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Research Article

Impact of Globalization and Renewable Energy Consumption on Environmental Degradation: A Lesson for South Africa

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Abstract. South Africa is one of Africa's most polluted countries, with rising CO_2 emissions posing a threat. South Africa must discover ways of minimizing pollution and take necessary steps before it is too late in order to achieve sustainable growth. For this purpose, this research assesses the ecological consequences of globalization, nonrenewable energy use, economic growth and renewable energy consumption in South Africa. The study leverages on the non-linearity advantages of the novel quantile on quantile regression (QQR) method for a robust analysis as opposed to the use of conventional linear approaches, thereby overcoming conspicuous shortfalls in extant studies, while offering a detailed explanation of the overall dependency structure between CO_2 emissions and globalization, nonrenewable energy use and renewable energy use using a dataset covering the period between 1970 and 2018. The outcomes suggest that nonrenewable energy use, globalization, and economic growth contribute to environmental degradation in the majority of the quantiles, while the effect of renewable energy use on CO_2 is not strong at all quantiles. The study highlights that economic expansion, nonrenewable energy use and globalization play key roles in in mitigating environmental sustainability in South Africa, while renewable energy is not sufficient to meet environmental requirements.

Keywords: Economic growth; Carbon emission; Globalization; Renewable Energy Consumption; Quantile-on-Quantile Regressions

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1. Introduction

Environmentalists, energy economists, and policymakers around the world who plan and enact energy and environmental policies have been debating the effects of constant demand on biodiversity and the environment. Considering the overall awareness of the need for safer, green energy sources, this is reasonable (Adebayo and Kirikkaleli, 2021). According to the literature on energy economics, energy consumption is associated with economic growth because increased energy use leads to increased economic expansion (Bekun *et al*. 2020; Alola *et al*. 2021). However, a rise in economic activity will lead to increased energy use and, as a result, a decrease in energy consumption. According to Halicioglu (2009) before the industrial revolution, energy use and economic expansion were found to be linked. Nevertheless, this association is to blame for the increase in environmental pollution caused by CO_2 emissions as a result of massive industrial production and fossil fuel usage for long-term economic development. A growing economy requires more energy and production to maintain actual economic growth (Ozturk, 2010; Fareed *et al*. 2021).

The use of energy is expected to augment pollution levels, and there is a strong link between pollution and economic expansion. As a result, the current research aims to evaluate the effect of energy use, globalization, and GDP on CO_2 emissions in South Africa. Since the innovative study of Grossman and Krueger (1991), the effect of economic growth on CO_2 emissions has been extensively investigated by scholars in the literature. In earlier environmental degradation studies, renewable energy consumption (REC) was also examined. Since decreasing CO_2 emissions by reducing energy use can have a detrimental impact on economic growth, governments have been exploring alternative energy sources such as nuclear and renewable energy as a replacement for fossil

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fuels (Pata, 2021). Cleaner renewable energy sources and technologies create less secondary waste, promote energy security, fulfil current and future economic and social demands, and decrease ecological concerns (Pata & Caglar, 2021; Akadiri & Adebayo, 2021; Vaseer *et al.* 2021).

Furthermore, several scholars have debated the effects of globalization on the environment on a regular basis, but the actual impact of globalization on CO2 emissions has yet to be determined. In other words, certain studies have demonstrated that globalization can lead to an upsurge in the degradation of the environment. For instance, the study of Kirikkaleli *et al.* (2020) on the relationship between CO_2 emissions and globalization in Turkey between 1970 and 2017 revealed that globalization contribute to environmentantal degradation. Furthermore, the study of Acheampong on the emissions-globalisation nexus in Australia using the novel quantile-on-quantile regression revealed that increase in globalization contribute to environmental degradation in Australia. Nevertheless, some studies found negative association between globalization and CO_2 emissions. For instance, the study of Yuping *et al.* (2021) on the nexus between globalization and CO_2 emissions in Argentina revealed that glbalisation mitigate environmental degradation. Similarly, the study of Rjoub *et al.* (2021) on the nexus between globalization and CO_2 emissions in Sweden disclosed that globalization aid in curbing environmental degradation in Sweden. The aforementioned discussions demonstrate that globalization is becoming increasingly prominent and that it is becoming an effective proponent of a country's economic growth. In general, globalization can lower tariffs and taxes while increasing trade openness and financial development, all of which can help stimulate economic expansion (Adebayo & Kirikkaleli, 2021).

Why South Africa? South Africa is the world's 12th largest emitter of greenhouse gases, and its fossil-fuel-based CO2 emissions have risen seven-fold since the 1950s, with coal accounting for about 90% of these emissions (Winkler, 2007). When it comes to ecological degradation in Africa, South Africa is a fascinating country to research. According to recent international research, whereas Kenya, Zambia, Ghana, and Mozambique are among the nations with the least environmental destruction, South Africa has one of the worst environmental records in Africa. Apart from environmental depletion, the economy of South Africa is heavily reliant on its energy market, thus explaining why it is included in this report. South Africa's energy sector contributes around 15% of the country's GDP, with coal being the primary energy source (Enerdata, 2019). Coal dominates South Africa's energy market, accounting for 69 percent of the primary energy supply in 2016, followed by crude oil with 14 percent and renewables with 11 percent. Over the same time frame, nuclear contributed 3% to the overall primary supply, whereas natural gas contributed 3% (WEC, 2016). Furthermore, South Africa is the world's 6thbiggest producer of coal, accounting for about 71 percent of the total electricity supply. Despite the fact that it has limited oil and natural gas production, it imports enough oil to meet its needs. The nation's energy sector employs nearly 250,000 workers and adds approximately 15% of the nation's real GDP (DEM, 2016). In South Africa, there are three main energy-consuming industries, namely the residential, transportation, and manufacturing industries. According to a DEM (2016) survey, these three industries accounted for approximately 80.4% of the total consumption of energy in South Africa in 2002. The manufacturing industry is the nation's biggest energy consumer, consuming about 36% of total energy generated, followed by the transport industry (26%), and the residential sector (18%). Subsequently, industrial demand dominates South Africa's electricity (power) consumption, accounting for 63% of the total consumption of electricity.

Based on the aforementioned interesting facts about South Africa, one may deduce that the country's economy is based on the consumption and production of energy. Therefore, we aim to investigate the relationship between CO_2 emissions, globalization, real growth, and energy use. This research expands the scope of the literature by examining the topic in South Africa, where few studies have been undertaken owing to the country's energy mix. The results of this study have the potential to answer the following questions: (i)What is the influence of nonrenewable energy consumption and economic growth on CO_2? (iii)Does globalization trigger CO_2 emissions in South Africa? and (iv)Does renewable energy use help in mitigating CO_2 emissions. Table 1 presents a summary of related studies.

Based on the reviewed literature, it is clear that the findings are mixed, which suggests that further studies are warranted on the association between CO_2 and globalization, economic growth, and nonrenewable energy consumption. This study contributes to the literature in the following ways: To the best of the authors' knowledge, this is the first empirical study to employ Sim and Zhou's (2015) QQ technique to examine the impact of globalization, nonrenewable energy consumption, economic growth and renewable energy use on CO_2 emissions in South Africa. Acheampong & Adebayo (2021) and Rjoub *et al.* (2021) claimed that econometric techniques are critical in attaining impartial study results, and they advocated for the use of sophisticated new econometric techniques. Because it combines the ideas of quantile regression (QR) with non-parametric estimate analysis, the QQ approach is beneficial. Outliers are not a problem for the QQ method, and it can account for slope heterogeneity. Second, according to the literature review, panel data modelling approaches are used in the majority of empirical studies. Although panel data estimates are efficient, due to country heterogeneities, their findings and policy implications may not apply to individual nations. Based on this reasoning, this research contributes to the existing knowledge by analyzing the influence of globalization, nonrenewable energy consumption, and renewable energy use on CO_2 emissions using a time-series method to provide policy suggestions for South Africa. Finally, this research relies on the KOF globalization index to give a wider perspective than previous studies that have relied on trade openness or foreign direct investment as proxies for globalization. Finally, this study is relevant for policy since the outcomes will contribute to the formulation and implementation of future climate change policies in South Africa

Table 1
Summary of Studies

Authors	Period	Country(s)	Technique(s) Used	Findings
Impact of Economic Growth on CO_2 Emissions				
Tufail *et al.* (2021)	1990-2018	Highly Decentralized Economies	CS-ARDL, Panel Causality	GDP➔CO_2 (+)
Akinsola *et al.* (2021)	1965-2018	South Korea	Wavelet Tools	GDP➔CO_2 (+)
Kihombo *et al.* (2021)	1990-2018	Emerging Nations	Panel AMG, CUP	GDP➔CO_2 (+)
Awosusi *et al.* (2021)	1965-2018	Indonesia	Wavelet Technique	GDP➔CO_2 (+)
Salari *et al.* (2021)	1997–2016	United States	ARDL	GDP➔CO_2 (+)
Impact of Nonrenewable Energy Consumption on CO_2 Emissions				
Abbasi *et al.* (2021)	1971-2018	Pakistan	Dynamic ARDL	EC➔CO_2 (+)
Mohsin *et al.* (2021)	2000–2016	developing Asian economies	Random Effect approach	EC➔CO_2 (+)
Wang & Zhang (2021)	1990–2015	182 countries	Panel Technique	EC➔CO_2 (+)
Nawaz *et al.* (2021)	1980–2016	BRICS and OECD regions	QARDL	EC➔CO_2 (+)
Impact of Globalization on CO_2 Emissions				
Muhammad,& Khan (2021)	1991–2018	31 developed and 155 developing countries	GMM	GLO➔CO_2 (-)
Oluwajana *et al.* (2021)	1991–2012	LAC countries	Panel ARDL	GLO➔CO_2 (-)
Haseeb *et al.* (2018)	1994-2014	BRICS nations	Panel DOLS, FMOLS	GLO➔CO_2 (-)
Lyulyov *et al.* (2021)	1996–2017	developing and advanced countries	Panel ARDL	GLO➔CO_2 (+)
Impact of Renewable energy use on CO_2 Emissions				
Kirikkaleli & Adebayo (2020)	1980–2017	Global Economy	FMOLS, DOLS	REC➔CO_2 (–)
Kirikkaleli & Adebayo (2021)	1990–2015	India	ARDL	REC➔CO_2 (–)
He *et al.*(2021)	1990-2018	Mexico	ARDL	REC➔CO_2 (+)
Pata & Caglar. (2021)	1980–2016	China	ARDL	REC≠CO_2

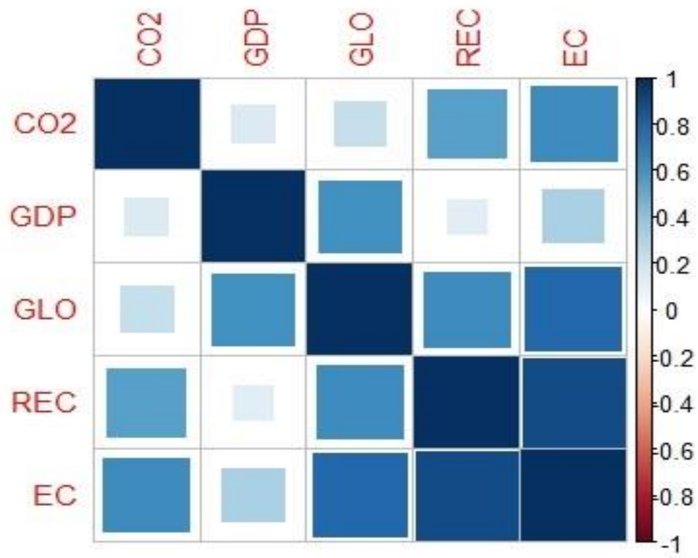

Fig 1. Correlation box (Source: Authors' compilation with R-Programme)

Table 2
Data Description

Symbol	Variables	Source
CO_2	Environmental degradation	British Petroleum Database
GDP	Economic Growth	World Bank Database
GLO	Globalization	Gygli *et al.* (2019)
EC	Nonrenewable Energy Consumption	British Petroleum Database
REC	Renewable Energy Use	British Petroleum Database

Table 3
Descriptive statistics

	CO_2	EC	GDP	GLO	REC
Mean	8.552	1013.7	6520.1	50.310	27.602
Median	8.609	1038.6	6388.2	40.697	35.180
Max	9.950	1429.5	7582.6	70.793	68.134
Min	6.779	421.4	5517.5	35.106	0.0695
SD	0.848	319.5	629.75	14.539	18.393
Skewness	-0.034	-0.354	0.3200	0.3389	-0.0937
Kurtosis	2.104	1.907	1.9768	1.2979	2.0729
JB	1.646	3.464	2.9734	6.8528	1.8262
Prob	0.4389	0.176	0.2261	0.0325	0.4012

Note: SD denotes standard deviation, Min and Max stand for Minimum and maximum

2. Data and Methodology

2.1. Data

The description, source, and measurement of the dataset are depicted in Table 2. Furthermore, a summary of the variables utilized in this empirical analysis is presented in Table 3. The skewness and kurtosis unveiled that the data conform to normality. The Jaque-Bera statistics unveil that EC and GLO are not normally distributed while GDP and CO_2 conform to normal distribution. The correlation between the indicators is depicted in Figure 1 (correlation box) which ranges from blue (positive correlation) to red (negative correlation). The outcomes of the correlation box disclosed that GDP, renewable energy use, and trade openness have a negative correlation with CO_2 emissions which infers that an increase in trade openness, renewable energy, and GDP is followed by a decrease in CO_2 emissions.

2.2. Methods

This study utilized the QQ method initiated by Sim & Zhou, (2015) to assess the effect of renewable energy use, economic growth, globalization and nonrenewable energy consumption on CO_2 emissions. The QQ approach is an improvement of the traditional quantile regression (QR) model that allows researchers to investigate how an indicator's quantiles influence the quantiles of another indicator. The use of nonparametric estimations and quantiles is fundamental to this technique. To begin, traditional quantile regression is utilized to explore the impact of an independent variable on the dependent variable's various quantiles. The traditional quantile regression technique is utilized as an enhancement to the traditional least square technique. Unlike the linear regression model, quantile regression investigates the impact of a variable not only on the conditional mean of the dependent variable, but also on distinct quantiles. In this sense, the quantile regression model, rather than the least square method, gives a more comprehensive relationship.

Moreover, Cleveland (1979) and Stone (1977) propose using standard linear regression to explore the effect of the independent variable's exact quantile on the dependent variable. Investigators can study the impact of different quantiles of the dependent variable on different quantiles of the dependent variable by combining these two techniques, namely conventional quantile regression and classic linear regression. As a consequence, rather than using standard techniques like OLS and simple quantile regression, combining these two approaches can assist in understanding the fundamental connection. Additionally, we use Sim and Zhou's (2015) Quantile-on-Quantile estimate to explore the effect of different quantiles of X on the various quantiles of Y using the following nonparametric quantile regression model.

$$Y_t = Y^{\sigma}(X_t) + \mu_t^{\sigma} \quad (1)$$

Where, Y_t illustrates dependent variable in period t, X_t illustrates independent variable in time t. σ is the σ^{th} quantile on the distribution of X. Additionally, μ_t^{σ} depicts quantile error term, where estimated σ^{th} quantile is equal to zero. Furthermore, $\propto^{\sigma}(.)$ is unknown since no information is available on the relationship between X and Y. Moreover, understanding bandwidth selection is essential when utilizing nonparametric analysis. Finally, it is vital to understand bandwidth selection when doing nonparametric analysis. This bandwidth assists in the simplicity of the target point, the size of the quarter backgrounds, and, as a result, bandwidth gearshifts the pace of the conclusion. A large bandwidth, h, decreases variance whilst raising estimate deviation, and vice versa. We use a bandwidth value of h = 0.05 in this investigation, as advised by Sim and Zhou (2015).

3. Results

3.1 Pre-estimation results

It is essential to conduct a linearity test to ascertain the variables' linearity feature. Accordingly, the research utilized the BDS nonlinearity test to verify this. The outcomes of the BDS test are illustrated in Table 4. According to these outcomes, utilizing the normal linear techniques will produce misleading outcomes. Thus, we employed a non-linear method to assess the influence of globalization, economic growth, and nonrenewable enrgy use and renewable energy consumption on CO_2 emissions in South Africa. Moreover, we verified the stationarity characteristics of the variables by employing the traditional ADF and PP unit root tests. The outcomes of the ADF and PP unit root tests are presented in Table 5, which revealed that all the series are stationary at level. Nevertheless, after the first difference was taken, all the series were found to be stationary. Although the present research employed both ADF and PP to capture the variables stationarity features, if there is evidence of a break(s) in the series, these conventional unit root tests will produce misleading outcomes. Thus, we employed both Lee and Strazicich (LS) and Zivot and Andrew (ZA) unit root tests. The advantage of these tests is that they can capture series stationarity features and breaks simultaneously. The findings of the ZA and LS tests are presented in Table 5 and the outcomes show that all the series are stationary at first difference.

3.2 Quantile-on-quantile Regression (QQR) Results

This part of the research presents the main empirical outcomes of the QQ analysis of the impact of non-renewable energy consumption, globalization, renewable energy consumption and economic growth on CO_2 emissions in South Africa. Fig. 2(a–d) reveals the slope coefficient estimates, $\beta_i(\theta,\tau)$ which captures the influence of the τth quantile of X on the θth quantile of Y at various values of θ and τ for South Africa.

The outcomes of the QQ approach are depicted in Figure 2(a-d). Figure 2a depicts the impact of GDP on CO_2 emissions in South Africa. The influence of GDP on CO_2 is negative at low quantiles of GDP (0.1–0.35) and also at low quantiles of CO_2 emissions (0.15–0.35). However, at middle and high quantiles of GDP (0.4–0.95), the impact of GDP on CO_2 is positive at medium and high quantiles of CO_2 emissions (0.4–0.95). In summary, the effect of GDP on CO2 is positive at the majority of combinations of quantiles of GDP and CO_2 emissions which implies that an upsurge in GDP impacts CO_2 positively. In Figure 2b, the effect of EC on CO_2 emissions is positive in all quantiles (0.1-0.95) of both EC and CO_2. This implies that an upsurge in EC impacts CO2 emissions positively in all quantiles. In summary, the influence of EC on CO_2 is positive.

Table 4
BDS Test

	CO_2	GDP	EC	GLO	REC
M=2	18.87*	20.56*	15.35*	25.82*	30.68*
M=3	19.35*	20.29*	16.34*	26.52*	30.56*
M=4	18.95*	19.88*	17.42*	27.63*	29.92*
M=5	18.80*	20.08*	18.89*	29.50*	30.22*
M=6	19.38*	20.74*	20.77*	32.23*	30.35*

Note * signifies 1% level of significance

Table 5
Unit Root Tests

	ADF	PP	ZA		LS	
Variables	I(0)	I(0)	1(0)	Break Date	1(0)	Break Date
CO_2	-2.142	-2.264	-3.221	1981	-5.954	1992 and 2002
GDP	-1.470	-1.161	-3.733	1990	-5.174	1997 and 2003
EC	-1.926	-1.866	-4.962	1981	-4.788	1986 and 2001
GLO	-2.869	-1.653	-3.508	1994	-6.246**	1985 and 1998
REC	-2.172	-1.839	-3.561	1993	-7.041*	1993 and 1997
	1(1)	1(1)	1(1)	Break Date	1(1)	Break Date
CO_2	-7.253*	-7.232*	-7.894*	1998	-7.903*	1986 and 1992
GDP	-4.358*	-4.304*	-5.327*	1989	-6.256*	1983 and 2007
EC	-7.348*	-7.466*	-7.780*	1998	-7.168*	1990 and 1983
GLO	-3.173**	-3.239**	-6.842*	1988	-8.250*	1991 and 2001
REC	-3.267**	-3.792*	-6.943*	1996	-8.621*	1993 and 2004

Note: * and ** represents 1% and 5% level of significance respectively

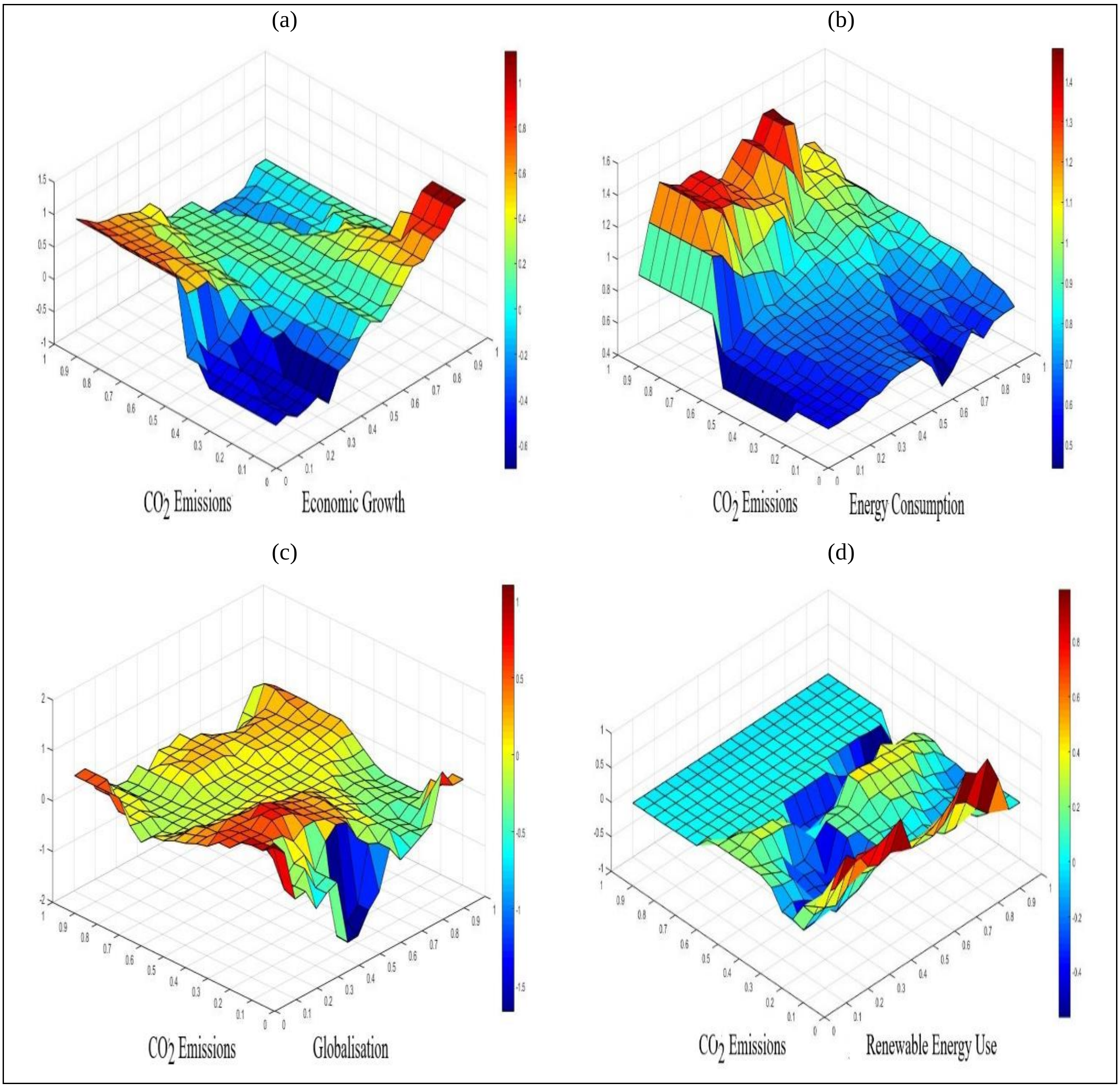

Fig. 2 Quantile-on-quantile (QQ) estimates of the slope coefficient. (a) Effect of GDP on CO_2. (b) Effect of EC on CO_2. (c) Effect of GLO on CO_2. (d) Effect of REC on CO_2

Figure 2c illustrates the effect of GLO on CO_2 emissions in South Africa. At all quantiles of GLO (0.1-0.95) and all quantiles of CO2 (0.1-0.95), the effect of GLO on CO_2 is positive. This demonstrates that an upsurge in GLO will exert a positive impact on CO_2, thereby increasing environmental degradation in South Africa. Lastly the influence of renewable energy use on CO_2 emissions is illustrated by Figure 2d. The effect of REC on CO_2 is weak and positive at lower and higher quantiles (0.1-0.40 and 1.70-0.95) of both CO_2 and REC. However, in the middle quantile (0.45-0.65), the influence of REC on CO_2 is negative.

3.3 Robustness check

The QQR methodology can be conceived of as a decomposition procedure for the traditional QR model's estimates, allowing for precise estimates for various quantiles of the dependent variable. The QR model used in this analysis is focused on regressing the αth quantile of Y on X, so the quantile regression parameters are only indexed by α. That being said, since the QQ analysis regresses the αth quantile of Y on the *th* quantile of X, the variables will be defined by both α and τ, as previously mentioned. As a result, the QQ method provides more disaggregated details about the X–Y connection than the quantile regression model, since the QQ method considers this relationship to be inherently heterogeneous through X quantiles. Given the QQ approach's inherent property of decomposition, the QQ estimates can be used to retrieve the traditional quantile regression estimates. The QQ parameters around τ can be used to produce the QR parameters that are only indexed by θ. For instance, the coefficient of the QR model slope, which is denoted by $\gamma_1(\theta)$, is utilized to calculate the influence of X on Y, as follows:

$$\gamma_1 \equiv \overline{\widehat{\beta_1}(\alpha)} = \frac{1}{S}\sum\nolimits_{\tau} \widehat{\beta_1}(\alpha, \tau) \qquad (2)$$

Where S = 19 is quantiles number $\tau = [0.05, 0.10, \ldots, 0.95]$ is taken into consideration

The graphs in Figure 3(a–d) show that irrespective of the quantile chosen, the averaged QQ estimates of the slope coefficient are very comparable to the QR estimates for South Africa. This graphical proof revealed that the main characteristics of the QR model can be retrieved by illustrating the more extensive details found in the QQ estimates, including a clear justification of the QQ approach. Thus, Figure 3a affirms the outcomes of the QQ analysis reported above. The outcomes of the QR disclosed that at all quantiles; the impact of GDP on CO_2 pollution is positive which is consistent with the QQ regression outcome. Furthermore, in Figure 3b, the outcomes of the QR disclosed nonrenewable energy consumption influences CO_2 positively at all quantiles and this is in accordance with the outcomes of the QQ. Also, in figure 3c, the influence of globalization on CO_2 emissions is negative at all quantiles as revealed by both QR and QQR outcomes. In Figure 3d, the effect of renewable energy use on CO_2 emissions is positive in the lower and upper tails; however, in the middle tail, the renewable energy use impact CO_2 negatively.

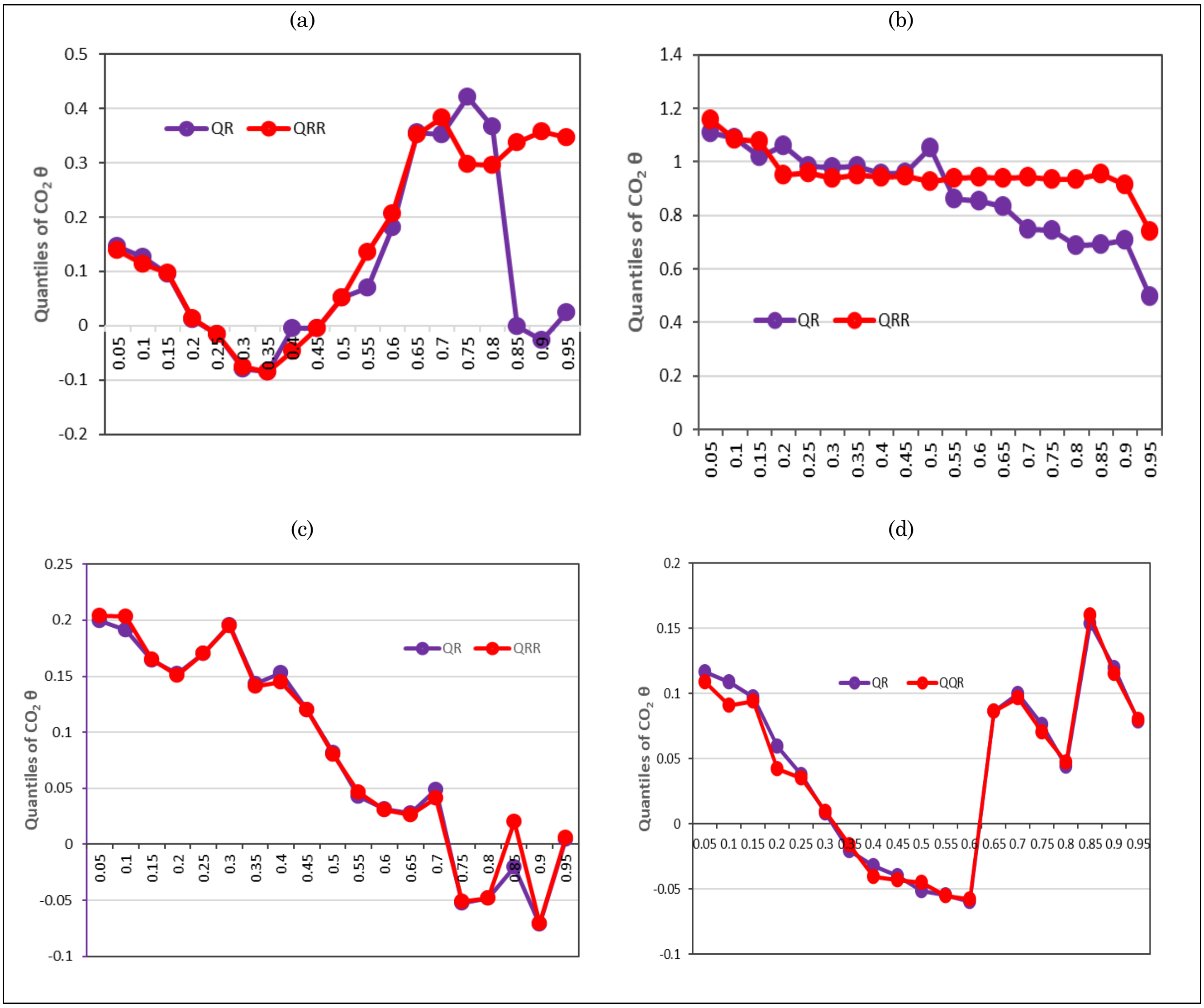

Fig 3. Comparison of quantile regression and quantile-on-quantile estimate. (a) Effect of GDP on CO_2. (b) Effect of EC on CO_2. (c) Effect of GLO on CO_2. (d) Effect of REC on CO_2

4.Discussion

The outcomes from the above analysis are discussed in this section. The outcomes revealed that GDP impacts CO_2 positively in the majority of the combination of quantiles of CO_2 and GDP. The major reason behind this is that fossil fuels are the primary inputs for manufacturing and agriculture, which affect both economic growth and environmental destruction, and this explains why economic growth has a positive effect on environmental degradation (Kirikkaleli *et al.* 2020). The outcomes further validate the EKC hypothesis, which states that there is a significant relationship between environmental pollution and per capita income. The expansion of infrastructure, as well as economic capitalization and high trade development in South Africa all contribute to a rise in CO_2 as a result of GDP, which has a positive impact on investment and economic activity, and as a result, raises energy use (Zhang *et al.* 2021). Another potential explanation for this effect is that increased economic growth will result in increased environmental pollution at high levels of income as industrial sectors expand. In other words, environmental pollution in South Africa would be lower in the initial stages of development but would rise later as economic activity exceeds the threshold parameter. As a result, during periods of economic growth, businesses and families will have more income and will therefore consume more energy from transportation, appliances, and electric devices among other sources, contributing to a rise in CO_2 emissions. This emphasizes the need for South African stakeholders and policymakers to take a more constructive approach in disengaging economic development from pollutant emissions in their energy policy mix. This outcome complies with those of Sarkodie *et al* (2020), Soylu *et al.* (2021), Akinsola *et al.* (2021), Awosusi *et al.* (2021), and Tufail *et al.* (2021).

Moreover, the energy use effect on CO_2 is positive at a majority of quantiles of combination of utilization of energy and CO_2. This demonstrates that an upsurge in utilization on energy triggers degradation of the environment. The major reason for this outcome is that nonrenewable energy consumption for economic activities also leads to an upsurge in CO_2 emissions. This result is consistent with the outcomes of He *et al.* (2020), Zhang *et al.* (2021), Kirikkaleli and Adebayo *et al.* (2021), and Awosusi *et al.* (2021). Currently coal is by far the major energy source for South Africa, comprising around 80 percent of the country's energy mix. However, according to the 2019 Integrated Resource Plan (IRP), 24,100 MW of conventional thermal power sources, specifically coal, are likely to be decommissioned within the next 10-30 years. While coal may be the dominant source now, its share of total capacity is likely to decrease as more renewable generation comes online in the coming years. South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) for utility-scale transactions signed 27 power purchase agreements in June 2018. The updated IRP outlines a number of steps the government will undertake to improve South Africa's unreliable and deteriorating energy sector, focusing on greater use of natural gas, maintaining the nuclear sector, while increasing the focus on social inclusion and a "just transition plan" to renewable energy.

Moreover, is interesting that in the lower and upper tails, the positive effect of REC on CO_2 is weak. Additionally, in the middle tail, the negative effect of REC on CO_2 is weak. Therefore, the significance of renewable energy consumption on CO_2 is weak. This outcome complies with the studies of Saboori *et al.* (2012) and Lin and Moubarak (2014), who stated that renewable energy is still not effectively utilized to mitigate CO_2. The increasing use of fossil fuels in South Africa has hastened ecological damage. In South Africa, renewable energy consumption is low relative to fossil fuel use, and it is not at the level required to mitigate environmental deterioration.

Furthermore, the effect of globalization on CO_2 is positive. The probable explanation for globalization's positive impact on CO_2 is that it encourages the transferal of modern technology from industrialized to emerging countries, allowing these nations to promote the division of labor and improve their competitive advantage. Additionally, increased trade increases overall factor productivity as a result of globalization. Foreign direct investment (FDI) and the transferal of advanced technologies between industrialized and developing economies fuel economic growth. Furthermore, the globalization trend creates investment prospects via FDI and strengthens capital markets via financial liberalization. Undoubtedly, this mechanism boosts capital markets, commerce, and economic development, resulting in increased energy demand and, as a result, environmental deterioration. According to Yuping *et al.* (2021) globalization triggers a gradual increase in CO_2 due to the intensive use of resources in the manufacturing and use of goods and services in both industrialized and developing economies. This outcome complies with the findings of Kirikkaleli *et al.* (2020) for Turkey, Le and Ozturk, (2020) for 7 emerging nations, and Saint Akadiri *et al.* (2019) for South Africa, who established a positive connection between GLO and CO_2. However, this outcome does not comply with those of Ahmed *et al.* (2021) for Japan, Usman *et al.* (2021) for the 15 highest emitting countries, and Zaidi et al. (2019) for APEC nations, who established that GLO impacts CO_2 emissions negatively.

5. Conclusion and policy direction

The current research employs the latest econometrics techniques to assess the connection between CO2 emissions, and energy use, globalization, and GDP in South Africa using a yearly dataset spanning between 1970 and 2018. This is done to properly equip decision-makers. Utilizing the novel QQ method, the current paper contributes to the ongoing literature on these relationships. As opposed to conventional methods that include OLS or quantile regression, the QQ approach assists with approximating how the quantiles of the independent variable impact the quantiles of the dependent variable, thereby offering a more detailed explanation of the overall dependency structure between CO_2 emission and globalization, nonrenewable energy consumption and renewable energy use. To the best of the authors' understanding, no prior study has examined these associations utilizing the novel QQ method.

As an initial test, the study examines the linearity of the variables under investigation by employing the BDS test and the outcomes revealed that using the linear techniques will yield a misleading result, which gives room for the utilization of non-linear techniques such as the QQ approach. Furthermore, the outcomes of the QQ regression illustrated that: (i) at all quantiles (0.1-0.95), the effect of nonrenewable energy consumption on CO_2 emissions is positive; (ii) at the majority of the quantiles, the effect of globalization on CO_2 emissions is positive; (iii) at all quantiles (0.1-0.95), the effect of economic growth on CO_2 emissions is positive; (iv) at all quantiles (0.1-0.95), the effect of renewable energy use on CO_2 emissions is weak. As a robustness check, we employed the quantile regression (QR) test and the outcomes give credence to the QQ results.

Given that it is an industrialized economy in Africa, it is certain that South Africa's energy demand will continue to rise, and the lack of implementation of a strategic green policy in due time will not only degrade the environment but also weaken and delay the country's economic success and development. Also, the effects of nonrenewable energy use, real income, renewable energy use and globalization explored in this study stand as pointers for policymakers in forecasting the impacts of energy usage, globalization, and GDP for the future generations in South Africa's future generation as well as to other nations in Africa with similar growing environmental threats from pollutant emissions.

To reduce costs, international firms could use the conventional technology of the host country as part of the process of globalization. In this case, multinational corporations' use of natural resources and industrial output contribute to environmental deterioration. Furthermore, as global trade and foreign direct investment grow, so does South Africa's nonrenewable energy use and production, resulting in contamination of water, air, and land. Globalization has an impact on environmental quality for these reasons. To offset this detrimental impact, South Africa should enact strong environmental rules and encourage multinational corporations to adopt renewable energy sources and environmentally-friendly technology in their manufacturing processes.

South Africa must use renewable energy sources more efficiently and effectively. South Africa's heavy reliance on fossil fuels puts additional strain on the environment and it should therefore replace fossil fuels with renewables in addition to expanding renewable energy consumption. As long as the rise in renewable energy consumption is smaller than the increase in fossil fuel use, environmental quality will not improve. Thus, policies must be implemented to increase the proportion of renewable energy year by year in their energy mix.

Lastly, although the present research has produced interesting outcomes in the case of South Africa, one of its shortcomings is that CO_2 emissions are considered as the only form of ecological pollution. Thus, it is recommended that more research is conducted to examine other proxies of environmental degradation for this country and this could be applicable to the analysis for other countries as well.

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