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Revisiting energy efficiency and energy related CO_2 emissions: Evidence from RCEP economies

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ABSTRACT

Since the last four decades, energy demand has been reached to the utmost level, which also leads to emissions and causes environmental degradation, global warming and climate change all over the world. In this sense, policy makers have suggested various measures including renewable adoption and energy efficiency. Current study aims to investigate the influence of economic growth, energy consumption, renewable electricity output, and energy efficiency on the energy related emissions. A panel of 12 RCEP economies are examined covering the period 1990-2020. Since the data follows irregular path, therefore a novel method of moment panel quantile regression is employed along with the Granger causality test. The empirical results indicate that economic growth and energy consumption significantly enhances energy related emissions, where the magnitude and significance level is found strengthening from lower to upper quantiles ($Q_{0.25}$, $Q_{0.50}$, $Q_{0.75}$ and $Q_{0.90}$). Conversely, renewable electricity and energy efficiency are the significant tools for lowering energy related emissions in the region. Additionally, a unidirectional causality is found from energy consumption and renewable electricity output to energy related emissions. However, a feedback effect is validated between economic growth, energy efficiency, and energy related emissions. Based on the empirical findings, this study suggests enhancement of renewable electricity output and adoption of energy efficient technologies to reduce environmental degradation and emission level.

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1. Introduction

Energy efficiency has been acknowledged as a critical feature of energy security and reducing carbon (CO_2) emissions globally in recent decades (Sovacool and Brown, 2010; Le and Nguyen, 2019). According to the research, deviation from energy

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efficiency objectives have a considerable impact on CO_2 emissions in both emerging and advanced economies (Akram et al., 2020; Javid and Khan, 2020). Currently, energy efficiency is universally recognized as a viable low-cost approach for addressing the rising challenge of CO_2 emissions (UNEP, 2016; Danish et al., 2020). The influence of energy efficiency on reducing emissions is an attractive research issue for policy-makers in both industrialized and developing economies (Özbuğday and Erbas, 2015), since considerable investment (Akram et al., 2020; Shahzad et al., 2022) and efforts have now been made to encourage efficient use of energy (Vieira et al., 2018). It is also worth noting that the standard patterns in CO_2 emissions and energy efficiency growth exhibit some unstable behavior across time. Energy efficiency's potential influence on CO_2 emissions cannot be overlooked in developing policy inputs for effective and practical energy efficiency measures. Given this context, the current study aims to draw academic attention to this growing field.

Overall, the manufacturing industry has not yet broken free from the high-energy-input, high-pollutant-emission growth pattern that exacerbates environmental concerns. As a result, industrial carbon reduction will be a key component of the low-carbon transition and the achievement of energy saving and pollution control targets (He et al., 2021; Song et al., 2022). Since 2000, the manufacturing industry has consumed more final energy and emitted more CO2 (EIA-US, 2020). As a result, improving industrial energy efficiency is critical for improving energy security and promoting low-carbon growth in all developed and developing regions (Wang and Wei, 2014; Lin and Chen, 2018; Shahzad et al., 2021). Despite recent improvements in industrial energy efficiency, there is still a large difference between underdeveloped and developed nations (Hasanbeigi et al., 2013; Ouyang et al., 2021). The industrial sector's energy efficiency has become one of the major roadblocks to global energy efficiency and emissions reduction.

The Regional Comprehensive Economic Partnership (RCEP) has become the world's biggest trade bloc, accounting for about a third of global gross domestic product (GDP). RCEP economies account for 2.3 billion people, or 30% of the earth's population, as well as a similar share of global trade and GDP. Besides, five RCEP economies (i.e., Indonesia, Australia, Japan, China, and South Korea) are members of the G-20 economies and are among the world's top 20 economies. The RCEP discussions started in November 2012, and ten Southeast Asian countries (including Cambodia, Brunei, Indonesia, Laos, Myanmar, Malaysia, Philippines, Thailand, Singapore, Singapore, and Vietnam) as well as five ASEAN free trade agreement allies signed the deal on November 15, 2020 (which includes Australia, Japan, China, Republic of Korea and New Zealand). Developing economies in the Asia-Pacific zone became the new model of globalized economic growth in recent decades, representing 60% of the world economy (Hassan et al., 2022). Alongside substantial growth potential, the trade-environment connection and the environment-growth link are becoming increasingly relevant. Renewable energy sources have grown at an average annual rate of 2% since 1990, slightly higher than the world's total energy supply growth rate of 1.8 percent . As per statistics from 2018, the global total energy supply was 14,282 Mtoe, including 13.5 percent coming from renewable energy sources (Hassan et al., 2022). How and when to ensure energy supply and what percentage of non-renewable and renewable energy can be provided to reduce environmental deterioration have become key government objectives and critical variables in accomplishing long-term development goals.

As mentioned earlier there is a significant difference or variation in the energy efficiency, renewable energy and carbon emission s in the developed and developing economies. Hence, the difference may be reported in Table-1, that presents average values of emissions, economic growth, renewable electricity output, energy efficiency, and energy consumption.

The main objective of this paper is to empirically revisit the association of energy efficiency and energy related emissions in the RCEP economies. Although many studies have provided empirical evidence regarding the association of energy efficiency and CO_2 emissions (He et al., 2021; Chen et al., 2021; Pei et al., 2021; Wang et al., 2011), yet these studies focused on the overall CO_2 emissions and ignored energy related emissions. This study also aims to examine the influence of renewable electricity output on the energy related emissions. Albeit the fact that renewable energy is widely studied in the existing literature (see, Hu et al., 2021; Saidi and Omri, 2020; Yang et al., 2021). However, these studies ignore the specific influence of renewable electricity output, which must be acknowledge for better policy setup. In addition, this study also aims to re-examine the association of economic growth and energy consumption on the energy related emissions. Although the earlier studies have provided evidence regarding the said nexus. Still, the picture is opaque in terms of RCEP economies.

This study is novel and contributes to the existing studies in three dimensions. Firstly, this study is unique as it provides empirical results for energy efficiency and energy related emissions, which is relatively ignored side from the academic research. Therefore, this study will play a pioneering role in this regard. Secondly, current study opted the role of renewable energy electricity output, which is different than the existing literature as these studies are more biased towards the role of renewable energy in relation to CO_2 emissions. Lastly, this study contributes to the existing literature by providing important outcomes of reinvestigating the influence of economic growth and energy consumption on energy related emissions in the RCEP economies.

The remaining parts of the study includes literature review provided in Section-2: while Section-3 indicates theoretical framework, data and methodological setup for empirical investigation; Section-4 demonstrates empirical results and discussion; while conclusion, policy implications and study limitations are provided in Section-5 of the paper.

2. Literature review and research gap

2.1. Literature Review

Since the last few decades, scholars and policy-makers provide extensive work regarding the association of economic growth and environmental degradation. The recent study of Li et al. (2020) examined G20 economies over the period 1992-2014 and employed the augmented mean group (AMG) and common correlated effect mean group (CCEMG) estimators. The empirical results reveal that economic growth as well as energy use significantly promote environmental degradation in the region. Moreover, the study found bidirectional causal nexus between economic growth, energy consumption, and CO_2 emissions. Akadiri and Adebayo (2021) also analyzed the asymmetric association between economic growth and other energy, economic growth and financial indicators in case of India. Using non-linear autoregressive distributed lags model, the results demonstrates that economic growth, financial development and non-renewable energy consumption promote environmental quality degradation. However, renewable energy consumption promotes environmental quality. For the same country, Hu et al. (2021) reveals the existence of bidirectional causal nexus between renewable energy use and CO_2 emissions, and the unidirectional causal nexus from CO_2 emissions and economic growth. Also, the study of Petrović-Ranđelović et al. (2020) asserted the existence of bidirectional causal nexus between energy consumption and CO_2 emissions while unidirectional causal association between CO_2 emissions and economic growth. In addition, the study claims that energy consumption and technical innovation leads to higher economic growth at the cost of environmental degradation. On the other hand, the recent study of Nathaniel et al. (2021) asserted that the African economies are energy dependent. Still, there is no contemporaneous association between economic growth and emissions.

The study of Li and Li (2020) demonstrates that energy investments and economic growth are the primary factors of increased CO_2 emissions in the region. Also, the study found that enhancement in the adjacent provinces' CO_2 emissions enhances the local CO_2 emissions via spatial spillover effects. In case of 58 OECD economies, Schröder and Storm (2020) uses the Kaya identity to construct a climate constrained global growth prognosis for the period 2014-2015. The results asserted that there is no significant link about the regarding the negative influence of increased income on CO_2 emissions. In addition, the study of Destek et al. (2020) examined the G7 economies over the period 1800-2010. Unlike the traditional environmental Kuznets curve (EKC) hypothesis, this study unveils different economies posits various pattern of the association between economy and environment. Specifically, the study uses time-varying cointegration, bootstrap-rolling window estimation techniques and asserted that existence of M, inverted W, N, inverted N-shaped, and inverted U-shaped relationships between the two variables for various economies. Saidi and Omri (2020) provides empirical evidence regarding 15 major renewable energy consuming economies and asserted that efficiency in renewable energy consumption not only encourages economic growth, but also discourages environmental hazards such as CO_2 emissions. Also, the study claimed the existence of bidirectional causal association between economic growth – renewable energy, and CO_2 emissions – renewable energy.

Since the existing studies revealed that non-renewable energy positively affects economic growth and CO_2 emissions in the countries and regions. Yet there are number of studies that empirically investigates factors that helps achieve carbon neutrality as well as economic growth and termed as win-win situation. Concerning, Dong et al. (2020) analyzed China and revealed that reduction of the CO_2 emissions significantly enhances industrial upgradation. However, the industrial structural upgradation not only encourages economic growth, but also these two adversely affects CO_2 emissions – validating win-win situation in the country. In other study, Dong et al. (2020b) illustrates that manufacturing, construction, and accommodation are the sectors playing a coupling role for economic growth and emissions, while agriculture, transportation, and retail sectors are playing a significant decoupling role of economic growth from CO_2 emissions. In addition, Saint Akadiri et al. (2020) demonstrates that using of renewable-based electricity consumption and economic growth could be used as tools form sustainable economic growth. In case of China, Song (2021) demonstrates that higher economic growth promotes investment in the technological and innovation sectors, which further encourages the adoption and use of environmentally friendly products and services causes reduction of pollution. Concerning global decoupling, Yang et al. (2021) reveals that energy efficiency (energy-saving) related technological development and production efficiency are the prominent decoupling factors for economic growth and CO_2 emissions.

Besides these other factors of decoupling or reducing CO_2 emissions, most of the existing studies have focused on the energy efficiency variable that plays a substantial role in the environmental quality of a country. In this regard, Mahapatra and Irfan (2021) analyzed that developed and developing economies have showed symmetric short-run results and asymmetric long-run results. Where it is noted that increasing energy efficiency leads to CO_2 emissions reduction while declination of energy efficiency promotes CO_2 emissions in the region. Additionally, the recent study of Razzaq et al. (2021) demonstrates that the recycling of municipal solid wastes is important for economic as well as environmental outcomes. Whereas, these wastes recycling unidirectionally causes CO_2 emissions, economic growth, and energy efficiency. He et al. (2021) reveals that the path of improved energy efficiency is induced by investment in research and development. Yet, enhancement in the energy efficiency could lead to environmental sustainability via reducing CO_2 emissions. Albeit the fact that energy efficiency promotes environmental sustainability and reduces CO_2 emissions, Chen et al. (2021) studied time series data over the period 2000-2017 for China and asserted that carbon emission trading scheme encourages energy efficiency improvement. Concerning industrial sector of China, Pei et al. (2021) used system generalized method of moments (Sys-GMM) and revealed that corruption promotes CO_2 emissions by reducing energy efficiency. However, energy efficiency played an opposite role here. Besides, the earlier study of Wang et al. (2011) discovered that in order to attain low carbon economy, the nuclear energy and energy efficiency are the possible solution to 2020 targets.

2.2. Literature Summary and research gap

Since there are many studies from the last few decades that empirically investigated the impact or causal association between economic growth and CO_2 emissions. Where majority of the results unveil that there is a positive association exist between the two, yet the causal association has been observed mixed in the existing literature. However, there is no existing study found that considers energy related CO_2 emissions and particularly in the case of RCEP economies. In addition, there is very limited literature available that considers renewable electricity output as an explanatory variable. Indeed, the existing literature provides evidence regarding the negative association of or adverse impact of renewable energy on the CO_2 emissions. Yet the renewable energy resources are a comprehensive measure of renewables, where renewable electricity plays a substantial role in running the industrial sector. Hence, this study identified the gap in the existing literature. Moreover, all the above-mentioned studies empirically investigated the relationship of energy consumption and energy efficiency on the CO_2 emissions while ignoring energy related emissions, which plays a substantial role in the environmental as well as economic sectors. Nonetheless, the estimated findings could be summarized as the positive nexus of energy consumption and the negative impact of energy efficiency on the CO_2 emissions. However, a gap has been identified since there is no existing study that considers energy consumption and energy efficiency in relation to energy related CO_2 emissions.

3. Data and methodology

3.1. Theoretical framework and model specifications

One of the growing areas of energy efficiency from a theoretical perspective is researching its implications on CO_2 emissions (Akram et al., 2020). Factors which affect energy efficiency give birth to the notion of energy efficiency's implications on CO_2 emissions. Economic growth, energy consumption (Shahbaz, 2018), and renewable energy use (Hu et al., 2021) all evolve in irregular ways across time. Dissimilar (in absolute terms) reactions in CO_2 emissions are unavoidable when energy efficiency shocks move irregularly (Akram et al., 2020). The environmental Kuznets curve (EKC) theory suggests that during a boom period, a rise in positive shocks in the energy efficiency may cause higher than proportional response in reduction of CO_2 emissions due to increased competition for improved quality of environmental (Shahbaz et al., 2017). Similarly, a rise in energy efficiency's negative shocks might lead to a lower or equivalent proportional increase in the CO_2 emissions (UNEP, 2016); the pollution reduction losses are offset by the usage of renewable energy (Grossman and Krueger, 1991). In a contractionary context, the opposite could occur as a result of a greater reliance on regaining economic development rather than enhancing environmental quality and renewable energy consumption (Shahbaz et al., 2017). Additionally, an interesting perspective ties asymmetric impacts to energy consumption patterns. Indicates that enhanced energy efficiency was attributed to a decrease in energy usage over time as a consequence of energy saving practice that did not return to energy-wasting practices (Shahbaz, 2018). Moreover, renewable energy and particularly the renewable electricity output could affect CO_2 emissions in two ways. Firstly, enhancement in the supply of renewable electricity output resulted in lower prices, which could greatly inspire the domestic as well as industrial use of renewable electricity and adversely affects CO_2 emissions in the region. Secondly, the enhancement in the efficiency of renewable energy not only promote environmental sustainability via reducing emissions, but also promote economic growth (Saidi and Omri, 2020).

Based on the above theoretical framework and objective of the study, this research utilized a total of five variables, where the dependent variable is energy related methane and symbolized as energy related emissions ($ERCO_2$) and measured in percent of total emissions. On the other hand, the focus variable is energy efficiency (*ENEF*) and is measured as constant 2017 PPP $per kg of oil equivalent. Besides, three control variables are also used in this study, i.e., economic growth (*GDP*) – measures an economy's health by considering aggregate consumption, expenditure, investments, among others, energy consumption (*ENEC*) captured by fossil fuel consumption measured as percent of total energy consumption, and renewable energy electricity output (*REO*) which is measured as percent of total energy output. Data for all the variables covers the period from 1990-2020 and obtained from the World Development Indicators[1]. Data for the last 31 years covers a panel of 12 RCEP economies including Indonesia, Australia, Malaysia, the Philippines, China, New Zealand, Thailand, South Korea, Japan, Myanmar, Singapore, and Vietnam.

Following the theoretical framework, this study constructed the following general model:

Model

$$ERCO_{2,it} = f(GDP_{it}, REO_{it}, ENEC_{it}, ENEF_{it})$$

The above general model reveals that *GDP*, *REO*, *ENEC*, and *ENEF* are the function of $ERCO_2$. However, in order to empirically examine the said model, this may be transformed into a regression model, which is expressed as follows:

$$ERCO_{2,it} = \theta_1 + \theta_2 GDP_{it} + \theta_3 REO_{it} + \theta_4 ENEC_{it} + \theta_5 ENEF_{it} + \varepsilon_{it}$$

Where θ'*s* are the coefficients to be estimated. The subscript "*i*" and "*t*" indicates cross-sections which is 12 and time, which is 31, respectively. Moreover, ε is the error term of the regression model.

3.2. Estimation technique

3.2.1. Descriptive Statistics and data normality

Current study calculated the descriptive statistics for the variables, i.e., $ERCO_2$, *GDP*, *REO*, *ENEC*, and *ENEF*. To be more specific, this study provides the estimated values of mean, median, and range for each specific variable. In addition, the values of standard deviation are derived, which is the distance of each observation from the mean value and also replicate volatility in variable under study. Beside these specifications, this study check for data normality, which is captured by the skewness and Kurtosis of the variable. Moreover, the comprehensive measure for data's normality is the Jarque and Bera (1987) normality test. This test allows for the skewness as well as excess Kurtosis to demonstrates whether the data is normality distributed. The statistical values of data normality could be obtained by using the following equation:

$$JB = \frac{N}{6}\left(S^2 + \frac{(K-3)^2}{4}\right), \tag{2}$$

The Jarque-Bera normality test assumes normal distribution of the data as a null hypothesis, while statistically significant estimates could reject the null hypothesis.

3.2.2. Slope heterogeneity and cross-sectional dependence

After evaluating the regularity-irregularity of variables, current study adopted panel data estimation techniques, i.e., slope heterogeneity and the panel cross-section dependence. After the industrial revolution, globalization and the international trade is rapidly improvising. There are various forces that pushes an economy to depend on one or more economies. Specifically, if a country specializes in one product or services, the demand for that product and services in other economies pushes them to depend on those economies, which lead them to achieve various financial, social, economic, environmental, technological goals, among others. Therefore, economies in relation to other countries may show similarities as well as differences in some respect. However, the issue of slope homogeneity and cross-section dependence in the panel data could create an estimating issue particularly in the econometric analysis (Le and Bao, 2020; Breitung, 2005). Therefore, this study uses the Pesaran and Yamagata (2008) slope coefficient homogeneity (SCH) test and the Pesaran (2021) cross-section dependence test to detect whether the slopes are homogenous/heterogenous and cross-sectionally dependent. The SCH could be estimated via the following equation:

$$\hat{\Delta}_{SCH} = \sqrt{N(2k)^{-1}}.(N^{-1}\acute{\mathrm{S}} - \mathrm{K}), \quad (3)$$

In addition, the said test also offers estimated results for the adjusted SCH, given as:

$$\hat{\Delta}_{ASCH} = \sqrt{N}.\sqrt{\frac{T+1}{2K.(T-K-1)}}.(N^{-1}\acute{\mathrm{S}} - 2\mathrm{K}), \quad (4)$$

The null hypothesis of this test assumes that the slopes coefficients are homogenous, while the alternative hypothesis revealed that the slopes coefficients are heterogenous, which could be obtained after the significant estimates are found.

Once the slope coefficients estimates are obtained, current study used the Pesaran (2021) cross-section dependence test between the RCEP economies, while ignoring the said issue could lead to estimation bias (Campello et al., 2019). The standard form through which cross-section dependency is evaluated is expressed as follows:

$$\mathrm{CD}_{Test} = \frac{\sqrt{2T}}{[N.(N-1)]^{1/2}} \sum_{i=1}^{N-1} \sum_{k=1+i}^{N} T_{ik}, \quad (5)$$

The null hypothesis of the said test asserted that the cross-sections are independent in the panel of RCEP economies. Whereas alternative hypothesis of the cross-section dependence could be accepted once the significant estimates are found.

3.2.3. Unit root

After validating that the slope coefficients are heterogenous, and cross-sectional dependency exists, this study used the second-generation unit root test that allows for the heterogenous slopes and cross-section dependency. Particularly, we used the Pesaran (2007) cross-sectionally augmented IPS (hereafter CIPS) test of unit root. Earlier, Pesaran (2006) proposed a factor modeling method that considers cross-section dependence. In this technique, the cross-sectional averages are unified as common unobserved components in the model. Following that techniques, Pesaran (2007) proposed another method for unit root that expands the Augmented Dickey-Fuller (ADF) regression model and allows the mean as well as first differenced cross-sectional lags. Besides, this approach also allows for panel data issue, i.e., cross-sectional dependency when the panel is unbalanced, that is, $N \neq T$. The regression equation of the cross-sectional ADF is provided in the standard form as follows:

$$\Delta y_{i,t} = \theta_i + \beta_i^* y_{i,t-1} + d_0.\bar{y}_{t-1} + d_1 \Delta \bar{y}_t + \varepsilon_{it}, \tag{6}$$

The equation above indicates that $\bar{y}_t$ is the observations' average. However, to tackle the serial correlation, the Eq. (6) could be translated by the addition of first difference lags of y_{it} and $\bar{y}_t$, presented as follows:

$$\Delta y_{i,t} = \theta_i + \beta_i^* y_{i,t-1} + d_0 \bar{y}_{t-1} + \sum_{j=0}^{n} d_{j+1} \Delta \bar{y}_{t-j} + \sum_{k=1}^{n} c_k \Delta y_{i,t-k} + \varepsilon_{it}, \tag{7}$$

Thus, the Pesaran (2007) constructed the CIPS, which we are using in the RCEP countries while utilizing the t-statistics averages for each cross-sectional unit, known as $CADF_i$, and it may be estimated as given in the Eq. (8).

$$CIPS = N^{-1} \sum_{i=1}^{N} CADF_i \tag{8}$$

The null hypothesis of the CIPS unit root test assumes that the time series is non-stationary or the unit root is present, which could be rejected of the estimates are found statistically significant.

3.2.4. Method of moment quantile regression

Firstly, Koenker and Bassett Jr (1978) provided a method of panel quantile estimating method, where the dependent variance and the conditional mean statistics analyzes the independent variables. Even if the variables are abnormally distributed, the quantile regression provides proficient estimates. Following this property of the quantile regression, current study used a novel method of moments quantile regression, provided by Machado and Santos Silva (2019). This method holds the property of evaluating the distributional as well as heterogenous effects of quantile numbers (Sarkodie and Strezov, 2019). The location-scale type of the conditional quantile $Q_y(\tau|X)$ estimates could be provided in the standard form as follows:

$$Y_{it} = \theta_i + \vartheta X_{it} + \left(\delta_i + \rho \acute{Z}_{it}\right).\mu_{it}, \tag{9}$$

The equation above reveals that $P.\left(\delta_i + \rho\acute{Z}_{it} > 0\right) = 1,$ where p demonstrates the probability (.) value. Whereas, the parameters to be estimated are θ, ϑ, δ, and ρ. Moreover, the subscript i demonstrates the fixed effect specified by θ_i and δ_i, $i = 1,\ 2,\ \ldots,\ n$. Finally, Z shows k-vector of predictable X elements that are variational conversions with the component "$\imath$", which is given as:

$$Z_\imath = Z_\imath(X),\ \imath = 1,\ 2,\ \ldots,\ k \tag{10}$$

Where Eq. (10) it is noteworthy that X_{it} is identically and independently distributed for every individual i and t. Similarly, μ_{it} is orthogonal to X_{it} and might be distributed across fixed cross-sections and time (Machado and Santos Silva, 2019), which is accommodating the stabilization the remaining components and anticipation of the extreme exogenic behavior. Thus, the above constructed Eq. (1) can be transformed to the following form:

$$Q_y(\tau X_{it}) = (\theta_i + \delta_i\ q(\tau)) + \vartheta X_{it} + \rho\acute{Z}_{it}q(\tau), \tag{11}$$

From the above Eq. (11), X_{it} indicates the independent variables' vector that includes *GDP*, *REO*, *ENEC*, and *ENEF*. Where all the variables are taken in the natural log form. Also, $Q_y(\tau X_{it})$ in the above equation reveals the quantiles distribution for dependent variable, which is $ERCO_2$ and will be estimated as conditional on the dependent variable's location. In addition, $-\theta_i\ (\tau) \equiv \theta_i +\ \ \delta_i\ q.(\tau),$ is the coefficient of scalar which is a fixed effect for the quantile τ for every individual cross-section (i). On the contrary to the conventional least square fixed effects, the individual effect does not control intercept shift. Due to the time-invariant features of variables, the heterogeneous influence is susceptible to shift and the conditional distribution across quantiles. Further, $q(\tau)$ demonstrates the sample of $\tau - th$ quantile, which are four in this case 25$^{\text{th}}$, 50$^{\text{th}}$, 75$^{\text{th}}$ and 90$^{\text{th}}$. The quantile equation utilized for identification of every individual quantile could be expressed as follows:

$$min_q \sum\nolimits_i \sum\nolimits_t \gamma_\tau\left(R_{it} - \left(\delta_i + \rho\acute{Z}_{it}\right)q\right), \tag{12}$$

Where

$$\gamma_\tau(A) = (\tau - 1).AI\{A \le 0\} + TAI\{A > 0\},$$

designates the check function.

3.2.5. Panel causality test

Employing the MMQREG method led to provide the long-run impact of each explanatory component on $ERCO_2$ at each specific quantile. However, this estimator lacks the property of showing the causal nexus between the variables. In this regard, current study employed the Dumitrescu and Hurlin (2012) Granger panel causality heterogeneity specifications. This specification is sufficient in this case as it deals the $T \neq N$ panel issue. Besides, this approach tackles the slope heterogeneity and cross-section dependence issues (Banday and Aneja, 2020).

4. Results and discussion

This study begins the section of empirical results by evaluating the descriptive statistics and normality test, for which the empirical outcomes are reported in Table-3. Concerning the descriptive statistics, the mean and median values of all the variables are found nearly equal but positive. This demonstrates that all the variables are following the positive trend. However, the range values (maximum-minimum) of all the variables, except *REO* is positive. Such values of *REO* started from the minimum of negative, i.e., −0.267% of total energy and reached to the positive 1.924% of total energy output. Besides, the standard deviation that simply measures volatility in the variable across time, reveals that $ERCO_2$, *GDP*, *REO*, *ENEC*, and *ENEF* are volatile or fluctuating across time. The variation of each observation from the mean value is although positive, yet the value is small and demonstrates that the variation from the mean exist between variables is smaller. Moreover, this study also tested the normality of each study variable, for which skewness and Kurtosis are generally used. The values of both of these statistics are found greater or lesser than the benchmark value that reports normality, i.e., Skewness (1) and Kurtosis (3). This represents that all the variables are following irregular path. However, the Jarque and Bera (1987) statistics reports significant estimates for $ERCO_2$, *REO*, *ENEC*, and *ENEF*, as the probability values suggest. This test is an extensive measure of the normality check as it allows for both the skewness and excess Kurtosis and the null hypothesis revealed that the variable could be normally distributed. Since the statistical values for the said variables are significant at 1% level, therefore the null hypothesis may be rejected and it is concluded that except the *GDP*, all other variables are abnormally distributed. Since most of the empirical estimates are limited in terms of handling irregular data, therefore, current study adopted an efficient estimator that empirically evaluate long-run results by tackling the issue of irregularity or abnormality of the variable.

As discussed earlier, there are various economic and non-economic reasons for which one country depends upon other countries to achieve such objectives and resulted in similarities and difference in some respects. In this regard, the Pesaran and Yamagata (2008) SCH test is employed and the results are provided in the Table-4. Since ignoring the issue of slope heterogeneity/homogeneity may lead to inefficient estimation (Le and Bao, 2020; Breitung, 2005). Therefore, it is important to analyze whether the slopes are heterogenous. Following the null hypothesis of slopes being homogenous, the empirical estimates of both SCH ($\sim\Delta$) and adjusted SCH ($\sim\Delta^{\text{Adjusted}}$) are highly statistically significant. This reveals that the null hypothesis may be rejected and it is concluded that the slopes coefficients are heterogenous.

On the other hand, Campello et al. (2019) argued that cross-sectional dependency issue may be identified in the panel data since it leads to estimation biased. Therefore, we employed the Pesaran (2021) CD test and the results are provided in Table-5. The empirical estimates asserted that all the variables, except $ERCO_2$ are found highly statistically significant, which rejects the null hypothesis of cross-sectional independence in the variables *GDP*, *REO*, *ENEC*, and *ENEF*. Yet, these variables are cross-sectional dependent that further illustrates that the economic growth, energy consumption, renewable electricity output, and energy efficiency of one country has a spillover effect on the said variables of other economies. However, the null hypothesis of cross-sectional dependence for $ERCO_2$ may not be rejected as the estimates are insignificant and insufficient. Thus, it is concluded that the $ERCO_2$ emissions do not hold the spillover effect of one economy over other economies, rather depends upon its own consumption pattern of energy.

Since the variables showed the property of slopes heterogeneity and cross-sectional dependency. Therefore, this study employed the second-generation unit root testing approach, i.e., Pesaran, (2007) CIPS test and the empirical results are provided in the Table-6. From the empirical results, it is noted that only two variables (*REO* and *ENEF*) provides statistically significant estimates at I(0) that rejects the null hypothesis of the presence of unit root in the time variables. However, the remaining three variables ($ERCO_2$, *GDP*, and *ENEC*) are non-stationary at I(0). Therefore, this study tested for the stationarity at I(1), where these variables provide significant estimates that rejects the null hypothesis of the presence of a unit root. Hence, all the variables are found being stationary while following mixed order of integration.

As mentioned earlier, the Jarque and Bera (1987) test asserted that the variables are following irregular path and are not normally distributed. Therefore, the current study employed the novel MMQREG, which deals the issue of non-normality of variables. The estimated results of the said approach are provided in Table-7. The empirical findings asserted that two variables (*GDP* and *ENEC*) exhibit positive influence on the energy related carbon emissions ($ERCO_2$). However, *REO* and *ENEF* are found in negative relation to $ERCO_2$. Specifically, it is noted that a one percent increase in the *GDP* causes an increase of 0.386 to 0.772% across the four quantiles ($Q_{0.25}$, $Q_{0.50}$, $Q_{0.75}$ and $Q_{0.90}$). These findings are highly statistically significant at 1%, 5% and 10% levels and are increasing while moving from lower to upper quantile(s). Similar results are provided by the empirical studies of Hu et al. (2021), Schröder and Storm (2020) in case of India and OECD economies. Thus, the positive association of economic growth and emissions are evident in the developing as well as developed economies. Similarly, the positive association of energy consumption is demonstrated in the empirical findings of MMQREG. In particular, a one percent increase in the *ENEC* enhances $ERCO_2$ by 0.945 to 1.958% in the middle and upper quantiles ($Q_{0.50}$, $Q_{0.75}$ and $Q_{0.90}$). These findings are highly statistically significant at 1% level. Whereas the lower quantile ($Q_{0.25}$) provides insignificant estimates with having negative association between the two variables. The positive association of energy consumption and emissions are consistent to the studies of Li et al. (2020) and Destek et al. (2020) in developed (i.e., G20 and G7) economies. While, consistent findings are also provided by Li and Li (2020), Destek et al. (2020), Akadiri and Adebayo (2021), and Nathaniel et al. (2021) in developing economies such as China and India. Besides, these studies also validate the positive association of *GDP* or economic growth and emissions for these mentioned regions.

On the other hand, the two variables are found in negative association to the emissions. Specifically, a one percent increase in the *REO* discourages energy related CO_2 emissions by 0.125, 0.014, and 0.154% in $Q_{0.50}$, $Q_{0.75}$ and $Q_{0.90}$, respectively. The estimated results are found increasing and more statistically significant while moving from lower to upper quantile(s). The results are statistically significant at 10% and 1% levels, respectively, while insignificant association is found in the first ($Q_{0.25}$)

quantile. The negative association of renewable energy or renewable electricity to emissions are consistent to the findings of Saidi and Omri (2020), Saint Akadiri et al. (2020), and Akadiri and Adebayo (2021). These studies empirically demonstrates that renewable energy and renewable electricity consumption not only reduces environmental degradation, but also contribute to achieve higher level of economic growth in the country. In addition, energy efficiency is also found in negative relation to the energy related emissions in the RCEP economies. Particularly, a one percent increase in the *ENEF* significantly reduces $ERCO_2$ by 0.691, 0.787, and 0.834% in the middle and upper quantiles, i.e., $Q_{0.50}$, $Q_{0.75}$ and $Q_{0.90}$. Similar to *REO*, the nexus of *ENEF* and $ERCO_2$ is insignificant in the lower ($Q_{0.25}$) quantile, while the magnitude level and the significance level is found increasing from lower to middle and to upper quantiles. These findings are in line to the existing studies of Wang et al. (2011), Yang et al. (2021), Mahapatra and Irfan (2021), He et al. (2021), Chen et al. (2021) and Pei et al. (2021). These studies empirically demonstrates that various factors including corruption and non-renewable energy consumption enhances emissions level in the country, whereas the energy efficiency significantly reduces environmental hazards by minimizing the CO_2 emissions level in the atmosphere.

Since the MMQREG is an efficient estimator to provides empirical results at each specific scale, location and quantile. However, it is insufficient to estimates the causal association exist between the variables. In this sense, we employed the Dumitrescu and Hurlin (2012) Granger panel causality test and the empirical results obtained are provided in Table-8. The results demonstrates that there is a bidirectional and unidirectional causal nexus exists between the study variables. Specifically, a bidirectional causal association exists between *GDP* and $ERCO_2$. That is the *GDP* significantly causes $ERCO_2$, and the $ERCO_2$ Granger causes *GDP*, which also validates the earlier findings and are consistent to the existing study of Li et al. (2020), which provides evidence of two-way causal nexus between these variables in case of G20 economies. In addition, the feedback effect is found between *ENEF* and $ERCO_2$. Which demonstrates that any policy change in the either *GDP*/*ENEF* or $ERCO_2$ will significantly affect the other variable. Furthermore, there is a unidirectional causal nexus found running from *REO* and *ENEC* to $ERCO_2$. The feedback association is missing between these explanatory and dependent variables, which are contrary to the findings of Hu et al. (2021) and Petrović-Ranđelović et al. (2020) by revealing that renewable energy and non-renewable energy are bidirectionally connected to the CO_2 emissions.

Discussion

Since the RCEP economies include both developed and developing economies, therefore the panel consists of variational data. In this regard, normality of the data is tested that reveals that most of the variables are following the property on non-normal distribution, which could lead to the adoption of effective estimator that deals in the estimation on non-normal data. Besides, the heterogenous slope coefficients and cross-sectional dependency allows current study to use second generation panel unit root test, which provides mixed order of integration in the data. The empirical estimates of the MMQREG illustrates that energy consumption, which plays a vital role in the economy's growth and is considered as the backbone of industrial sector positively affect energy related CO_2 emissions in the regions (Li et al., 2020; Destek et al., 2020; Akadiri and Adebayo, 2021; Nathaniel et al., 2021). Since, the RCEP economies are primarily focusing on the development of an economy, where the industrial sector is considered as key for the economic growth and income level. Therefore, enhancement in the industrial production and expansion although enhances the GDP level, but requires more energy to consume. In addition, the increased level of income further promotes the accessibility and adoptability of non-renewable energy use, which are harmful to environmental quality. As a result, the increased level of income and use of traditional fossil fuel energy resources significantly increases the energy related emissions in the RCEP economies. On the other hand, renewable electricity output and the energy efficiency are playing a role as a remedial measure that significantly reduces the emission level and promote environmental sustainability (Saidi and Omri, 2020; Saint Akadiri et al., 2020; Akadiri and Adebayo, 2021; Wang et al., 2011; Yang et al., 2021; Mahapatra and Irfan, 2021). That is, the level of renewable electricity and energy efficient technologies promote energy saving products and services, which in turn reduces the level of energy related emissions in the region. Further, the developed economic growth also contributes to research and development and technological innovation sectors, which encourages the use of renewable energy products and services. Therefore, the empirical results unveil the negative association of such variables with the $ERCO_2$ emissions. Thus, in order to achieve low carbon economy and rapid economic growth, the RCEP economies need innovative and sufficient revision of the policies regarding environmental sustainability and energy consumption.

5. Conclusion and policy implications

The last four decades are very important since the global energy demand has been risen to the utmost level and the emissions are also reported as all-time high during the last three decades. The higher energy demand is fulfilled via consuming traditional fossil fuel that leads to environmental degradation, climate change and global warming. In order to achieve environmental sustainability, scholars and scientist have suggested the use of renewables and energy efficient tools. In this regard, current study analyzes the influence of *GDP*, *REO*, *ENEC*, and *ENEF* on $ERCO_2$. Examining the 12 RCEP economies, this study covers the period from 1990 to 2020 and the results are estimated via employing the MMQREG specifications. The estimated results reveal that both economic growth and energy consumption significantly enhances energy related emissions. Enhancement in the income level encourages investors and industrialists to invest in the industrial sector that enhances production, diversification, and expansion. However, increased production and expansion of such sector requires more energy, and this demand is fulfilled by consuming the traditional energy resources that causes energy related emissions in the RCEP economies and adversely affects environmental quality of the region. On the other hand, the findings illustrate that renewable electricity output and energy efficiency could be the possible

Table 1. Average Statistics for Each RCEP Country.

S. No.	Country	Energy Related Methane Emissions (% of total)	Renewable Electricity Output (% of total electricity output)	GDP (constant 2015 US$)	Energy efficiency (GDP per unit of energy use (constant 2017 PPP $ per kg of oil equivalent))	Fossil fuel energy consumption (% of total)
1	Australia	24.32993	10.36426	1.03E + 12	7.42252	93.57102
2	China	43.26126	18.86842	5.97E + 12	3.973616	83.48263
3	Indonesia	15.71169	14.85776	5.79E + 11	9.361315	62.82236
4	Japan	10.95258	10.94706	4.11E + 12	9.950358	85.74494
5	South Korea	4.928094	52.37859	3.18E + 10	7.306253	26.94846
6	Malaysia	3.250357	73.80341	1.41E + 11	8.339669	65.70505
7	Myanmar	7.581751	33.26718	2.05E + 11	11.5479	56.44429
8	New Zealand	17.41054	1.310606	1.98E + 11	13.0272	96.95685
9	Philippines	52.66175	9.719699	2.01E + 11	7.746658	95.35166
10	Singapore	21.46444	1.732446	1.03E + 12	6.422663	83.43918
11	Thailand	17.23315	7.535716	2.95E + 11	8.476309	78.24901
12	Vietnam	17.8584	49.17169	1.21E + 11	7.990562	54.33014

Source: calculated by the authors.

remedial measures for environmental disasters. Since both the variables are negatively associated to energy related emissions, still the energy related emissions are reported in the increasing trend, which indicates that the level of renewable energy electricity output and energy efficiency are not up to the mark level in these economies.

Based on the empirical results, this study recommends policy suggestions that could be used as a tool for environmental recovery. Since economic growth is positively associated to energy related emissions, therefore it is noteworthy that a major portion of the income is fossil fuel energy oriented, which speeds up the emission level. Therefore, policies must be revised that help in the adoption and promotion of renewable energy resources. Besides, the industrial sector is the key sector that helps economy to stabilize, therefore achieving higher economic growth level must be accommodated to structural transformation of the industrial sector towards renewable energy resources. In addition, policies that targets renewable electricity should be paid more attention to attain low carbon economy in the future. Moreover, energy efficient resources must be adopted and promoted in order to save energy, lower energy demand, and reduce energy related emissions. Furthermore, investment in advance technologies and research and development should be promoted as it will promote the culture of renewables and energy efficient products and services.

Nonetheless, this research provides important and novel important findings, still this study is limited in few dimensions, which could be considered in the future studies. Specifically, this study is limited due to examining only the energy related emissions. However, future researchers are directed to consider the overall emissions level in case of the RCEP economies. In addition, renewable energy related energy resources need investigation regarding the specific influence of thermal, solar, hydro sectors, which are suggested for future researchers. Furthermore, this study can be extended by enlarging the time period for investigation in order to comprehensively analyze the said nexus. Lastly, this study may be used as a pioneering study for the rest of

Table 2. Summary of the Literature Review.

Author(s)	Country (period)	Methodology	Findings
Li et al. (2020)	G20 (1992-2014)	AMG, CCEMG	Economic growth and energy consumption promote CO_2 emissions.
Akadiri and Adebayo (2021)	India (1970-2008)	NARDL	Economic growth, non-renewable energy, and financial growth enhances CO_2 emissions. Renewable energy reduces CO_2 emissions.
Hu et al. (2021)	India (1990-2018)	VECM, Granger causality	Energy consumption and technology improves economic growth and CO_2 emissions. Renewable energy reduces carbon emissions.
Nathaniel et al. (2021)	African economies (1990-2014)	Statistic and dynamic estimations	Economic growth is energy dependent. No significant association exists between CO_2 emissions and economic growth.
Li and Li (2020)	30 Chinese provinces	Spatial econometric model	Energy investment and economic growth promote carbon emissions.
Schröder and Storm (2020)	58 OECD countries (2007-2015)	Fixed effect	Economic growth significantly promote enhances emissions while no link of the EKC existence.
Destek et al. (2020)	G7 countries (1800-2010)	Time-varying cointegration, bootstrap-rolling window estimation	Mixed association exists between economic growth and emissions.
Saidi and Omri (2020)	15 major renewable energy consuming economies	FMOLS, VECM	Increased efficiency of renewable energy promotes economic growth and emissions reduction.
Dong et al. (2020a)	China (1978-2017)	Vector autoregressive model	Industrial structure upgradation leads to win-win situation of economic growth and emissions reduction.
Dong et al. (2020b)	China	STIRPAT	Agriculture, transportation, and retail sectors are the prominent decoupling factors of economic growth from emissions.
Petrović-Ranđelović et al. (2020)	CIVETS economies (1989-2016)	Cointegration, causality test	Bidirectional causality between energy use – CO_2, unidirectional causal nexus between CO_2 and GDP.
Saint Akadiri et al. (2020)	Turkey (1970-2014)	ARDL bound test, Toda-Yamamoto Granger causality test	Economic growth and electricity consumption enhances emissions.
Song (2021)	China (2001-2016)	Non-dynamic panel data method	Higher economic growth enhances investment in technologies, leads to reduce emissions.
Yang et al. (2021)	78 countries (2000-2017)	Comprehensive decomposition framework	Technological progress related to energy saving and efficiency in production are the prominent decoupling factors.
Mahapatra and Irfan (2021)	34 developing and 28 developed economies (1990-2017)	Non-linear panel ARDL	Increase in energy efficiency reduces emissions and reduction in energy efficiency enhances CO_2 emissions in the long-run.
Razzaq et al. (2021)	USA (1990-2018)	Bootstrapping ARDL	Solid wastes are a substantial indicator of economic growth and CO_2 emissions, and also causes energy efficiency.
He et al. (2021)	China	Multi-objective optimization model	Energy efficiency induced by research and development investment reduces emissions.
Chen et al. (2021)	China 30 provinces (2000-2017)	Difference-in-difference model	Improved energy efficiency can be achieved via emission trading scheme.
Pei et al. (2021)	Chinese industrial sector (2005-2015)	System GMM	Corruption enhances industrial emissions whereas energy efficiency reduces it.
Wang et al. (2011)	China	Time-series approaches	Nuclear energy and energy efficiency are the effective tools of low carbon economy.

Source: calculated by the authors.

Table 3. Descriptive Statistics and Normality Check.

	$ERCO_2$	GDP	REO	$ENEC$	$ENEF$
Mean	1.168403	11.55897	1.114016	1.841369	0.900107
Median	1.222684	11.47742	1.146553	1.904128	0.919224
Maximum	1.739800	13.16510	1.923518	1.997350	1.244691
Minimum	0.469463	9.833959	−0.266868	1.140276	0.268686
Std. Dev.	0.348902	0.671267	0.540654	0.166169	0.162634
Skewness	−0.261816	0.115066	−0.527657	−1.855224	−0.949587
Kurtosis	2.313570	2.924147	2.539461	6.403872	5.052047
Jarque-Bera	11.55335	0.910076	20.54963	392.9834	121.1753
Probability	0.003099	0.634424	0.000034	0.000000	0.000000

Source: calculated by the authors.

Table 4. Slope Heterogeneity.

Slope Heterogeneity Test	Statistics
$\tilde{\Delta}$	23.692***
$\tilde{\Delta}$ Adjusted	25.870***

*Note: Significance level is denoted by #x0002A;** for 1%, ** for 5% and * for 10%.*
Source: calculated by the authors.

Table 5. Cross-Section Dependence.

Cross-Section Dependence	
$ERCO_2$	GDP
−1.038	44.457***
REO	$ENEC$
9.913***	5.674***
$ENEF$	
21.154***	

*Note: Significance level is denoted by *** for 1%, ** for 5% and * for 10%.*
Source: calculated by the authors.

Table 6. Unit Root Testing (Pesaran, 2007).

	Intercept and Trend	
Variables	I(0)	I(1)
$ERCO_2$	−2.070	−4.099***
GDP	−1.481	−3.287***
REO	−3.760***	–
$ENEC$	−2.616	−5.042***
$ENEF$	−2.995***	–

*Note: Significance level is denoted by *** for 1%, ** for 5% and * for 10%. I(0) is for level, and I(1) is for the first difference.*
Source: calculated by the authors.

Table 7. Estimates of Quantile Regression–MMQREG.

	Quantiles			
DV: $ERCO_2$	$Q_{0.25}$	$Q_{0.50}$	$Q_{0.75}$	$Q_{0.90}$
GDP	0.386***	0.449***	0.772***	0.630***
	[0.150]	[0.105]	[0.176]	[0.121]
REO	0.173	−0.125*	−0.014***	−0.154***
	[0.195]	[0.065]	[0.003]	[0.011]
$ENEC$	−0.007	0.945***	1.627***	1.958***
	[0.387]	[0.264]	[0.375]	[0.455]
$ENEF$	−0.396	−0.691***	−0.787***	−0.834***
	[0.366]	[0.146]	[0.214]	[0.258]
$Constant$	−3.169*	−0.376	−0.103	0.029***
	[1.655]	[0.400]	[0.586]	[0.707]

*Note: DV is dependent variable used here is $ERCO_2$. Significance level is denoted by *** for 1%, ** for 5% and * for 10%.*
Source: calculated by the authors.

Table 8. Causality Check.

Pairwise Dumitrescu Hurlin Panel Causality Tests

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
$GDP \nrightarrow ERCO_2$	4.944***	8.24303	2.E-16
$ERCO_2 \nrightarrow GDP$	2.038**	2.04263	0.0411
$REO \nrightarrow ERCO_2$	3.560***	5.28943	1.E-07
$ERCO_2 \nrightarrow REO$	1.849	1.64059	0.1009
$ENEC \nrightarrow ERCO_2$	14.261***	28.1177	0.0000
$ERCO_2 \nrightarrow ENEC$	1.433	0.75203	0.4520
$ENEF \nrightarrow ERCO_2$	4.805***	7.94576	2.E-15
$ERCO_2 \nrightarrow ENEF$	17.060***	34.0873	0.0000

*Note: Significance level is denoted by *** for 1%, ** for 5% and * for 10%.*
Source: calculated by the authors.

the developed and developing economies, which the researchers are suggested to adopt.

Notes

1. For data and other information, visit: https://databank.worldbank.org/source/world-development-indicators-#advancedDownloadOptions

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