL techniques using data between 1980 and 2012. The results revealed that the consumption of renewable energy improves the quality of the environment. In the study conducted by Qi et al. (2014) on China for the period between 2010 and 2020, the authors found that renewable energy consumption decrease environmental degradation. Additionally, several studies have agreed that renewable energy consumption improves environmental quality (Salahuddin et al., 2015; Rauf et al., 2018; Saidi and Omri, 2020; Jebli et al., 2020; Ullah et al., 2020).

To this end, this paper tests the validity of the EKC hypothesis and investigates the long run relationship between CO<sub>2</sub> emissions and non-renewable energy consumption, renewable energy consumption, economic growth and urbanization. The rest of the paper is organized as follows: Section 2 presents Methodology. Section 3 yields estimation results, and Section 4 provides conclusions and policy recommendations.

## 2. METHODOLOGY

### 2.1. Quantile Regression

Quantile regression (QR), introduced by Powell (2022), is a common approach in econometrics for parameter estimation and model analysis. Compared to the ordinary least squares (OLS) method which estimates the conditional mean of the dependent variable, the QR is based on the median and aims to estimate the quantiles of the dependent variable. Suppose that  $y$  and  $x$  are respectively dependent and independent variables. The assumption of linearity in the conditional relation leads to the following:

$$y_p = x'_p \alpha_p \quad (1)$$

Where  $\alpha_p$  is the coefficient of the quantile  $p$ ,  $p \in [0, 1]$ .  $\alpha_p$  can be estimated by minimizing the following sum of the objective function of absolute differences:

$$\min_{\alpha_p} \sum_{i \in \{y_i \geq x'_i \alpha_p\}} p |y_i - x'_i \alpha_p| + \sum_{i \in \{y_i < x'_i \alpha_p\}} (1-p) |y_i - x'_i \alpha_p| \quad (2)$$

The parameters of equation (2) can be evaluated using linear programming (Buchinsky, 1995). By gradually varying  $p$  from 0 to 1 and solving for  $\alpha_p$ , we obtain for each explanatory variable a graph explaining its relationship with the dependent variable. The QR estimate is more robust to outliers and large data variations than the OLS estimate. More importantly, when the distribution of the dependent variable does not follow the normal distribution, which is the case for most environmental and economic data, the OLS estimation becomes unreliable while the QR estimation can detect heterogeneous relationships with the dependent variable (Lin and Xu, 2018).

### 2.2. Model Specifications

This study uses the EKC framework in Eq. (1), following recent studies by Chen et al. (2020) and Usama et al. (2020), to analyze the impacts of economic growth, renewable energy consumption, non-renewable energy consumption and urbanization on CO<sub>2</sub> emissions:

$$\begin{aligned} CO_{2t} = & \alpha_0 + \alpha_1 GDP_t + \alpha_2 GDP_t^2 + \alpha_3 REC_t \\ & + \alpha_4 NREC_t + \alpha_5 URB_t + \varepsilon_t \end{aligned} \quad (3)$$

Where CO<sub>2</sub> is the carbon dioxide emissions per capita; GDP is the economic growth measured by the real gross domestic product per capita in constant 2015\$; RENC denotes renewable energy consumption; NREC is the non-renewable energy consumption; URB is urbanization.

To better understand the data, this study reports statistics of CO<sub>2</sub> emissions, real GDP, renewable energy consumption, non-

**Table 1: Descriptive statistics**

Variables	Mean	Minimum	Maximum	Median	SD	Skewness	Kurtosis
CO <sub>2</sub>	0.76	-2.55	2.89	1.05	1.22	-0.64	3.22
GDP	8.22	4.27	10.62	8.03	1.35	-1.34	3.54
RENC	5.24	1.98	7.53	6.34	2.06	-0.57	3.84
NREC	7.56	4.081	11.02	8.31	1.11	-0.51	3.77
URB	3.98	1.67	4.01	4.21	0.12	-1.06	4.01

SD: Standard deviation

**Table 2: Results of unit root tests**

Variables	ADF		PP	
	0	First difference	Level	First difference
CO <sub>2</sub>	-1.101	-4.522***	-0.122	-4.507***
GDP	-1.214	-7.974***	-0.214	-6.297***
RENC	-0.044	-4.011***	-0.640	-3.171***
NRENC	-0.248	-6.541***	-0.054	-6.088***
URB	-0.108	-5.051***	-0.201	-4.121***

\*\*\*indicates 1% level of significant respectively.

renewable energy consumption and urbanization. Table 1 shows the mean, median, minimum, and maximum values of the data, as well as the skewness and kurtosis statistics. It can be said that the analyzed variables are not symmetric and normally distributed because the values of the skewness statistics are different from zero. In addition, the values have heavier tails than a normal distribution because the flattening stats are greater than +3. Finally, the descriptive statistics demonstrate the heterogeneity of the data, suggesting the use of the quantile regression method for reliable empirical results.

### 3. EMPIRICAL RESULTS

Before estimating equation (3), we use the Augmented Dickey-Fuller (ADF, 1979) and Phillips-Perron (PP, 1988) unit root test to determine the order of integration of these four variables. Table 2 shows the results of the unit root test in levels and first differences with trend and intercept. The results demonstrate that we cannot reject the null hypothesis of unit root for four level variables. However, we reject the null hypothesis of a unit root at the 1% significance level for the first difference of these three variables. Based on the ADF and PP test results, these four data series are integrated in the first order (I(1)).

Table 3 presents the results of the OLS model and the quantile regressions. The results of the OLS and quantile regressions confirm the existence of the EKC hypothesis, except for the lowest quantile. According to the OLS results, a 1% increase in GDP increases CO<sub>2</sub> emissions by 0.661%, and a 1% increase in GDP<sup>2</sup> reduces CO<sub>2</sub> emissions by 0.021% with a statistical significance of 1%. Therefore, the results of the OLS show an inverted U-shaped pattern, and the validity of an inverted U-shaped pattern of the EKC in Saudi Arabia indicates that this country has reached a threshold of economic growth and is point to a green growth phase in its production (Grossman and Krueger, 1995).

Quantile regression results are provided for the quantiles of 0.05, 0.25, 0.50, 0.75 and 0.95 and provide a detailed analysis of the determinants of carbon emissions across the different emission

quantiles of carbon. The impact of economic growth on CO<sub>2</sub> emissions is positive and statistically significant at all quantiles except the 0.05<sup>th</sup> quantile, and the effect of growth on emissions is stronger at other quantiles. The impact of squared economic growth is negative and statistically significant for all quantiles other than the 0.05<sup>th</sup> quantile. Carbon emissions increase significantly with growth, and the impact is higher in other quantiles. On the other hand, economic growth reduces emissions to a certain level. Thus, the results depict an inverted U-shaped pattern for all quantiles, and the EKC turning points are positioned at different levels. These findings are consistent with findings from previous studies (Dogan and Seker 2016; Anwar ERlkafi, 2021).

On the other hand, according to the OLS regression results, the impact of renewable energy consumption on carbon emissions is statistically insignificant, whereas this impact is statistically significant for all quantiles in the quantile regressions. The impact of renewable energy consumption increases across the quantiles and the coefficient becomes higher for the 0.95<sup>th</sup> quantile. The effect of renewable energy consumption on carbon emissions is also supported by previous literature (López-Menendez et al., 2014; Shafiei and Salim 2014; Álvarez-Herranz and BalsalobreLorente 2015; Al-Mulali et al., 2016; Akram et al., 2020).

The results of OLS and quantile regressions indicate a positive and statistically significant impact of non-renewables on emissions. This finding was reported with Farhani and Shahbaz (2014) for MENA countries and in Bölük and Mert (2015) for Turkey. OLS results indicate that a 1% increase in non-renewable energy consumption increases CO<sub>2</sub> emissions by 0.51%. The results of the quantile regression are interesting since the impact of non-renewable energy consumption shows a decreasing trend when going from the 0.05<sup>th</sup> quantile to the 0.95<sup>th</sup> quantile. Non-renewable energy consumption increases CO<sub>2</sub> emissions. A coefficient higher non-renewable energy than renewable energy is also reported. This is because the consumption of renewable energy remains lower; thus, the impact of renewable energy consumption is still limited compared to non-renewable energy consumption. The lower quantiles of the analysis could rely more on fossil fuels to achieve economic progress, resulting in a larger impact of non-renewables on CO<sub>2</sub> emissions (Zafar et al., 2017).

It can be seen that urbanization positively influences CO<sub>2</sub> emissions in the OLS and quantile regressions. According to the regression of the OLS model, if the URB increases by 1%, CO<sub>2</sub> emissions increase by 0.124%. Quantile regression results show that the impact of URB is higher in lower quantiles. From 0.05<sup>th</sup> quantile to 0.95<sup>th</sup> quantile, the coefficient is 0.781, 0.525, 0.506, 0.304, and 0.202, respectively. Urbanization is a factor that deteriorates environmental quality,



**Table 3: Results from quantile regression**

Variables	OLS	Quantile regression				
		q0.05	q0.25	q0.5	q0.75	q0.95
GDP	0.661***	0.504	0.307***	0.567***	0.706***	0.901***
GDP <sup>2</sup>	-0.021***	-0.011	-0.021***	-0.027***	-0.033***	-0.031***
RENC	-0.03	-0.03**	-0.022**	-0.043	-0.041***	-0.069***
NRENC	0.510***	0.674***	0.537***	0.466***	0.418**	0.368***
URB	0.124**	0.781**	0.525***	0.506***	0.304***	0.202*
Constant	-9.652***	-10.861***	-8.651***	-9.658***	-11.067***	-10.354***

\*\*\*, \*\*, and \*The significance level of 1%, 5%, and 10%, respectively. OLS: Ordinary least squares

suggesting that urbanization is a major source of emissions. Our results are in agreement with Chu et al. (2022). The difference between the quantiles could be explained by the various stages of development (Poumanyvong and Kaneko, 2010).

## 4. CONCLUSIONS AND POLICY IMPLICATIONS

This article examined the determinants of carbon dioxide emissions by considering the impact of renewable and non-renewable energy consumption under the EKC using the quantile approach of OLS and Powell (2022) in Arabia Saudi during the period 1990-2015. The quantile regression method provides an understanding of the differences between different carbon emission levels, allowing us to interpret the relationship between carbon dioxide emissions and the determinants at different emission levels.

The purpose of this article is to determine whether renewable and non-renewable energy consumption affects environmental degradation in Saudi Arabia during the period 1990-2019. Using the OLS method and the quantile approach developed by Powell (2022), the results of the analysis validate the existence of EKC and describe an inverted U-shaped pattern in both the OLS regression and the quantile approach. Economic growth increases carbon emissions up to a certain threshold and then slows emissions. The results of the regression of the quantiles give us valuable results in determining different thresholds of the level of GDP. The GDP coefficients in the EKC curve are 0.504; 0.307; 0.567; 0.706 and 0.901 for the 5<sup>th</sup>, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> quantiles, respectively, suggesting that the effect of economic growth on environmental degradation is volatile. This result is not only significant for Saudi Arabia, but may also have valuable implications for other countries.

Consistent with previous studies, renewable energy consumption has a statistically significant negative effect on carbon emissions. This result is also valid for all quantiles. However, the effect of renewable energy consumption is not significant for the OLS regression. The results of the quantile method demonstrate that the substitution of non-renewable energies is an important factor in reducing environmental degradation. However, for Saudi Arabia, there is more room to adopt greener energy sources to reduce CO<sub>2</sub> emissions due to the scale effect. Saudi Arabia should pursue effective strategies to find cheaper avenues to intensify the use of renewable energy sources. The insignificant results of the OLS regression also indicate that future research should adopt quantile approaches, as they give us robust results when the data exhibit heterogeneity. On the other hand, the consumption of

non-renewable energy significantly increases CO<sub>2</sub> emissions in both approaches.

These results provide new insights for policymakers in the Saudi Arabia. This country should focus on policies to promote the adoption and use of renewable energy sources to prevent environmental deterioration. This is particularly crucial for the most carbon-emitting sectors; thus, the promotion of research and investment activities to increase the production and consumption of renewable energy sources should be a priority to reduce carbon emissions. Despite the high costs of renewable energy, the government should promote investment in different clean energy sources, such as wind and solar. Since renewable energy sources are critically important in reducing emissions, it is essential to design regulations to prevent environmental degradation. In addition, the country should allocate more funds to technological advancements and research to encourage the shift from non-renewable sources to cleaner renewable energy sources. In addition, policymakers in this country should design and implement policies aimed at economic growth to achieve a steady decline in carbon emissions. Growth-oriented economic policies encourage the use of cleaner sources and could enhance the reduction of environmental degradation.

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