Environmental Science and Pollution Research (2022) 29:74841–74850
https://doi.org/10.1007/s11356-022-21117-w

RESEARCH ARTICLE

Criticality of geothermal and coal energy consumption toward carbon neutrality: evidence from newly industrialized countries

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Received: 3 March 2022 / Accepted: 23 May 2022 / Published online: 31 May 2022

Abstract
This study examines the long-term effects of coal and geothermal consumption on carbon emission while controlling for globalization and economic growth toward carbon neutrality in newly industrialized countries, including Brazil, China, India, Mexico, Malaysia, the Philippines, South Africa, Turkey, Indonesia, and Thailand for the period of 1990–2008. We compare the resulting relationships from various estimation techniques, such as fixed-effect ordinary least squares, dynamic ordinary least squares, fully modified ordinary least squares, and method of moment quantile regression. Overall, this study determines that the consumption of coal and geothermal energy is a significant determinant with a causal effect on carbon emission. The rise in coal energy consumption significantly increases carbon emission across all quantiles (0.1–0.90), whereas the rise in geothermal energy consumption reduces it across all quantiles (0.1–0.90). This relationship is also consistent across all quantiles (0.1–0.9). Policy suggestions are proposed on the basis of these findings.

Keywords Coal energy · Geothermal energy · Globalization · Economic growth · MMQR · NICs

Responsible Editor: Roula Inglesi-Lotz

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Introduction

Globalization has currently become a central driving force in increasing a country's economic growth. Through globalization, households, firms, and governments across countries can interact and trade through consistent policies to reduce transaction costs and diminish economic barriers (Adebayo et al. 2022; Akadiri et al. 2022a). The world's KOF de facto globalization index has increased dramatically in the last two decades, i.e., from 47.51 in 1998 to 58.65 in 2018, reflecting the rising social and economic integration of countries worldwide. This increase in globalization is also consistent with the rise in annual per capita income from US$5530 in 2000 to US$11,347 in 2018, i.e., nearly a double increase. However, as the world is increasingly globalized and economies are accelerating, environmental pollution has become a serious concern (World Bank 2022). The World Bank estimates that carbon emission has increased from 3813 metric ton per capita in 2000 to 4484 metric ton per capita in 2018 because the rise in economic activities of either producing firms or consuming households demands more energy.

Coal is one type of energy source that contributes significantly to pollution. Coal is nonrenewable energy created from fossils, and, thus, it is well-known as a fossil fuel. Despite its negative effects, coal remains as the most utilized and significant energy source at present. Amid the increasing pollution problem, awareness on utilizing more renewable energy sources to reduce pollution is also rising. Some alternative renewable energy sources, such as solar energy, wind energy, hydro energy, geothermal energy, tidal energy, and biomass energy, are widely known (Akadiri et al. 2022b; Adebayo 2022b). The current study focuses on geothermal energy, which is derived from the heat that is continuously produced within the Earth, as an alternative renewable energy. However, the extent to which renewable energy consumption affects pollution relative to coal energy consumption requires further elaboration.

The effect of energy consumption on carbon emission has been studied intensively either at the country group or individual level by using various methodologies. At the regional level, the findings of some related studies are motivating. For example, in the case of BRICS (Brazil, Russia, India, China, and South Africa) countries, Chang et al. (2017) demonstrated no causal relationship between coal consumption and economic growth at the country group level. Assuming that pollution positively corresponds to economic growth, then this finding implies that coal consumption has no effect on carbon emission in BRICS countries, i.e., the so-called carbon neutrality. Their study even demonstrated that lowering coal energy consumption can be detrimental to the regional economy. By contrast, carbon neutrality was not observed in the case of the 11 countries belonging to the Commonwealth of Independent States. Apergis and Payne (2009) found that coal consumption unidirectionally causes economic growth, increasing carbon emission in the short run and making causality bidirectional in the long run. In the case of Organization for Economic Co-operation and Development countries, Apergis and Payne (2010a, b) determined that the effect of coal consumption on pollution is negative, reflecting regional efficiency in utilizing coal energy. Apergis and Payne (2010a, b) also demonstrated that a bidirectional relationship occurred between coal consumption and carbon emission in the short and long run in the case of the 15 emerging market countries of Morgan Stanley Capital.

The current study aims to expand the literature at the regional level by investigating the long-term effect of coal and geothermal consumption on the carbon emission of a group of newly industrialized countries (NICs). This group of NICs consists of Brazil, China, India, Mexico, Malaysia, the Philippines, South Africa, Turkey, Indonesia, and Thailand. To the best of our knowledge, no identical study has utilized NICs as study sample. Hence, understanding past evidence regarding the topic can be traced to studies on the individual country members of this NIC group. For example, Govindaraju and Tang (2013) examined the relationship between carbon emission and coal consumption in China and India by using co-integration and Granger causality test. They found bidirectional causality between carbon emission and coal consumption in China in the short and long run. In case of India, however, only short-run causality is detected. Lin et al. (2018) also investigated the nexus between carbon emission and economic growth in China and India by using the autoregressive distributed lag (ARDL) bound test. Their study demonstrated that coal consumption increased carbon emission, but the increase reduced coal consumption in both countries. Shahbaz et al. (2013) examined the relationship between coal consumption and carbon emission in China and India by using the vector error correction model Granger causality test. Their study showed that coal energy consumption stimulates carbon emission. Their work also confirmed the occurrence of the environmental Kuznets curve (EKC) hypothesis in India but not in China. Joshua et al. (2020) found a bidirectional link between coal consumption and carbon emission, wherein the former stimulates the latter.

In terms of geothermal energy consumption, some studies have argued that geothermal energy can reduce carbon emission. For example, Aissa and Hartono (2015) demonstrated that substituting investment from fossil fuels to geothermal energy reduces carbon dioxide emission in the case of Indonesia. However, carbon emission intensifies if coal is classified under high carbon content or high heating value (Damayanti and Khaerunissa 2018). Barbe (2017) reported that renewable energy reduces environmental degradation and confirmed the EKC hypothesis. Baba and Armannsson (2006) investigated the environmental impact of utilizing geothermal areas in Turkey. Their study determined that although geothermal energy is known as an environmentally benign energy source, it is not completely pollutant-free. Nevertheless, carbon emission from geothermal energy consumption is smaller than that from fossil fuels (Bonafin et al. 2019). Bosnjakovic et al. (2019) indicated that the negative impact of renewable energy consumption on the environment can be temporary or permanent depending on some factors, such as land use, atmospheric emissions, groundwater, and land subsidence. Yurchenko (2005) investigated the environmental impact of geothermal energy on carbon emission and found that geothermal development exerts negative effects on the environment. Given the mixed findings from the past literature, the current study aims to investigate whether different findings can be obtained in the case of NICs. The sample NICs are studied for the period of 1990–2018.

Our study contributes to the ongoing literature in the following ways. First, this study uses NICs as sample; NICs have not been investigated in other similar literature. Understanding how energy consumption affects the environment is considered essential because NIC economies, such as China, Mexico, and India, are among the world's largest carbon emitters and energy consumers. Except for the Philippines, all the other NICs included in our sample are within the top 50 exporting countries in the world based on the highest dollar value of exports shipped.[1] These countries are heavily linked to one another in terms of international trade; such condition can be a source of cross-sectional dependence from facing common unobserved shocks and spatial spillover effects. Statistically, the selected NICs emitted 16,256.090 million tonnes of CO_2 in 2017, accounting for 48.847% of the world's emissions. The gross domestic product (GDP) of these NICs in 2017 was also significant, constituting 24.98% of world's GDP; in the same year, these countries consumed 38.855% of the world's energy and contributed 20.704% of world's export (World Bank 2022). Thus, exploring the influences of these factors on the CO_2 emissions of NICs is crucial.

Second, in terms of modeling strategy and to the best of our knowledge, this work is the first to study interacting coal and geothermal energy consumption with carbon emission within the same model. The closest to this study is the work of Shahzad et al. (2021), who investigated the interaction among coal energy consumption, geothermal energy consumption, and carbon emission in the Philippines by using ARDL and Granger causality test. Finally, in terms of methodology and to the best of our knowledge, this study is the first to employ the method of moment quantile regression (MMQR) to explain the relationship between renewable (coal) and nonrenewable (geothermal) energy consumption with carbon emission. Other studies have also used MMQR (e.g., Akadiri et al. 2022c; Anwar et al. 2021; Aziz et al. 2020b; Gomez and Rodriguez 2020). However, these studies did not simultaneously examine the interaction between coal and geothermal energy consumption.

The remainder of this paper is organized as follows. Section 2 discusses the data and methodology adopted for the empirical analysis. Section 3 presents the results and discusses the findings. Section 4 provides the concluding remarks with attendant policy suggestions.

Data and method

Data

Using advanced panel regression, the present research assesses the effects of energy (coal and geothermal), globalization, and economic growth on the CO_2 emissions of NICs by adopting a dataset that spans from 1990 to 2018. Furthermore, the present research seeks to evaluate the EKC hypothesis. To accomplish this task, this research utilizes variables, such as CO_2 emission (dependent variable) and globalization, economic growth, and coal and geothermal consumption (dependent variables). The source and description of the variables are provided in Table 1. The research economic function is depicted by Eq. 1 as follows:

$$CO_{2t} = f\left(GDP_t, GDPSQ_t, GLO_t, COAL_t, GEO_t\right) \quad (1)$$

Table 2 provides the data description of the variables used. The mean of GDP is the highest, followed by coal, globalization, geothermal, and CO_2 emissions. All the variables are skewed positively with the exemption of GLO, which is negatively skewed. The kurtosis value reveals that CO_2, GDP, and GLO are leptokurtic (less than 3) while GEO and COAL are platykurtic (greater than 3). The Jarque–Bera value also reveals that CO_2, GDP, GEO, and COAL do not conform to normal distribution while GLO aligns with normality. The lack of normality, except for GLO, allows investigators to use quantile estimation (Adebayo and Kirikkaleli 2021; Adebayo and Rjoub 2021; Orhan et al. 2021; Soylu et al. 2021). Moreover, Fig. 1 presents the stages of analysis.

Panel estimation techniques

We use the fixed effects of fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and fixed-effect ordinary least squares (FE-OLS) for comparative analysis. The FE-OLS approach is enhanced using Driscoll and Kraay standard errors, which are resistant to typical kinds of cross-sectional dependency and autocorrelation up to a certain lag. The fundamental rationale for estimating dynamic co-integrated panel models is heterogeneity, as identified by Pedroni (2004), with mean differences between cross sections and changes in cross-sectional readjustment to the co-integrating equilibrium. FMOLS addresses these difficulties by incorporating individual intercepts and allowing features of heterogeneity serial correlation of error processes among individual panel members (Pedroni 2004). On the basis of the results of Monte Carlo simulations, Kao et al. (1999) expanded DOLS to panel settings. DOLS was found to be impartial in finite samples compared with FMOLS and ordinary least squares (OLS) estimators. Endogeneity can also be addressed by amplifying lagged and lead differences, decreasing the feedback of endogeneity in DOLS. Prior estimation approaches exhibit shortcomings, and, thus, a panel quantile regression (QR) strategy is used to investigate heterogeneous and distributional effects across quantiles (Aziz et al. 2020a, b).

The panel QR approach was developed by Koenker and Bassett in 1978. Compared with OLS, which produces conditional mean estimations of the explanatory parameter related to definite standards of the explanatory variables, QR is typically used to evaluate the conditional mean or

[1] Export statistics: http://www.worldstopexports.com/worlds-top-export-countries/

Table 1 Variables of the study

Symbol	Description	Measurement unit	Source
CO_2	Carbon emissions	Metric tons per capita (CO_2 emissions)	BP
COAL	Coal consumption	Exajoules	BP
GEO	Geothermal energy consumption	Exajoules	BP
GLO	Globalization	Globalization index	KOF
GDP	Economic growth	Per capita GDP (constant 2010 US$)	WDI

WDI stands for World Development Indicators and BP represents British Petroleum.

Table 2 Descriptive statistics

	CO_2	GDP	GEO	GLO	COAL
Mean	3.587482	5669.176	19.68673	51.12154	1904.012
Median	2.970200	5734.931	10.78682	52.27981	191.6027
Maximum	9.950263	15,186.83	232.9395	77.03150	22,900.34
Minimum	0.662661	575.5016	0.057947	14.74376	12.43768
Std.Dev	2.495846	3524.129	31.11701	13.12339	4676.804
Skewness	0.848215	0.292954	3.380969	− 0.275342	3.358474
Kurtosis	2.644061	2.066545	17.23438	2.923272	13.70872
Jarque–Bera	36.30521	14.67674	3000.793	3.735440	1930.846
Probability	0.000000	0.000650	0.000000	0.154475	0.000000

various dependent variables' quantiles pertaining to the explanatory parameters' values. In terms of estimates, QR is more resilient in the presence of outliers. Furthermore, it is the appropriate strategy to utilize when the correlation between two variables' conditional means is insignificant (Binder and Coad 2011). In the current investigation, we nonetheless use the approach developed by Machado and Santos Silva (2019), known as MMQR with fixed effects. Although QR is resilient to outliers, it fails to account for any unobserved variations between individuals within a panel. This technique detects the covariance conditional heterogeneous effects of CO_2 predictors by allowing the individual effect to influence the whole distribution rather than just modifying means similar to what Canay (2011) and Koenker (2011) did. This strategy is ideal when panel data are grounded in individual effects and independent indicators exhibit endogenous features. It is a highly straightforward approach because it produces non-crossing estimates in QR. The following equations express the conditional quantile estimates Qy(|X) of the location-scale variant model:

$$Y_{it} = \alpha_i + X'_{it}\beta + \left(\delta_i + Z'_{it}\gamma\right)U_{it}, \tag{2}$$

$$Y_{it} = \alpha_i + X'_{it}\beta + \left(\delta_i + Z'_{it}\gamma\right)U_{it}. \tag{3}$$

In Eq. 3, $(\alpha, \beta', \delta, \gamma')'$ are the estimated parameters, Z is regarded as the k-vector of the recognized parts of X, and Pr $\left(\delta_i + Z'_{it}\gamma\right) > 0) = 1.U_{it}$ is an error term, and the independent variables are depicted by U_{it} and X'_{it}. To consider

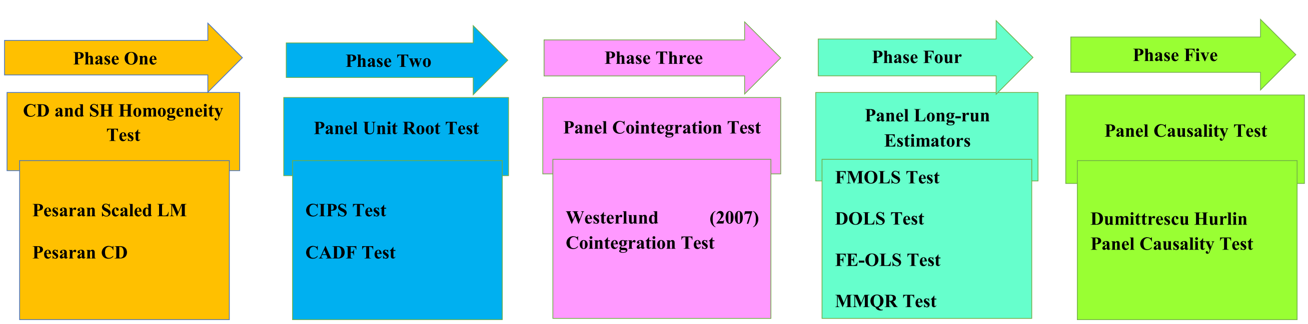

Fig. 1 Flow of analysis

moment conditions, U_{it} is normalized as follows: $E(U) = 0$ and $E(/U/)=1$. The following are depicted by Eq. 4:

$$Q_Y\left(\tau/X_{it}\right) = \left(\alpha_i + \delta_i q(\tau)\right) + X_{it}^{'}\beta + Z_{it}^{'}\gamma q(\tau), \tag{4}$$

where the distributional effect at quantile (τ) is depicted by $\alpha_i(\tau) \equiv \alpha_i + \delta_i q(\tau)$.

Results, findings, and discussion

A cross-country heterogeneity test is conducted as a first step in the empirical analysis. Table 3 provides the test findings. The delta and adjusted delta tests reject the null hypothesis of slope homogeneity at $P < 1\%$ significance level. This finding indicates that the NICs sampled in this study exhibit unique economic characteristics.

As the second stage of our empirical analysis, cross-sectional dependence and second-generation panel unit root tests are conducted. The results are provided in Table 4. The test statistics produced by the cross-sectional dependence tests lead to the rejection of the null hypothesis of no cross-sectional dependence at $P < 1\%$ significance level for the following variables: CO_2, GDP, GLO, COAL, and GEO. This finding suggests that shocks are transmitted across these NICs. No cross-sectional dependence is detected in investment volatility. The presence of cross-sectional dependence in the data series indicates that conventional unit root testing is inappropriate for this study. Consequently, the cross-sectionally augmented Dickey–Fuller (CADF) and cross-sectionally augmented Im, Pesarvan, and Shin (CIPS) second-generation unit root tests, which are robust to cross-sectional dependence, are employed. Both tests unanimously show that all the variables contain unit roots but become stationary after first differencing I(1). All the results are significant at $P < 1\%$.

Table 5 presents the four-panel co-integration tests of Westerlund (2007). As indicated in the table, one of the group-mean statistics (Gt) and both of the panel statistics (Pt and Pa) reject the null hypothesis of no co-integration at $P < 10\%$ significance level or better. The results provide evidence to support the existence of a long-term relationship between CO_2 and independent variables.

On the basis of the panel regression results reported in Table 6, we infer the following: the effects of per-capita GDP and its quadratic form on carbon emissions are positive and negative, respectively. The results are also significant at $P < 10\%$. They are robust across all three estimation techniques, and the reported coefficients range between 1.1686 and 2.0805 for GDP and between − 0.084 and − 0.0253 for GDPSQR. This result indicates that increases in economic activity induce pollution in the examined NICs. It also confirms the EKC hypothesis, which states that the relationship between GDP and pollution takes the form of an inverted U shape rather than being linear. As explained by Bekun et al. (2020), Adebayo (2022a), Alola et al. (2020), and Coskuner et al. (2020), the rationale for the EKC hypothesis is that when nations move from low to middle level of development, they prioritize economic growth over environmental quality and, thus, are prone to environmental problems. However, as they transit from middle to high level of development, they begin to give more attention to the environment.

The findings also reveal that geothermal energy consumption lowers carbon emissions while coal consumption and globalization raise carbon emissions in the panel of sampled NICs. The negative effect of geothermal energy consumption ranges between − 0.1622 and − 0.1533, while the positive effects of coal consumption and globalization range between 0.2212–0.2756 and 0.013–0.022, respectively. All the results are significant at $P < 10\%$ or better, and the results are robust across all three employed estimation techniques.

Tables 7 present the results of MMQR, while Fig. 2 is the graphical depiction of the coefficients obtained from the four estimation techniques employed in this study (FM-OLS, D-OLS, FE-OLS, and MMQR). Overall, the sign and magnitude of the coefficients are not too far from those obtained from the previously used estimation techniques reported in Table 6. The results show that except for the lowest quantile (0.1), GDP exerts a significant positive influence on carbon emissions across the grid of all quantiles. However, the square of GDP negatively affects carbon emissions across the grid of all quantiles except for the lowest one (0.1). These findings again confirm the EKC hypothesis for the panel of NICs. The results further reveal that geothermal energy consumption exerts a significant negative effect on carbon emissions across the grid of all quantiles. By contrast, coal consumption and globalization have significant positive effects on carbon emissions. Figure 2 presents the comparison of panel estimators (FMOLS, DOLS, FE-OLS, and MMQR).

Finally, we employ Granger causality testing to determine causal relationships among the variables. The test outcomes are presented in Table 8. We infer unidirectional long-run causality in the panel of NICs for the following variables: carbon emission and coal consumption, carbon emission and GDP per capita, carbon emission and the square of GDP per capita, and carbon emission and globalization. In particular,

Table 3 Slope homogeneity outcomes

Test	Value	P-value
$\hat{\Delta}$	9.395	0.000
$\hat{\Delta}_{\text{adjusted}}$	10.328	0.000

Table 4 CSD and CIPS and CADF unit root test

Variables	CSD results		CIPS		CADF	
	Pesaran scaled LM	Pesaran CD	I(0)	I(I)	I(0)	I(I)
CO_2	65.593*	22.522*	−2.103	−4.470*	−1.835	−3.454*
GDP	117.88*	34.080*	−2.143	−3.227*	1.714	2.900*
GLO	68.131*	24.601*	−2.033	−4.745*	−2.074	−3.519*
COAL	113.30*	33.426*	−1.914	−4.747*	−2.336	−4.732*
GEO	70.433*	25.594*	−1.831	−3.635*	−1.969	−5.108*

Note: *, **, and *** represent $P<1\%$, $P<5\%$, and $P<10\%$

Table 5 Cointegration outcomes (Westerlund 2007)

Value	*P*-value	*Z*-value
−2.668	−1.459	0.072
−12.209	−0.559	0.288
−8.971	−2.741	0.003
−10.745	−1.584	0.057

one-way causal effects are found running from coal consumption to carbon emission, from GDP per capita and its quadratic form to carbon emission, and from globalization to carbon emission. However, bidirectional causality is detected between geothermal energy consumption and carbon emission in the panel of NICs. The causality findings show that coal consumption GDP per capita and its quadratic form, geothermal energy consumption, and globalization are significant predictors of carbon emissions in the sampled countries.

Conclusion and policy recommendations

Conclusion

The current study is presented to contribute to expanding the literature by investigating the long-term effects of coal and geothermal consumption on carbon emission toward carbon neutrality in several NICs (Brazil, China, India, Mexico, Malaysia, the Philippines, South Africa, Turkey, Indonesia, and Thailand) over the period of 1990–2008. The dependent variable in this study is carbon emission. It is measured in metric tons per capita, while the independent variables are coal consumption and geothermal energy consumption, which are presented in terms of exajoules. To achieve a comprehensive finding, this study obtains comparative results by using different estimation methods. In addition, this study incorporates two control variables, namely, globalization and economic growth. The methods include FE-OLS, DOLS, FMOLS, and MMQR. MMQR is presented to determine whether the relationship between dependent and

Table 6 FMOLS, DOLS, and FE-OLS outcomes

	GDP	GDPSQR	GEO	COAL	GLO
FM-OLS	1.1686**	-0.0253*	-0.1622**	0.2407*	0.016***
D-OLS	1.4169***	-0.0443*	-0.1533*	0.2756*	0.013**
FE-OLS	2.0805*	-0.0844**	-0.1534**	0.2212***	0.022*

Note: *, ** and *** stands for $P < 1\%$, $P < 5\%$ and $P < 10\%$

Table 7 Outcomes of the MMQR

	Lower quantile			Middle quantile			Higher quantile		
Variables	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
GDP	0.2575	0.7125	1.1626	1.6657	2.1570	2.8442	3.3123	3.5719	3.8520
GDPSQR	− 0.0190	−0.0069	−0.0326	−0.0614	−0.0894	−0.1288	−0.1554	−0.1702	−0.1862
GEO	−0.1112	−0.1206	−0.1300	−0.0360	−0.1505	−0.1648	−0.1744	−0.1798	−0.1856
COAL	0.2865	0.2735	0.2607	0.2504	0.2324	0.2129	0.1996	0.1922	0.1842
GLO	0.0266	0.0241	0.0216	0.0187	0.0160	0.0121	0.0095	0.0080	0.0065

Note: *, **, and *** stand for 1%, 5%, and 10% significance level.

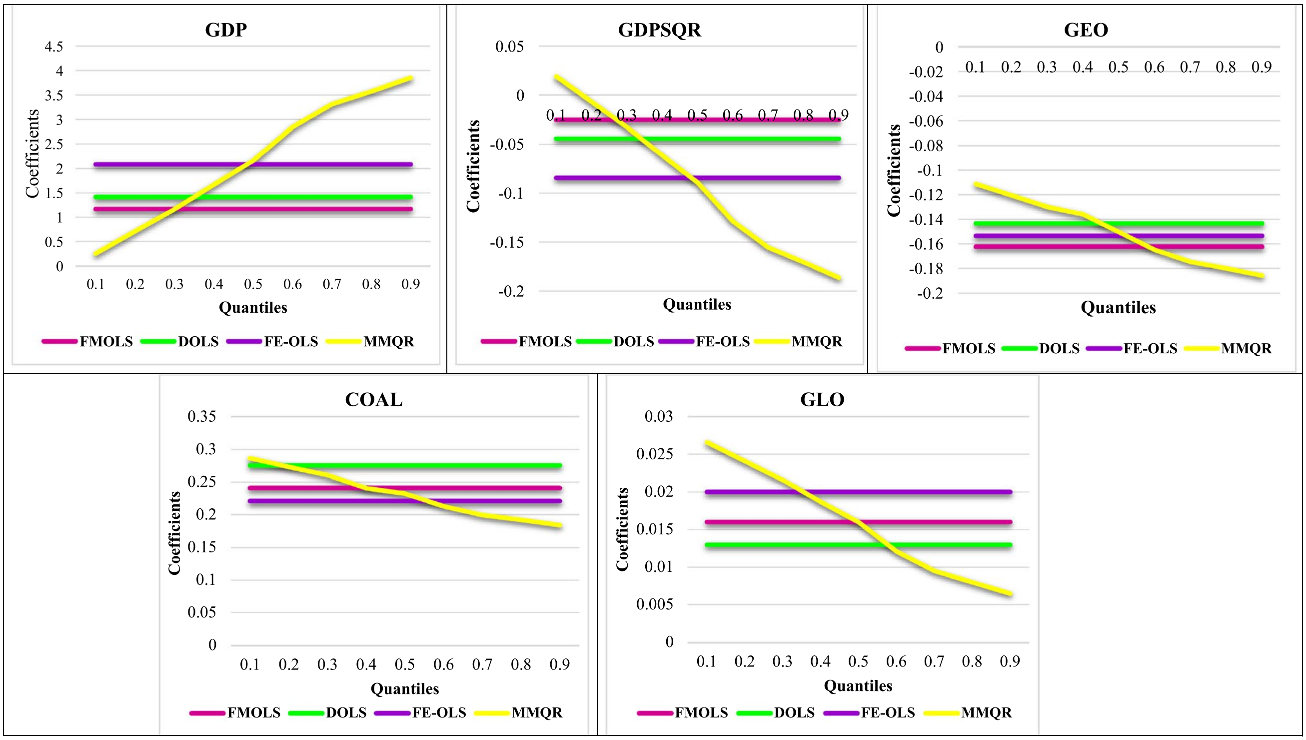

Fig. 2 Comparison of panel estimations (FMOLS, DOLS, FE-OLS, and MMQR)

independent variables is affected by distributional heterogeneity in the panel dataset. Finally, the study also employs Dumitrescu–Hurlin panel causality test to detect the predictive causal nexus among carbon emission and regressors. All data are derived from British Petroleum.

Some notable findings from this study are as follows. First, on the basis of the mean value, the consumption of coal energy is considerably more intensive than that of geothermal energy. Second, on the basis of OLS regression, coal consumption and geothermal energy consumption are statistically significant in producing carbon emissions. However, the two types of energy source exhibit different effect vector and magnitude. In particular, the three OLS regressions (FMOLS, DOLS, and FE-OLS) consistently demonstrate that the effect of coal consumption on carbon emission is positive and higher (in absolute value) compared with that of geothermal energy. Thus, higher coal consumption corresponds to greater carbon emission when everything else is equal. By contrast, all OLS regressions demonstrate that geothermal energy exerts a negative and significant effect on carbon emission, i.e., higher geothermal energy consumption corresponds to lower carbon emission. Third, globalization and economic growth positively and significantly influence carbon emission. In particular, higher economic growth corresponds to greater carbon pollution when everything else is equal. Similarly, the more globalized economy also corresponds to greater carbon emission.

Furthermore, the outcomes of MMQR deliver consistent findings. In terms of the effect of coal consumption on carbon emission, this study demonstrates that higher coal energy consumption corresponds to greater carbon emission. By contrast, higher geothermal energy consumption reduces carbon emission when everything else is equal. This finding is consistent across all quantiles, including the lower quantile (0.10–0.30), middle quantile (0.40–0.60), and higher quantile (0.70–0.95), indicating

Table 8 Dumitrescu–Hurlin panel causality tests

Path of causality	W-Stat	Zbar-Stat	Prob
COAL → CO_2	10.8593	5.02255	0.000
CO_2 → COAL	4.40299	−0.13454	0.8930
GDP → CO_2	7.02948	1.96340	0.0496
CO2 → GDP	5.45553	0.70619	0.4801
GEO → CO_2	7.75895	2.54607	0.0109
CO2 → GEO	8.33028	3.00242	0.0027
GLO → CO_2	7.96580	2.71130	0.0067
CO_2 → LGLO	4.04837	−0.41780	0.6761
GDPSSQ → CO_2	7.14693	2.05721	0.0397
CO_2 → GDPSSQ	5.50475	0.74550	0.4560

that the relationship is independent of the heterogeneity of the panel dataset. MMQR also demonstrates that GDP is positively correlated with carbon emission, while the square of GDP is negatively correlated, indicating that the relationship between GDP and carbon emission follows an inverted U-shape curve. The latter finding confirms the occurrence of the EKC hypothesis in the sample countries. Finally, the panel causality test demonstrates that causal relationships exist between some pair of variables. In particular, the predictive test shows that coal energy consumption has a causal effect on carbon emission but not the other way around. By contrast, geothermal energy consumption also exhibits causality on carbon emission and the causal relationship is bidirectional. Furthermore, a unidirectional causal relationship is found from economic growth on carbon emission and from globalization on carbon emission.

Policy recommendations

From a policy standpoint, two evident policies can be inferred. First, given that coal energy consumption is inevitable for industrial production among NICs, certain policies to prevent its excessive use/abuse have to be enacted to curb its grievous effects on humans, animals, and the environment at large. Policy makers in this region should formulate a policy regarding the threshold in which the consumption of coal must not exceed. For example, environmental/energy policy laws that will prevent the emission-increasing effects of coal consumption should be enacted and stringently pursued to enhance energy-saving technologies or to reduce the excessive use of coal consumption. In addition, as stated in Apergis and Payne (2010a, b), the adoption of sustainable coal technologies that allow storage and carbon emission capture should be encouraged because they may also reduce the environmental effect of unrestrained coal consumption. This result appears to pave the way for the emergence of alternative renewable energy sources, such as geothermal energy consumption, in this region. Second, geothermal energy consumption exhibits a carbon emission-decreasing effect on the environment; thus, we are of the opinion that such renewable energy sources may render these NICs less intensive or dependent on coal.

In conclusion, we advocate for increased investment in geothermal energy sources or the enactment of environmental policies that will encourage the use of geothermal energy sources for households and local and foreign businesses that rely on energy for their production activities. The combination (mixed) of nonrenewable (coal) and renewable (geothermal) energy sources appears to be inevitable in this region. However, more of geothermal and less of coal is suggested for consumption and production activities as the world becomes a global village wherein economic activities are pronounced via trade and industrialization. This strategy will ensure a sustainable environment and healthy living for the immediate and future generations.

Limitations of study

This study's scope was limited to NICs, and only a few variables were considered when investigating the effect of geothermal and coal energy consumption on CO_2. Technological innovation, trade openness, and financial development can be incorporated into the model in future research. Additionally, evaluation at the local and state levels will be constructive for more specific policy implications.

Author contribution Tomiwa collected and analyzed the data. Haouas wrote the introduction and literature review. Seyi worked on the methodology, the conclusion, and policy suggestion. Godwin worked on study development and proofreading.

Data availability Corresponding authors can provide data used in the study on appropriate request.

Declarations

Ethics approval and consent to participate NA

Consent for publication NA

Competing interests The authors declare no competing interests.

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