CO2 emissions mitigation among energy importers and energy exporters along BRI countries. What role do renewable energy and nuclear energy play

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CO₂ emissions mitigation among energy importers and energy exporters along BRI countries. What role do renewable energy and nuclear energy play

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ABSTRACT

Background: In achieving the goal of sustainable development (Goal 13), United Nations has related global warming to greenhouse gas emissions in recent years. Emissions of carbon dioxide, are known to be the biggest contributor to global warming. Hence this study disaggregates energy consumption that is Nuclear energy, renewable energy and fossil fuel consumption and investigates their impact on CO₂ emissions along the Belt and Road Initiative.

Methods: This paper determined the cross-sectional dependency and utilized second generation panel unit root test for precise estimation. Westerlund cointegration test was used to determine the long-run equilibrium relationship among the variables. Lastly the Pooled Mean Group (PMG) estimation approach was applied to investigate the long and short run output elasticities between the variables.

Results: The results indicates that; for energy importers, CO₂ emissions has a significant positive correlation with Fossil fuel and nuclear energy, while renewable energy has a significant negative correlation with CO₂ emissions. For energy exporting countries, a significant positive two-way relationship amidst Fossil fuel and CO₂ emissions, and a significant negative one-way causal relationship from nuclear energy and renewable energy unto CO₂ emissions.

Conclusion: The results clearly show that in all panel grouping renewable energy contribute negatively on CO₂ emissions, thus more implant of renewable system is need along the belt and road initiative. These recent methodologies employed and findings revealed that in a pollution reduction tender, causal affiliations are affected in a tender to reduce emissions along with long and short-term estimated effects among employed variables by the energy groupings of Belt and Road countries.

Keywords: BRI Countries, Nuclear Energy, Renewable Energy, Energy Importers, Energy Exporters, PMG Estimation.

1. Introduction

Economic cooperation, Individual countries as well the United Nations (UN), in other to achieve the sustainable development goals (goal 13¹) have linked global warming to greenhouse gas (GHG) emissions in recent years. The emissions of carbon dioxide (CO₂) is believed as the main contributor to global warming among other GHG (Liu et al. 2016). For the past two decades, developed and developing countries, have employed for their economic growth purposes fossil energy intensively in almost all economic sectors such as manufacturing industry, agriculture and transport (Schandl et al. 2016). This therefore has headed to CO₂ emissions in almost all parts of the world. Since energy consumption is a major contributor to economic growth and as well the major contributor to environmental pollution, Begum et al. (2015), expanding production technologies based on renewable and nuclear energy will significantly abridge greenhouse gas emissions (Irandoost 2016). Economics literature recently have discussed the linkages between CO₂ emissions with economic growth, renewable energy and nuclear energy (Baek 2015; Cai et al. 2018; Dong et al. 2018b; Ito 2017; Long et al. 2015; Omri et al. 2015). The results in general indicate a strong relationship amongst renewable energy consumption and economic growth, amongst nuclear energy use and economic growth, and also amongst CO₂ emissions and economic growth. However, Baloch et al. (2019) have stated that the debate is still not clear about renewable energy and nuclear energy mitigating pollution of environment.

¹ Goal 13: Take urgent action to combat climate change and its impacts. Levels of carbon dioxide (CO₂) and other ambient greenhouse gases rose to new levels in 2019. Each nation on each continent is affected by climate change. It disrupts national economies, and it impacts lives. Climate patterns change, sea levels rise and climate events become more extreme. The Paris Agreement, adopted in 2015, aims to reinforce the global response to the climate change challenge by holding a global temperature increase well below 2 degrees Celsius above pre-industrial levels this century. The Agreement also seeks to improve countries' ability to cope with climate change impacts through adequate a new technology system, financial flows and an improved capacity building process.

Renewable energy usage, such as geothermal energy, solar energy, wind power, biofuels and biomass power and other has increased about 10% that is 24% in 2018 from 14% in 2002 (Petroleum 2018). Renewable energy technologies have gained popularity into economies in developed and developing countries since it cheaper, more reliable and more accessible (IEA 2015). In 2015, developing countries invested US \$156 billion in renewable energy, an increase of 19% over 2014 and more than developed countries' total investment in renewable energy (Ren21 2016). This was the first, investment into renewable energy in developing economies exceeded that in developed economies (Adib et al. 2015). Researchers such (Bilgili et al. 2016; Sebri 2015) found a one way causal effect from renewable energy to CO₂ emissions in their study in 17 OECD countries and BRICS countries respectively. Others such as (Dogan and Seker 2016; Jebli et al. 2016) observed two way causal effect between renewable energy consumption and CO₂ emissions in 15 EU countries and 25 OECD countries respectively.

On the other side, the use of nuclear power is regarded as the alternative energy source to allot the high oil prices and reduce dependence on other countries for energy needs (Hewitt and Collier 2018). Oil and gas usage show that the world's energy demand is growing fast, reserves could run out in generations to come, alternative resources are scarce and security of energy supplies is vital. In response to these challenges, considering long-term development and environmental strategy, nuclear energy consumption is a sure way Hori (2000). For the past decade, researchers have studied the association between nuclear power and CO₂ emissions. (Jaforullah and King 2015; Saidi and Mbarek 2016) respectively proved that no causal relationship amidst nuclear energy and carbon dioxide emission in the US and 9 developed countries using used vector error correction model (VECM) Granger causality method. Their results again confirmed the growth hypothesis in these regions. However, (Menyah and Wolde-Rufael 2010; Richmond and Kaufmann 2006) found

one way causal effect from nuclear energy to CO₂ emissions in the US and in OECD and non-OECD countries.

In as much as the relationship between CO₂ emissions, renewable energy and nuclear energy have been studied and reported, analysis on countries being energy importers and exporters along the BRI remain unclear. Responding to this deficiency, this study propose the relevance in analyzing the energy classifications of countries along the BRI. By exploring links between these variables, researchers may be able to help determine whether renewable energy or nuclear energy is the best in mitigating CO₂ emissions in these groups. If renewable energy or nuclear energy helps mitigate emissions in these groups, then pursuing more renewable energy or the usage of nuclear energy will have beneficial effects on mitigating CO₂ emissions. Specific questions in regards to this study are as follows: first, from the perspective of the whole process, does the consumption of renewable energy and nuclear energy contribute to CO₂ emissions reduction? Secondly, if so, which energy source contributes more? Fossil fuels, an important additive variable was included since they are known as the main producer of CO₂. Labor is also added as an additional variable, because through economic cooperation, local and foreign industries will hire more workers, which will increase energy consumption in the long run. Since energy consumption is related to CO₂ emissions, we consider human capital. Table 1 unveils recent studies that employed the nuclear and renewable energies in different research location.

INSERT TABLE 1

The remainder of this paper is organized as follows: Section 2 presents data and classification methodology in section 3, section 4 introduces estimation of results and discussion, lastly conclusion and policy recommendation in section 5.

2. Data and classification

Some countries were omitted in this study as a result of missing data, thus annual data covering 1990-2018 for 40 BRI countries were utilized. The characteristics of the variables in this study are presented in Table 2.

INSERT TABLE 2

Since energy is an important input to production, energy trade is critical to the economic growth of countries whose energy reserves cannot meet their energy needs. Likewise energy cooperation based on free trade is an important part of BRI. Thus due to the lack of conventional energy reserves and increasing reliance on energy imports, it is necessary to divide these countries into energy importers and energy exporters (Table 3). This offers the belt and road initiative a way to diversify energy sources and ensure energy security. The classification is determined based on a ratio of net energy imports to energy usage, where energy imports are defined as energy consumption minus the output expressed in oil equivalent, according to the international energy agency (IEA). Net exporters are countries with negative net energy imports (Liu and Hao 2018).

INSERT TABLE 3

3. Methodology

3.1. Model specification

The relationships amidst nuclear energy, renewable energy, labor force, fossil fuels, economic growth and CO₂ emissions can be estimated as a function following a similar study done by Saud et al. (2019) and written as;

$$CO_2 = f(GDP, NUC, REW, LAB, FOS) \quad (1)$$

Equation one can be converted into an econometric model including a constant term (β_0) and an error term (ε_{it}) as in Eq. (2):

$$CO_{2it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 NUC_{it} + \beta_3 REW_{it} + \beta_4 LAB_{it} + \beta_5 FOS_{it} + \varepsilon_{it} \quad (2)$$

where $i = 1, 2, 3, \dots, N$ indicating each panel country; $t = 1, 2, 3, \dots, N$ indicating the time span, β_0 is the intercept term and ε_{it} is the error term. The parameters $\beta_1 - \beta_5$ indicate the unknown coefficients of GDP, NUC, REW, LAB, FOS respectively. In order to better fit the estimation, natural logarithmic transformation is taken.

3.2. Econometric approach

3.2.1. Cross sectional dependence (CSD)

With the increasing degree of economic integration, interdependence between countries is often strong. Ignoring cross sectional effects in estimation of panel data may therefore lead to deviation in estimation and error in prediction. When $T > N$, the Lagrange multiplier (LM) test developed (Breusch and Pagan 1980) can be employed. On the other hand, when $T < N$, which is the most common case in panels, the LM test statistics have no satisfactory statistical properties because they show a large amount of dimensional distortion (De Hoyos and Sarafidis 2006). Thus, before analyzing the stationary properties of variables, we used three different tests, the Pesaran CD test, the Friedman test, and the free test, to verify whether the panel data had cross-sectional correlations (De Hoyos and Sarafidis 2006).

The Pesaran CD test also can be computed as:

$$CD = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^N T_{ij} \hat{\rho}_{ij}^2 \rightarrow N(0,1) \quad (3)$$

Where ρ_{ij} is the coefficients of correlation obtained from the residuals;

165 The Friedman's test can be calculated by;

$$167 \quad R_{ave} = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{r}_{ij}$$

166 (4)

168 Where $\hat{r}_{ij}$ is the sample estimate of the rank correlation coefficient of the residuals. The *CD* and
 169 R_{ave} share a mutual characteristics; they involve the sum of the correlation coefficients of the
 170 residual matrix, not the sum of the correlation squared used in the *LM* test. The free's test can also
 171 be computed as;

$$173 \quad R_{ave}^2 = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{r}_{ij}^2$$

172 (5)

174 Where R_{ave}^2 been the sample estimate of the rank correlation coefficient of the residuals squared.

175 3.2.2. Panel unit root test

176 Considering the fact that CSD errors was characterized in the panel data, unit roots test that
 177 considers CSD must be taking into account to obtain reliable estimates. In responds to this, a
 178 second generation panel root test such as Pesaran (2007) cross-sectionally dependent augmented
 179 dickey fuller (CADF) test was adopted. The regression for this test is given as:

$$181 \quad \Delta y_{it} = \alpha_i + \beta_i y_{it-1} + \theta_i \bar{y}_{t-1} + \sum_{j=1}^{\rho} \gamma_{ij} \Delta y_{it-1} + \sum_{j=0}^{\rho} \delta_{ij} \Delta \bar{y}_{t-j} + d_{it} + \varepsilon_{it}$$

180 (6)

182 Where $\bar{y}_t = \frac{1}{N} \sum_{i=1}^N y_{it}$ and it is included in the equation as a proxy for the effects for unobserved
 183 common factor. α_i is time invariant individual nuisance parameter, $\beta_i, \theta_i, \gamma_{ij}$ and δ_{ij} respectively

represent individual-specific effect, individual-specific linear trend and common time effect. After running the CADF statistic, which similar to the IPS statistic of Im et al. (2003), it is computed as

$$CIPS(N, T) = \frac{1}{N} \sum_{i=1}^N t_i(N, T) \quad (7)$$

Where $t_i(N, T)$ is the value of β_i in equation 7. $\bar{y}_t$ inclusion in the unit root equation, makes the test statistic inconsistent with the ADF statistics, so Peseran provide the critical values.

3.2.3. Westerlund-Edgerton Cointegration test

The Westerlund-Edgerton bootstrap panel cointegration test was employed in estimating the long run effects of the parameters. They proposed two panel cointegration tests for the null hypothesis without cointegration, taking into account structural break in the intercept and slope of the cointegration regression. This test not only provides good results, but also applies to all situations where CSD exists or does not exist. Westerlund and Edgerton (2007) hinted four residual test statistics to evaluate the null hypothesis without cointegration. Two of the tests are group statistics, and the other two are panel statistics, which are normally distributed. In essence, this test measure the existence of cointegration by judging whether there is error correction in a single panel group and the whole panel. The model was built on:

$$y_{it} = \delta_{0i} + \delta_{1it} + n_i D_{it} + x'_{it} \beta_i + (D_{it} x_{it})' \gamma_i + z_{it} \quad (8)$$

Where $i = 1 \dots N, t = 1 \dots T$, $x_{it} = x_{i,t-1} + v_{it}$ is k -dimensional vector, $I(1)$. Dummy variables is D_{it} . $D_{it} = 1$ if $t > T_i^b$ and otherwise zero. T_i^b corresponds to the break date for individual i such that $T_i^b = \theta_i^b$ with $\theta_i^b \in (\Psi, 1 - \Psi)$ and $\Psi \in (0, 1)$, δ_{0i} and n_i are unknown coefficient vectors and z_{it} is the residual term. z_{it} is then develop as;

$$\vartheta_i(L) \Delta e_{it} = \vartheta_i e_{i,t-1} + \varepsilon_{it}$$

(9)

With $\vartheta_i(L) = 1 - \sum_{j=1}^{p_i} \vartheta_{ij} L^j$ being a scalar lag polynomial and ε_{it} is the error process.

$H_0 = \vartheta_i = 0$ No existence of cointegration for $\forall_i$

$H_1 = \vartheta_i < 0$ Existence of cointegration for $\forall_i$

In panel testing, the alternate hypothesis means that the adjustment to equilibrium is uniform across different populations. Therefore, rejecting the null hypothesis means the existence of cointegration in the various groups.

$H_0 = \vartheta_i = 0$ No existence of cointegration for $\forall_i$

$H_1 = \vartheta_i < 0$ Existence of cointegration for $\forall_i$

In addition, the alternative hypothesis means that the adjustment for equilibrium among different groups is heterogeneous, and the refusal of the null hypothesis means there is an indication of cointegration among group member. Where $\hat{a}_{\hat{a}}$ is the standard error of $\hat{a}_i$, such that both the statistics diverged to negative infinity, indicating the test decisions were done based on the left tail of the standard normal distribution such that ;

$$\hat{a} = \left(\sum_{i=1}^N \sum_{t=2}^T \tilde{y}_{i,t-1} \right)^{-1} \sum_{i=1}^N \sum_{t=2}^T \frac{1}{\hat{a}_i} \tilde{y}_{i,t-1} \Delta \tilde{y}_{it} \quad (10)$$

$$\hat{a}_{\hat{a}} = \left[\left(\frac{1}{N} \sum_{i=1}^N \left(\frac{\hat{a}_i}{\hat{a}_i(1)} \right)^2 \right)^{-1} \sum_{i=1}^N \sum_{t=2}^T \tilde{y}_{i,t-1}^2 \right]^{-1/2} \quad (11)$$

3.2.4. The pooled mean group estimator (PMG)

In estimating the short and long run estimates for the variables, the pooled mean group was employed. PMG allowed the short-term parameters to be different between groups and the long-term coefficients to be equal between groups. Pooled mean group (PMG) was developed by Pesaran et al. (1999). The PMG model accepts that the intercept, short-term coefficient and error

variances between groups are heterogeneous, while the long-term slope coefficient between groups is uniform. The ARDL model of late has been employed because it can be used in situations where the sequence is $I(1)$ or $I(0)$, as well as to obtain both short and long run estimates. Finally, the Hausman poolability test, was performed to determine whether pooling long-term coefficients were appropriate and effective. Observing an $ARDL(p,q)$ model as an example, where the lag order is p of the response variable and the lag order of the explanatory variables is given by q . The model can be expressed as;

$$y_{it} = \sum_{j=1}^p \lambda_{ij} y_{i,t-j} + \sum_{j=1}^q \delta'_{ij} x_{i,t-j} + \varepsilon_{i,t} \quad (12)$$

y_{it} indicates the response variable, $x_{i,t-j}$ represents $k - 1$ vector of explanatory variables, δ'_{ij} is a $k - 1$ vector for the coefficients of the independent variables, λ_{ij} is a scalar vector, $\varepsilon_{i,t}$ indicates the error terms, $i = 1, 2, \dots, N$ stands for the individual countries and, $t = 1, 2, \dots, T$ is the periods. The error correction model of equation (15) under the equilibrium state is expressed as;

$$\Delta y_{i,t} = \phi_i y_{i,t} + \alpha'_i x_{it} + \sum_{j=0}^{m-1} \lambda^*_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{m-1} \delta^{*'}_{ij} \Delta x_{i,t-j} + \varepsilon_{i,t} \quad (13)$$

$$\begin{aligned} \phi_i &= -1 + \sum_{j=1}^m \lambda_{ij}; \quad \alpha_i = \sum_{j=1}^n \delta_{ij}; \quad \lambda^*_{ij} = \sum_{j=1}^n \lambda_{ip} + , j = 1, 2, \dots, m - 1 \\ \hat{\delta}_{ij} &= \sum_{p=j+1}^n \hat{\delta}_{ip} \end{aligned}$$

By regrouping equation (16) can be summarized as

$$\Delta y_{i,t} = \phi_i (y_{i,t} + \theta'_i x_{it}) + \sum_{j=0}^{m-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{m-1} \delta^{*'}_{ij} \Delta x_{i,t-j} + \varepsilon_{i,t} \quad (14)$$

θ_i interprets the long run association amongst the response ($y_{i,t}$) and exploratory variables (x_{it}) whilst, δ_{ij}^* show parameters in the short run. The short-term causalities from the explanatory variables to the dependent variables are describe by the short-run parameters. δ_{ij} 's on the other hand indicates coefficients in the long-term which are concerned with the long-term causalities between the dependent variables and their corresponding explanatory variables. ϕ 's indicates the error correction terms . They are expected to be negative and significant, indicating long term relationship among the variables. The rate of adjustment is calculated according to the inverse ratio of the absolute value of the error correction terms. Hence we constructed the modified model in equation (2) as ARDL model in the following format;

$$\begin{aligned}
 \Delta CO_{2i,t} = & \beta_0 + \phi_{1,i} [CO_{2i,t-1} - \theta'_{1,i} (CO_{2.1i,t} + GDP_{2i,t} + REW_{3i,t} + NUC_{4i,t} + LAB_{5i,t} + FOS_{6i,t})] \\
 & + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta CO_{2.1i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta GDP_{2i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta REW_{3i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta NUC_{4i,t-j} \\
 & + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta LAB_{5i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta FOS_{6i,t-j} + \varepsilon_{i,t}
 \end{aligned} \tag{15}$$

$$\begin{aligned}
 \Delta GDP = & \beta_0 + \phi_{1,i} [GDP_{i,t-1} - \theta'_{1,i} (CO_{2.1i,t} + GDP_{2i,t} + REW_{3i,t} + NUC_{4i,t} + LAB_{5i,t} \\
 & + FOS_{6i,t})] + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta CO_{2.1i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta GDP_{2i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta REW_{3i,t-j} \\
 & + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta NUC_{4i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta LAB_{5i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta FOS_{6i,t-j} + \varepsilon_{i,t}
 \end{aligned} \tag{16}$$

$$\begin{aligned}
 \Delta REW_{i,t} = & \beta_0 + \phi_{1,i} [REW_{i,t-1} - \theta'_{1,i} (CO_{2.1i,t} + GDP_{2i,t} + REW_{3i,t} + NUC_{4i,t} + LAB_{5i,t} + FOS_{6i,t})] \\
 & + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta CO_{2.1i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta GDP_{2i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta REW_{3i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta NUC_{4i,t-j} \\
 & + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta LAB_{5i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta FOS_{6i,t-j} + \varepsilon_{i,t}
 \end{aligned} \tag{17}$$

$$\begin{aligned}
\Delta NUC_{i,t} = & \beta_0 + \phi_{1,i} [NUC_{i,t-1} - \theta'_{1,i} (CO_{2,1i,t} + GDP_{2i,t} + REW_{3i,t} + NUC_{4i,t} + LAB_{5i,t} + FOS_{6i,t})] \\
& + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta CO_{2,1i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta GDP_{2i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta REW_{3i,t-j} \\
& + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta NUC_{4i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta LAB_{5i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta FOS_{6i,t-j} + \varepsilon_{i,t}
\end{aligned} \tag{18}$$

$$\begin{aligned}
\Delta LAB_{i,t} = & \beta_0 + \phi_{1,i} [LAB_{i,t-1} - \theta'_{1,i} (CO_{2,1i,t} + GDP_{2i,t} + REW_{3i,t} + NUC_{4i,t} + LAB_{5i,t} + FOS_{6i,t})] \\
& + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta CO_{2,1i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta GDP_{2i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta REW_{3i,t-j} \\
& + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta NUC_{4i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta LAB_{5i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta FOS_{6i,t-j} + \varepsilon_{i,t}
\end{aligned} \tag{19}$$

$$\begin{aligned}
\Delta ENR_{i,t} = & \beta_0 + \phi_{1,i} [ENR_{i,t-1} - \theta'_{1,i} (CO_{2,1i,t} + GDP_{2i,t} + REW_{3i,t} + NUC_{4i,t} + LAB_{5i,t} + FOS_{6i,t})] \\
& + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta CO_{2,1i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta GDP_{2i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta REW_{3i,t-j} \\
& + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta NUC_{4i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta LAB_{5i,t-j} + \sum_{j=0}^{m-1} \delta_{ij}^* \Delta FOS_{6i,t-j} + \varepsilon_{i,t}
\end{aligned} \tag{20}$$

Equation (15) together with equation (16), (17), (18) (19) and (20) will be estimated utilizing the PMG estimator.

3.2.5. PVECM granger causality test

In order to check the validity of the PMG estimation was tested using panel vector error correction technique (PVECM) granger causality. If there is evidence of cointegration among the variables, then the relationship among the variables can be modelled with VECM, which can be used to reveal the direction of granger causality between variable pairs. VECM can also be used to detect the short-term and long-term relationships between variables and can identify the source of causality. When there is no long-term relationship, the auto regression (AR) model is used. For

the latter, it estimates only short-term causalities. This study employed the former granger causality method because cointegration results suggested a long-term relationship among the variables selected. The PVECM can be showed as;

$$\begin{bmatrix} \Delta CO_{2,it} \\ \Delta gdp_{it} \\ \Delta nuc_{it} \\ \Delta rew_{it} \\ \Delta lab_{it} \\ \Delta fos_{it} \end{bmatrix} = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \\ \delta_6 \end{bmatrix} + \sum_{j=1}^k \begin{bmatrix} \beta_{11,j} & \beta_{12,j} & \beta_{13,j} & \beta_{14,j} & \beta_{15,j} & \beta_{16,j} \\ \beta_{21,j} & \beta_{22,j} & \beta_{23,j} & \beta_{24,j} & \beta_{25,j} & \beta_{26,j} \\ \beta_{31,j} & \beta_{32,j} & \beta_{33,j} & \beta_{34,j} & \beta_{35,j} & \beta_{36,j} \\ \beta_{41,j} & \beta_{42,j} & \beta_{43,j} & \beta_{44,j} & \beta_{45,j} & \beta_{46,j} \\ \beta_{51,j} & \beta_{52,j} & \beta_{53,j} & \beta_{54,j} & \beta_{55,j} & \beta_{56,j} \\ \beta_{61,j} & \beta_{62,j} & \beta_{63,j} & \beta_{64,j} & \beta_{65,j} & \beta_{66,j} \end{bmatrix} \times \begin{bmatrix} \Delta ems_{it-1} \\ \Delta gdp_{it-1} \\ \Delta nuc_{it-1} \\ \Delta rew_{it-1} \\ \Delta lab_{it-1} \\ \Delta fos_{it-1} \end{bmatrix} + \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \gamma_4 \\ \gamma_5 \\ \gamma_6 \end{bmatrix} \times (ECT_{it-1}) + \begin{bmatrix} \mu_{1it} \\ \mu_{2it} \\ \mu_{3it} \\ \mu_{4it} \\ \mu_{5it} \\ \mu_{6it} \end{bmatrix} \quad (21)$$

Where Δ is the first difference operator, δ_i indicate heterogeneity parameter, ECT_{it-1} is the lagged error correction term, j represents the lag length and μ indicate the random error term.

4. Estimation results and discussion

4.1. Descriptive statistics

All variables are transformed into natural logarithm form to interpret coefficients into elasticities, the time frame were due to the data available. Table 4 reveals the descriptive statistics of 40 countries along the Belt and Road from 1990 to 2018. For the sampled of BRI countries, CO₂ (M = 4.720, SD = 3.926), GDP (M = 7.786, SD = 1.331), LAB (M = 15.890, SD = 1.685), NUC (M = 7.522, SD = 2.198), FOS (M = 7.208, SD = 0.909) and REW (M = 2.761, SD = 0.909). Comparing the descriptive for the two groups, table 3 revealed that CO₂ in energy exporters (M = 2.129, SD = 1.073) to importers countries (M = 5.125, SD = 3.985). For GDP, energy importers (M = 7.911, SD = 1.307) to energy exporters (M = 6.981, SD = 1.307). LAB has (M = 17.182, SD = 0.787) compared to energy importers (M = 15.688, SD = 1.698). In regards to NUC, energy importers (M = 5.421, SD = 0.261) compared to energy exporters (M = 6.774, SD = 1.387). For REW energy exporters (M = 3.192, SD = 1.387) compared to

(M = 2.693, SD = 0.619) in energy importers countries. Lastly comparing FOS, energy importers (M = 7.319, SD = 0.886) to energy exporters (M = 6.498, SD = 0.718).

In general, for normal distribution using kurtosis and skewness, the normal value of skewness and kurtosis is "3" and "0" respectively. Table 4 revealed that using skewness and kurtosis, none of the observed variables were normally distributed. CO₂ in all the panel groups indicates that, it is flatter to the right. It peakness in the main panel and energy exporters show a mesokurtic distribution (value of kurtosis approximately 3) whereas in energy importers we have platykurtic distribution (value of kurtosis below 3). Skewness in GDP is approximately 0 for the main panel as well in energy importers panel but in energy exporters, it is negatively skewed. For kurtosis, all the panel groups indicate platykurtic distribution (value of kurtosis below 3). LAB from table 4 show that for all panel group, it is skewed to the right, while for kurtosis, the main panel and energy importers are leptokurtic (value of kurtosis greater than 3) while that of energy exporters are platykurtic (value of kurtosis less than 3). For NUC, the skewness value indicates that all panel groups are flatter to the right, while for kurtosis, the main panel and energy exporters indicate a leptokurtic distribution while energy importers show a platykurtic distribution. REW in all panel groups show that a negative skewness, indicating REW in all group as flatter to the left. Kurtosis in both the main panel and energy importers indicate a leptokurtic distribution while energy exporters show a platykurtic distribution. Lastly for FOS, the main and energy importers panel indicate that FOS is skewed to the left while in energy exporters panel, FOS is skewed to the right. For kurtosis, all panel group indicate a platykurtic distribution for FOS.

INSERT TABLE 4

4.2. Correlation and Multicollinearity test results

The Pearson product moment correlation results among the variables is revealed in table 5. CO₂ is positive and significantly correlated with GDP, NUC, and FOS but negatively and statistically significantly correlated with LAB and REW. GDP was identified to be positively and significantly related with NUC and FOS but negatively and significantly associated with LAB and REW. It was also evidenced that a negative and significant correlation was linked from LAB to NUC and FOS but positively and significantly correlated with REW. While NUC is positively and significantly related with REW and FOS. Lastly it was evidenced that a negative link was found between REW and FOS. Pearson product difference correlation, is calculated by the formula;

$$r = \frac{\sum_{i=1}^n (x_{1i} - \hat{x}_1)(x_{2i} - \hat{x}_2)}{\sqrt{\sum_{i=1}^n (x_{1i} - \hat{x}_1)^2} \sqrt{\sum_{i=1}^n (x_{2i} - \hat{x}_2)^2}} \quad (22)$$

where $\hat{x}$ is the sample mean value

INSERT TABLE 5

Checking for multicollinearity among the independent variable (GDP, LAB, NUC, REW, and FOS), the Variance Inflation Factor (VIF) together with Tolerance for each variable is calculated. Table 6 indicates no presence of multicollinearity among the independent variables because the VIF values are far less than 5 and Tolerance values are not less than 0.2 (Thompson et al. 2017). This implies that, the variables (GDP, LAB, NUC, REW, and FOS), independently have impact on CO₂ emissions.

INSERT TABLE 6

Figure 1: Graphical representation of the econometric approach.

4.3. Cross sectional independence test

Table 7 provides the results for cross sectional dependence test. The Pesaran CD test rejects the null hypothesis of no cross-sectional dependence. But a possible drawback of CD test is the possibility of adding positive and negative correlations which may lead to acceptance of the alternate hypothesis, even if there are enough evidence of cross-sectional correlation in the error terms. Therefore the mean absolute correlation of the residuals is used to make the decision.

Therefore from the results of the Pesaran CD test, frees' and Friedman's test the null of cross-sectional independence was rejected and concluded that cross sectional correlation exist among the panels in this study. This results is consistent with work done by Wang and Dong (2019), who also identified cross sectional independence in 14 Sub-Saharan African countries. Likewise that of the work by Chen et al. (2020) in OECD countries.

INSERT TABLE 7

4.4. Panel unit root test

Table 8 indicates the results obtained from the Pesaran CADF and Pesaran CIPS panel unit root tests. The results show that the null hypothesis of unit root cannot be rejected at levels of the variables, whether the time trend is included or not. However after the first difference, the six variables were stable at significant levels of 1%, 5%, and 10%. Therefore, all variables in this study were of order 0, $I(0)$, then turned to an integral of order 1, that is, $I(1)$. Estimating non-stationary variables in econometrics is potentially generating spurious results. Thus before estimation, the stationarity of the variables was ascertained. The stationarity of the employed variables are in line with the work done by Haseeb et al. (2018) in BRICS countries while studying the relationship between financial development, globalization and CO₂ emissions.

INSERT TABLE 8

4.5. Panel cointegration test

Having confirmed that the series in our panel data set are cross sectionally dependent and are integrated of order one, Westerlund and Edgerton (2007) cointegration test, was used to establish their long run association. For comparative analysis, Pedroni (2004) cointegration test was also employed. The results from long run test are revealed in Table 9 and table 10. The null hypothesis of no cointegration is vehemently rejected at various significant level with respect to the statistics G_τ , G_α , P_τ and P_α . Our argument was centered by the robust p-value, which present a robust proof

of the cointegration within variables as shown in table 9. For pedroni's panel cointegration test, Table 10 reports a total of seven tests, by a majority decision with four tests the null hypothesis of no cointegration was rejected and concluded that there is enough evidence of cointegration among variables in the panel data set. The long run association among the variables are in coherent with the work done by Khattak et al. (2020) in BRICS countries but does not aligned with the study Acaravci and Ozturk (2010) who for 15 interim countries fail to establish a long term affiliation between energy usage and economic growth.

INSERT TABLE 9

INSERT TABLE 10

4.6. Parameter estimations

Having infer cointegration among the variables, it was necessary to determine estimates for the short-term and long-term and again analyze the causalities. To be able to employ the best estimator, hausman test was used as required by literature to determine the proper estimator for the model. The hausman test was used to confirm the hypothesis of long-term homogeneity, hence it was reasoned that PMG estimator was more effective. According to the results from the PMG estimator, estimate of error correction terms of all variables (ECTs) have expected signs indicating statistically significant at the 1% level.

4.6.1. Pooled Mean Group (PMG) for the sampled BRI countries

Estimations in regards to Equation (15-20), considering the variables under study are revealed in Table 11. At 1% increase in GDP, LAB, NUC, REW, and FOS, the variables GDP, NUC and FOS have a positive and significant impact on CO₂, however the variables REW has negative and significant impact on CO₂. This indicates that GDP, NUC and FOS increase CO₂ by 0.890%, 0.134% and 0.701% respectively, while REW reduce CO₂ by 0.416%. However labor force has no significant impact on CO₂ considering the main panel for the sampled BRI countries. In regards

to the CO₂-GDP relationship, a positively significant one way causal connection was found from GDP to CO₂ in both the short and long run. A positively significant two way bidirectional link was depicted between FOS and CO₂ in the short and long run, this results is in line with work done by Sasana and Ghazali (2017) in BRICS countries. A negatively significant causal link was revealed from REW to CO₂ in the long run but none was depicted in the short run. The outcome is in resonance with the study done by Apergis and Payne (2015) in south America. A one way positively and significant causal links was found from NUC and CO₂ in the long run, similarly in the short run, a one way link from NUC to CO₂ was felt. This results is similar to the study done by Al-Mulali (2014) in 30 major nuclear energy consuming countries.

In regards to these energies and economic growth relationship, GDP has a positive and significant bidirectional causal relationship with FOS, REW and NUC in the long run. The outcome between REW and GDP is in line with the study done by Kahia et al. (2017) in 11 MENA net oil importing countries. However in the short run, GDP has a two way causal link with FOS while a one way causal link was presented from NUC and REW to GDP. The link between GDP and NUC with REW is in line with work done (Ohler and Fetters 2014); Saidi and Mbarek (2016) in 20 OECD and nine developed countries respectively. The addition of labor force is an important contribution of this study to ease the bias related to the missing variables. The estimation from PMG results point that, the variables CO₂ emissions (CO₂), economic growth (real GDP), nuclear energy (NUC), renewable energy (REW) and fossil fuel (FOS) are very significant, the rates of adjustment correspondingly is given by 5.38, 1.16, 1.23, 3.04 and 4.95 years respectively, hence the long term equilibrium show that the variables deviation response quickly. Table 11 as well confirms that the use of REW are beneficial to the countries along the BRI because it reduces CO₂ emissions while it increases GDP. However the use of fossil fuel and NUC increase GDP but

reduces the quality of the environment in the long run. The same occurs in the short run with exception of NUC which reduces GDP.

INSERT TABLE 11

4.6.2. Pooled Mean Group (PMG) results for energy importers countries

Parameter estimations for energy importers in regards to Equation (15-20), considering the variables under study are revealed in Table 12. 1% increase in the variables GDP, LAB, NUC, REW and FOS, CO₂ depreciates by 0.093% with respect to REW but CO₂ appreciates by 0.568%, 0.169% and 1.378% in regards to GDP, NUC and FOS respectively. A one way causal effect was felt from GDP to CO₂ in the long run while a two way causal association was depicted in the short run for CO₂-GDP relationship. Considering energies consumption and CO₂ emissions, a positively significant two way association was depicted between CO₂ and FOS and with NUC in the long run but a negatively significant unidirectional causal link was seen from REW to CO₂. However in the short run, a positively two way causal effect was depicted between FOS and CO₂ while a negatively significant association was seen from REW to CO₂ in the short run. In the short run no causal effect was felt between NUC and CO₂. Similar results was depicted by Saidi and Mbarek (2016) in their research in nine developed countries.

Considering energies consumption and economic growth, in the long run all three energy consumptions have a positively and significant bidirectional association with GDP. Nevertheless in the short run, FOS and REW have positive and significant two way association with GDP but NUC has no significant impact with GDP. The variables CO₂, economic growth (real GDP), nuclear energy (NUC), renewable energy (REW) and fossil fuels (FOS) are all significant,

corresponding to the adjustment rates 8.771, 3.788, 4.717, 2.985 and 4.878 years respectively, indicating that each variable reacts rapidly to deviances equilibrium in long-term.

INSERT TABLE 12

4.6.3. Pooled Mean Group (PMG) results for energy exporters countries

Parameter estimations in regards to Equation (15-20), considering the variables under study are revealed in Table 13. The results depict that one percent increase in GDP, LAB, NUC, REW and FOS decrease CO₂ by 0.473% and 0.528% for NUC and REW respectively. However, an increase of 0.264% and 0.518% by GDP and FOS respectively is felt by CO₂ emissions. Considering energies consumption and CO₂ emissions associations, a positively significant bidirectional association was seen between FOS and CO₂ in the long run but a negatively one way causal effect was depicted from NUC and REW to CO₂ also in the long run. The results is in line with the study done Dong et al. (2017) in BRICS countries. Likewise in the short run, a negatively and significant one way causal effect was depicted from REW and NUC to CO₂ but a one way causal association from CO₂ to FOS was felt as well.

Considering economic growth and energies consumption associations, a positive significant two way association was depicted between GDP with FOS and REW in the long run. However in the long run, a negatively significant one way link was found from NUC to GDP. Likewise, a two way causal links amidst GDP with REW in the short run as the finding of Shahbaz et al. (2015) in their work in Africa, while a unidirectional relationship was depicted from FOS and NUC to GDP. A positively and statistically significant link amidst CO₂ and GDP in the long run while in the short run, a negative and significant link was seen from GDP to CO₂. The estimation results designate that, the variables CO₂ emissions(CO₂), economic growth (real GDP), nuclear energy (NUC), renewable energy (REW) and fossil fuels (FOS) are extremely significant, corresponding to the

adjustment rates 3.135, 6.303, 4.132, 2.268 and 1.092 years respectively, indicating that each variable reacts rapidly to deviances equilibrium in long-term. Table 14 represent the summary of the causalities depicted during the PMG estimation.

INSERT TABLE 13

INSERT TABLE 14

Figure 2: Graphical representation of two-sided and one sided causal affiliations among variables in different country group.

4.6.4. PVECM granger causality

In addition, the panel vector error correction model (PVECM) was applied in testing the granger causality. Although results from the estimation differ, the results are generally coherent with the results of casualties caused by CO₂, GDP, NUC, REW and FOS employing the PMG estimator of the ARDL model. The PVECM granger causality test samples were performed separately, as shown in table 15.

For main panel, considering energies and CO₂ emissions relationship, FOS has a two way causal relationship with CO₂ in the short run and long run as well. In the long run no causal effect was depicted for REW and CO₂, nevertheless, in the short run a one way causal effect was felt from REW to CO₂. Two way causal effect was felt between NUC and CO₂ in the short run and in the long run, a unidirectional causal effect was found from REW to CO₂. Looking at energies and economic growth relationship, GDP, has a bidirectional cause and effect association with NUC, REW and FOS in the long run. Notwithstanding in the short run, GDP has a one way causal relationship with NUC and FOR while a bidirectional causal effect relationship was found between REW and GDP.

Considering CO₂ emissions and energy consumption relationships for energies importers, a two way causal association was felt between FOS and CO₂ in the long run, however in the short run, a unidirectional causal effect was felt from FOS to CO₂. No causal relationship was found in the long run between REW and CO₂, however in the short run, a one way causal effect was depicted from REW to CO₂. Also a one way causal relationship was depicted from NUC to CO₂ all in the long and short run. This affirms the work done by (Wolde-Rufael and Menyah 2010) in nine developed countries. Considering Energies and economic growth relationship, a directional cause and effect association was felt between FOS and GDP in the long run however, a unidirectional association was depicted from FOS and GDP. A two way causal effect was felt amidst REW and

GDP in the long run however, in the short run a one way causal effect was found from REW to GDP. Lastly, a unidirectional causal effect was depicted from NUC to GDP in the long run, however no causal effect was depicted in the short run. Lastly on Energies exporters, energies and CO₂ emissions relationship, a bidirectional causal association was depicted among FOS and CO₂ in the long run, however in the short a unidirectional causal effect was depicted from FOS to CO₂. No causal effect was revealed between REW and CO₂ in the long run, as shown by Wang et al. (2016) in their study in China but a unidirectional causal effect was felt from CO₂ to REW in the short run. A one way causal effect was found from NUC to CO₂ in the long run but none was felt in the short run. Considering Energies and economic growth relationship, a bidirectional causal association amidst FOS and GDP in the long run but a one way causal effect was felt from FOS to GDP in the short run. Both in the long and short, a one way causal effect was revealed from REW to GDP run. Likewise in the long and short run, a one way causal effect from NUC to GDP was felt.

INSERT TABLE 15

5. Conclusion and policy implications

The study examined the impact of nuclear energy, renewable energy, economic growth, labor and fossil fuel consumption on CO₂ emissions over the period 1990–2018 for 40 countries along the BRI. For much exploitation, the countries were clustered based on being energy importer or energy exporter. The econometric approach in this study are as follows; Pesaran CD test, Frees' test and the Friedman test was used to determine the presence of cross sectional dependency among the series. For stationarity, the CADF and the CIPS was used. The test result revealed the series in this study were I(0) but turn to I(1). Since stationarity has been inferred, it was necessary to find out the structural long run association of the variables, therefore Westerlund-Edgerton panel

bootstrap cointegration test was applied. The results indicated the variables are cointegrated. Lastly, in order to infer causality and the magnitude of the effect of the explanatory variables on the response variable, the PMG estimator was employed. The results from the PMG can be summarized as: (a) for the main panel, a significant two-way relationship amongst FOS and CO₂ in the long and short term. In the long term, there is a significant negative causal relationship from REW to CO₂, but it is not found in the short term. In the long run, there is a positive and significant causal relationship between NUC and CO₂, but in the short run, there is a one-way relationship from NUC to CO₂. (b) For energy importers, In the long run, CO₂ is positively and significantly correlated in a two-way causal relationship with FOS and NUC, while REW is negatively and significantly correlated with CO₂ in a one way. However, in the short term, there is a positive two-way causal relationship between FOS and CO₂, while there is a significant negative correlation amongst REW and CO₂. There is no causal relationship between NUC and CO₂ in the short term. (c) For energy exporters, in the long run, there is a significant positive two-way relationship between FOS and CO₂, and a significant negative one-way causal relationship from NUC and REW to CO₂. Similarly, in the short term, the influence of REW and NUC on CO₂ is negative and significant one-way causality, while the influence of CO₂ on FOS is one-way causality.

The long-term elasticities and causalities between variables are essential for the effective design of energy policies. The empirical analysis of this study shows that the energy consumption of renewable energy, nuclear energy and fossil fuels all contribute to economic growth. However, with regards to the quality environmental, renewable energy is a better choice. To this extent, increase in consumption of renewable energy abridge CO₂ intensity along the BRI.

- a) Therefore governments in the various energy groups can subsidize the development and use of renewable energy by imposing higher taxes on fossil fuels. Again subsidies

could come in the form of research and development, as well as credit, low-cost loans and production tax credits to renewable energy developers to induce the growth of renewable energy products.

b) Again, policymakers along the BRI need to develop policies that encourage public-private partnerships by providing opportunities for small investors to produce renewable energy from different sources. Recognition of the disadvantages of nuclear and fossil fuels and the advantages of using renewable sources of energy are also important for improving the quality of the environment, governments of both energy importing and exporting countries should increase trade activities, formulate green trade policies and ensure sustainable development.

c) Trade activities provide a channel for developed countries to transfer technology to emerging economies. Such technology transfer aids reduce production costs and increase production of renewable energy. In conclusion, different business policies, such as feed-in tariffs and home solar panels, should also give companies the privilege of selling excess renewable energy, and these policies must be well implemented to encourage consumption.

Abbreviations

GDP: Gross domestic product, REW: Renewable energy, ARDL: Autoregressive distributed lag, VAR: Vector auto regression model, GMM: Generalized method of moments, PMG: Pooled mean group, AMG: Augmented mean group, CU-BC: Continuously-Updated Bias-Corrected, CCEMG: Common correlated effects mean group, VIF: Variance Inflation Factor, PVECM panel vector error correction technique, PMG: Pooled mean group, CADF cross-sectionally dependent augmented dickey fuller, CIPS cross-sectionally, CSD: Cross sectional dependency, NUC: Nuclear energy, REW: Renewable energy, LAB: Labor force, FOS: Fossil fuel, EU: European

590 Union, BRI: Belt and Road Initiative, BRICS: Brazil, Russia, India, China and South Africa,
591 OECD: Organization for Economic Co-operation and Development. MENA: Middle east and
592 North Africa, BRI: Belt and Road Initiative

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595 **Authors' contributions**

596 Professor JIYING Wu supervised the research from the beginning to the end. Olivier Joseph Abban
597 conceived the study, collected the data, estimated the econometric model and drafted the
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602 **Availability of data and materials**

603 All data used in this study are publicly available online. The information on the sources of data is
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605 **Ethics approval and consent to participate**

606 Not applicable

607 **Consent for publication**

608 Not applicable

609 **Competing interests**

610 The authors declare that they have no competing interests.

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Table 1: Recent empirical studies on the relationship among the variables.

Authors	Research Area	Duration	Methodology	Inference
Waheed et al. (2018)	Pakistan	1990-2014	ARDL	REW has a negative and significant effect on CO ₂
Nathaniel and Iheonu (2019)	Africa	1990-2014	AMG	REW inhibits CO ₂ emissions insignificantly
Chen et al. (2019)	China	1980-2014	ARDL and VECM	REW has a negative impact on CO ₂ in the long-run
Baloch et al. (2019)	BRICS	1990-2015	AMG	REW mitigates CO ₂ emissions
Khattak et al. (2020)	BRICS	1980-2016	CCEMG and AMG	REW was found to have a disrupting effect on CO ₂
Dong et al. (2018a)	128 countries	1990–2014	CCEMG	REW usage lessen CO ₂ emissions
Bekun et al. (2019)	16-EU countries	1996-2014	PMG-ARDL	Feedback causality was seen between REW and GDP
Dong et al. (2018b)	China	1993-2016	ARDL	NUC can lead to less CO ₂ emissions
Luqman et al. (2019)	Pakistan	1990–2016	ARDL	NUC has a positive effect on GDP
Cai et al. (2018)	G7 countries	1970-2015	ARDL bounds	Unidirectional effect from NUC to CO ₂ was felt
Saidi and Omri (2020)	15 OECD	1990–2018	FMOLS and VECM	NUC reduces CO ₂ emissions
Vo et al. (2020)	CPTPP	1971-2014	FMOLS and DOLS	NUC mitigates CO ₂ emissions
Mahmood et al. (2020)	Pakistan	1973-2017	ARDL	Bidirectional causation between NUC and CO ₂
Hassan and Tarar (2020)	BRICS	1993 -2017	CUP-BC	NUC has less impact on CO ₂
Usman et al. (2020)	Pakistan	1975–2018	ARDL	NUC has insignificant effect on CO ₂
Do and Dinh (2020)	Viet man	1980-2014	VECM	Bidirectional affiliation between CO ₂ and GDP
Munir et al. (2020)	5 ASEAN	1980–2016	Granger causality	Unidirectional causality from GDP to CO ₂
Beşe and Kalayci (2019)	3 developed countries	1960-2014	Granger causality	Unidirectional causality from GDP to CO ₂
Abban et al. (2020)	BRI	1990-2015	AMG	Bidirectional affiliation between CO ₂ and GDP
Wu et al. (2020)	BRI	1991-2018	AMG and CCEMG	Unidirectional causal effect from GDP to CO ₂
Ameyaw and Yao (2018)	West African countries	2007–2014	SEM	Bidirectional causation between GDP and CO ₂
Wang et al. (2019)	18 OECD	1975–2017	ARDL	Bidirectional causation between GDP and CO ₂
Hashmi and Alam (2019)	OECD countries	1999–2014	GMM	Population has a significant impact on CO ₂
de Souza Mendonça et al. (2020)	50 economies	1990–2015	Hierarchical regression	Population increases CO ₂ emissions
Zhang et al. (2018)	China	2005-2014	Spatial Analysis	Population has significant impact on CO ₂ emissions
Sulaiman and Abdul-Rahim (2018)	Nigeria	1971-2010	ARDL	Bidirectional causation between POP and CO ₂

Note: CO₂ = CO₂ emissions, GDP= economic growth, REW= renewable energy, ARDL = autoregressive distributed lag, VAR = vector auto regression model, GMM=generalized method of moments, PMG= Pooled mean group, AMG: Augmented mean group, CU-BC= Continuously-Updated Bias-Corrected, CCEMG= Common correlated effects mean group, EU= European Union, BRI= Belt and Road Initiative, BRICS= Brazil, Russia, India, China and South Africa, OECD= Organization for Economic Co-operation and Development.

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2 Table 2: Variable units and reference

Variables	Symbol	Unit	Reference
Carbon dioxide emission	CO₂	Kilo tonnes	World bank development indicators (WDI)
Gross domestic product	GDP	constant 2010 US dollars	World bank development indicators (WDI)
Nuclear energy consumption	NUC	Ktoe per capita	World bank development indicators (WDI)
Renewable energy consumption	REW	Ktoe per capita	World bank development indicators (WDI)
Fossil fuel consumption	FOS	kg of oil equivalent per capita	World bank development indicators (WDI)
Labor force	LAB	millions	World bank development indicators (WDI)

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4 Table 3: Classification of selected BRI countries

Panel Groups	List of countries selected
Energy importers	Albania, Armenia, Azerbaijan, Bangladesh, Belarus, Bulgaria, China, Croatia, Czech rep., Estonia, Georgia, Hungary, India, Israel, Jordan, Kazakhstan, Kyrgyz rep. , Latvia, Lithuania, Moldova, Nepal, Pakistan, Poland, Romania, Russia, Singapore, Slovenia, Slovak rep., Sri Lanka, Thailand, Turkey, Ukraine
Energy exporters	Bhutan, Cambodia, Egypt, Indonesia, Malaysia, Myanmar, Uzbekistan, Vietnam

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6 Table 4: Descriptive statistics

Panel	Variable	Mean	Std. dev.	Skewness	kurtosis	JB test
Main panel	CO ₂	4.720	3.926	0.877	3.046	118.883 ^a
	GDP	7.785	1.331	0.006	2.242	22.126 ^a
	LAB	15.890	1.684	0.756	3.120	88.271 ^a
	NUC	7.523	2.198	1.414	4.103	355.601 ^a
	REW	2.761	0.608	-1.498	6.741	885.580 ^a
	FOS	7.207	0.909	-0.454	2.214	55.587 ^a
Energy importers	CO ₂	5.125	3.985	0.762	2.841	78.458 ^a
	GDP	7.911	1.307	0.011	2.115	26.091 ^a
	LAB	15.688	1.698	1.064	3.609	163.329 ^a
	NUC	5.421	2.569	1.209	1.209	204.157 ^a
	REW	2.693	0.619	-1.418	6.449	664.940 ^a
	FOS	7.318	0.886	-0.660	2.594	63.696 ^a
Energy exporters	CO ₂	2.129	1.073	1.399	3.006	44.481 ^a
	GDP	6.980	1.196	-0.139	2.322	4.7951 ^b
	LAB	17.181	0.787	0.228	2.154	4.8157 ^a
	NUC	6.774	1.387	1.632	5.848	97.775 ^a
	REW	3.192	0.261	-0.428	2.437	5.467 ^c
	FOS	6.498	0.718	0.500	2.361	7.349 ^b

Note: All the variables are transformed as natural logarithms. Data for 37 BRI countries from 1991 to 2015. Ascertaining if a variable follow a normal distribution, the jarque-bera test was utilized .It tests the H_0 that a given variable is normally distributed.

Table 5: Pearson correlation analysis

Variables		CO ₂	GDP	LAB	NUC	REW	FOS
CO ₂	Pearson corr. Sig.(2-tailed)	1	0.643 ^b (0.000)	-0.213 ^b (0.000)	0.423 ^b (0.000)	-0.357 ^b (0.000)	0.875 ^b (0.000)
GDP	Pearson corr. Sig.(2-tailed)		1	-0.336 ^b (0.000)	0.191 ^b (0.000)	-.417 ^b (0.000)	0.761 ^b (0.000)
LAB	Pearson corr. Sig.(2-tailed)			1	-0.393 ^b (0.000)	0.422 ^b (0.000)	-0.354 ^b (0.000)
NUC	Pearson corr. Sig.(2-tailed)				1	0.260 (0.007)	0.192 ^b (0.000)
REW	Pearson corr. Sig.(2-tailed)					1	-0.335 ^b (0.000)
FOS	Pearson corr. Sig.(2-tailed)						1

Note: “b” significance of correlation is at 5%. The 5% level of statistical significance provides evidence that the probability of rejecting or accepting the null hypothesis is a type 1 error.

Table 6: Multicollinearity test

Model	Collinearity statistics	
	Tolerance	VIF
Gross domestic product	0.386	2.589
Labor force	0.628	1.592
Alternative and renewable energy	0.761	1.314
Combustible renewable and waste	0.665	1.503
Fossil fuels	0.410	2.438

Note: Dependent variable is CO₂ emissions. Tolerance value must be greater than 0.2 and VIF must be less than 5, implying no multicollinearity

29 Table 7: Cross sectional dependence

Panel group	Test statistics	CO ₂	GDP	LAB	NUC	REW	FOS
Main panel	Pesaran CD	5.585 ^a (0.401)	63.902 ^a (0.626)	1.821 ^c (0.597)	2.787 ^a (0.466)	6.671 ^a (0.410)	3.372 ^a (0.589)
	Frees	6.015 ^a	14.263 ^a	14.027 ^a	7.357 ^a	4.146 ^a	5.774 ^a
	Friedman	64.853 ^a	424.338 ^a	44.328 ^c	50.544 ^c	68.455 ^a	0.005
Energy importers	Pesaran CD	5.254 ^a (0.411)	66.063 ^a (0.687)	1.934 ^c (0.603)	2.257 ^b (0.487)	6.176 ^a (0.342)	2.389 ^b (0.412)
	Frees	5.342 ^a	14.091 ^a	12.016 ^a	7.335 ^a	3.526 ^a	5.302 ^a
	Friedman	61.630 ^a	441.107 ^a	48.635 ^c	44.782 ^c	63.749 ^a	56.835 ^b
Energy exporters	Pesaran CD	2.127 ^b (0.439)	2.954 ^a (0.397)	1.854 ^c (0.377)	2.682 ^a (0.319)	2.224 ^b (0.311)	2.173 ^a (0.340)
	Frees	0.799 ^a	0.549 ^a	0.287 ^a	0.334 ^a	0.425 ^a	0.235 ^a
	Friedman	32.972 ^a	47.956 ^a	37.647 ^a	46.065 ^a	35.675 ^a	32.810 ^a

Note: H_0 : existence of cross sectional independence, a,b,c denote statistical significance at 1%, 5%, 10%. () is the absolute correlation of the residuals.

Variables	CIPS				CADF			
	Levels		First difference		Levels		First difference	
	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend
Main panel								
CO ₂	-1.288	-2.591	-4.701 ^a	-4.922 ^a	-1.260	-2.621	-3.726 ^b	-4.038 ^a
GDP	-2.424	-2.612	-4.234 ^a	-4.376 ^a	-2.392	-2.282	-3.277 ^b	-3.352 ^a
LAB	-1.690	-1.900	-3.213 ^b	-3.663 ^b	-2.048	-2.169	-2.551 ^a	-3.023 ^b
NUC	-1.369	-2.609	-4.674 ^a	-4.895 ^a	-1.017	-2.380	-3.441 ^b	-3.719 ^a
REW	2.256	-2.605	-5.164 ^a	-5.309 ^a	-2.012	-2.126	-3.541 ^a	-3.752 ^a
FOS	-1.698	-2.527	-4.665 ^a	-4.985 ^a	-1.928	-2.504	-3.131 ^b	-3.511 ^a
Energy importers								
CO ₂	-1.276	-2.428	-4.813 ^a	-5.043 ^a	-1.178	-2.560	-3.710 ^a	-4.086 ^a
GDP	-2.607	-2.469	-4.021 ^a	-4.216 ^b	-2.996	-2.977	-3.339 ^a	-3.430 ^a
LAB	-1.741	-2.111	-3.292 ^b	-3.737 ^a	-2.074	-2.496	-2.722 ^a	-3.217 ^a
NUC	-1.314	-2.627	-4.662 ^a	-4.911 ^a	-0.957	-2.444	-3.483 ^a	-3.782 ^a
REW	-2.314	-2.610	-5.157 ^a	-5.316 ^a	-2.069	-2.217	-3.587 ^a	-3.817 ^a
FOS	-1.763	-2.610	-4.772 ^a	-5.079 ^a	-1.983	-2.565	-3.191 ^b	-3.556 ^a
Energy exporters								
CO ₂	-2.035	-2.786	-3.836 ^a	-3.804 ^a	-2.080	-2.873	-4.481 ^a	-4.154 ^a
GDP	-2.389	-2.310	-3.75 ^a	-3.745 ^a	-2.536	-2.120	-3.861 ^a	-4.021 ^a
LAB	-1.552	-1.342	-2.519 ^a	-3.124 ^b	-1.380	-2.129	-2.731 ^a	-2.932 ^b
NUC	-1.471	-2.114	-4.454 ^a	-4.492 ^a	-1.586	-2.036	-3.480 ^a	-2.936 ^c
REW	-2.562	-3.883	-5.892 ^a	-5.985 ^a	-1.377	-2.344	-2.940 ^c	-4.006 ^b
FOS	-2.167	-3.242	-3.781 ^a	-3.701 ^b	-2.808	-2.072	-4.667 ^a	-4.430 ^a

54 **Note:** CIPS: H0 is “series have unit root for each panel”. CADF: H0 is “series have unit root for each panel”. a, b, c indicate
55 Statistical significance at 1%, 5%, 10% level respectively.
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58 Table 9: westerlund’s panel cointegration test results

Country groups	G_{τ}		G_{α}		P_{τ}		P_{α}	
	Value	Robust p-value	Value	Robust p-value	Value	Robust p-value	Value	Robust p-value
Main panel	-2.566 ^a	(0.000)	-7.212 ^a	(0.007)	-14.291 ^b	(0.030)	-7.501 ^b	(0.021)
Energy importers	-2.609 ^a	(0.000)	-7.715 ^b	(0.040)	-13.495 ^c	(0.012)	-7.704 ^a	(0.003)
Energy exporters	-3.208 ^b	(0.020)	-19.732 ^a	(0.000)	-13.210 ^a	(0.000)	-50.989 ^a	(0.000)

59 **Note:** the optimal lag length was determined by AIC, and the width of the bartlett nucleus was also set as 1. In the
60 cointegration test, we consider a constant, but there is no definite trend, and we report a robust p-value.

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63 Table 10: Pedroni's panel cointegration test results

Country groups	Panel statistics				Group statistics		
	V-statistic	Rho-statistic	PP-statistic	ADF-statistic	Rho-statistic	PP-statistic	ADF-statistic
Main panel	-0.679	4.813	-9.240 ^a	-9.525 ^a	4.537	-11.439 ^a	-11.898 ^a
Energy importers	-1.887	2.638	-6.950 ^a	-7.467 ^a	5.162	-10.324 ^a	-7.354 ^a
Energy exporters	2.4262 ^c	-2.356 ^c	-13.119 ^a	-16.599 ^a	1.159	-6.538 ^a	-6.757 ^a

64 **Note:** a, b, c denote the rejection of the null hypothesis at 1%, 5% and 10% significance level. The pedroni
65 cointegration test assumes the null hypothesis of no cointegration.

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67 Table 11: Long and short run estimations results for main panel

Dependent var.	CO ₂ (eq.15)	GDP(eq.16)	LAB(eq.17)	NUC(eq.18)	REW(eq.19)	FOS(eq.20)
Long-run coeff.						
CO ₂	-	0.078	-0.215	0.109	-0.116	0.697 ^a
GDP	0.890 ^a	-	0.489 ^b	0.269 ^a	0.356 ^a	0.288 ^c
LAB	-0.078	0.345	-	-0.112	-0.940 ^a	0.345 ^a
NUC	0.134 ^a	0.152 ^c	0.06	-	1.534	-0.761
REW	-0.416 ^a	0.281 ^a	0.112	-0.044	-	-0.056
FOS	0.701 ^a	0.314 ^a	0.484 ^a	0.111 ^a	-0.095	-
Ect	-0.186 ^a	-0.861 ^a	-0.206 ^a	-0.788 ^a	-0.329 ^a	-0.202 ^a
Short-run coeff						
Δ CO ₂	-	0.257	1.158	-0.048	-0.027	2.948 ^a
Δ GDP	0.116 ^b	-	0.135	0.048	0.115	0.744 ^a
Δ LAB	0.045	0.261 ^c	-	0.064 ^c	0.014	-0.033 ^b
Δ NUC	0.136 ^c	-0.226 ^b	1.850	-	-0.283	4.968
Δ REW	-0.084	0.127 ^c	-1.416	0.066	-	0.429
Δ FOS	0.169 ^a	0.368 ^a	-0.280	-0.139 ^c	0.018	-
Hausman test value	4.49	1.88	0.76	2.92	6.12	3.87
p-value	0.732	0.865	0.979	0.359	0.294	0.567

68 **Note:** a, b, c refer to level of significance at 1%, 5% and 10%. The results obtained in table 10, 11 and 12 were as a
69 results of estimating equations (15) to (20).

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80 Table 12: Long and short run estimations results for energy importers

Dependent var.	CO ₂ (eq.15)	GDP(eq.16)	LAB(eq.17)	NUC(eq.18)	REW(eq.19)	FOS(eq.20)
Long-run coeff.						
CO ₂	-	0.485	0.136	0.430 ^c	-0.063	1.630 ^a
GDP	0.568 ^a	-	1.294 ^a	0.165 ^c	1.208 ^c	1.122 ^a
LAB	0.031	0.261	-	0.361	0.607	0.102
NUC	0.169 ^b	0.404 ^c	-0.484	-	-0.487	0.007
REW	-0.293 ^b	0.281 ^c	-0.088	0.013	-	0.084
FOS	1.378 ^a	0.029 ^a	0.079 ^a	0.114	-0.016	-
Ect	-0.114 ^a	-0.264 ^b	-0.399 ^b	-0.212 ^a	-0.335 ^a	-0.205 ^a
Short-run coeff						
Δ CO ₂	-	0.063 ^c	1.573	-0.276	-0.019	3.703 ^c
Δ GDP	0.280 ^b	-	0.478	0.028	0.386 ^c	0.649 ^a
Δ LAB	-0.057	0.167 ^b	-	-0.377	0.518	-0.252
Δ NUC	0.048	-0.075	-0.057	-	-0.534	0.041
Δ REW	-0.322 ^b	0.215 ^a	-1.447	0.065	-	0.319
Δ FOS	0.180 ^a	0.272 ^a	-0.218	-0.148	0.169	-
Hausman test value	1.48	0.97	1.45	2.01	0.76	2.08
p-value	0.56	0.43	0.29	0.78	0.24	0.61

81 **Note:** a, b, c refer to level of significance at 1%, 5% and 10%. The results obtained in table 10, 11 and 12 were as a
82 results of estimating equations (16) to (21).

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84 Table 13: Long and short run estimations results for energy exporters

Dependent var.	CO ₂ (eq.15)	GDP(eq.16)	LAB(eq.17)	NUC(eq.18)	REW(eq.19)	FOS(eq.20)
Long-run coeff.						
CO ₂	-	0.574 ^a	0.428 ^a	0.039	0.301	0.689 ^a
GDP	0.264 ^a	-	-0.283	0.109	0.140 ^c	0.712 ^b
LAB	-0.217	1.598	-	-0.041	-0.247	0.596
NUC	-0.473 ^c	-0.149 ^a	-0.104 ^c	-	0.179	-5.525
REW	-0.528 ^a	0.027 ^b	-0.122	0.0382	-	-0.916
FOS	0.518 ^a	0.131 ^a	0.113 ^a	0.121	0.145 ^c	-
Ect	-0.319 ^a	-0.147 ^b	-0.015 ^b	-0.242 ^b	-0.441 ^b	-0.232 ^a
Short-run coeff						
Δ CO ₂	-	0.266	-0.914	-0.219	-0.315	0.142 ^b
Δ GDP	0.071 ^c	-	-2.478	0.089	0.079 ^c	0.989 ^b
Δ LAB	0.268	0.473 ^c	-	0.042	0.125	-1.034
Δ NUC	-0.629 ^c	0.417 ^c	-0.680 ^c	-	1.194	-0.499 ^b
Δ REW	-0.121 ^b	0.218 ^a	0.041	0.107	-	0.657
Δ FOS	0.280	0.280 ^b	-0.123	-0.312	-0.059	-
Hausman test value	9.49	4.44	5.40	11.13	4.76	2.79
p-value	0.214	0.487	0.368	0.088	0.5357	0.732

85 **Note:** a b, c refer to level of significance at 1%, 5% and 10%. The results obtained in table 10, 11 and 12 were as a
86 results of estimating equations (16) to (21).

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90 Table 14: Summary of PMG causality

Grouping	Long run causality	Short run causality
Main panel	$CO_2 \leftarrow GDP$	$CO_2 \leftarrow GDP$
	$CO_2 \leftarrow NUC$	$CO_2 \leftarrow NUC$
	$CO_2 \leftarrow REW$	$CO_2 \neq REW$
	$CO_2 \leftrightarrow FOS$	$CO_2 \leftrightarrow FOS$
	$GDP \leftrightarrow NUC$	$GDP \leftarrow NUC$
	$GDP \leftrightarrow REW$	$GDP \leftarrow REW$
	$GDP \leftrightarrow FOS$	$GDP \leftrightarrow FOS$
Energy importers	$CO_2 \leftarrow GDP$	$CO_2 \leftrightarrow GDP$
	$CO_2 \leftarrow NUC$	$CO_2 \neq NUC$
	$CO_2 \leftarrow REW$	$CO_2 \leftarrow REW$
	$CO_2 \leftrightarrow FOS$	$CO_2 \leftrightarrow FOS$
	$GDP \leftrightarrow NUC$	$GDP \neq NUC$
	$GDP \leftrightarrow REW$	$GDP \leftrightarrow REW$
	$GDP \leftrightarrow FOS$	$GDP \leftrightarrow FOS$
Energy exporters	$CO_2 \leftrightarrow GDP$	$EMS \leftarrow GDP$
	$CO_2 \leftarrow NUC$	$EMS \leftarrow NUC$
	$CO_2 \leftarrow REW$	$EMS \leftarrow REW$
	$CO_2 \leftrightarrow FOS$	$CO_2 \leftarrow FOS$
	$GDP \leftarrow NUC$	$GDP \leftarrow NUC$
	$GDP \leftrightarrow REW$	$GDP \leftrightarrow REW$
	$GDP \leftrightarrow FOS$	$GDP \leftarrow FOS$

91 **Note:** CO₂, NUC, REW, FOS and GDP symbolized CO₂ emissions, nuclear energy, renewable energy, fossil fuel and gross
92 domestic product respectively. $\neq$, $\leftarrow$ and $\leftrightarrow$ indicates no, one way and two way causality.

107 Table 15: Panel VECM granger causality results

Dependent variables	Source of causality (Independent Variables)											
	Short run						Long run					
	ΔCO_2	ΔGDP	ΔNUC	ΔREW	ΔLAB	ΔFOS	ΔCO_2	ΔGDP	ΔNUC	ΔREW	ΔLAB	ΔFOS
							ECT	ECT	ECT	ECT	ECT	ECT
	Wald test						Wald test					
All countries												
ΔCO_2	-	0.12	4.15 ^a	2.11 ^b	1.13	3.01 ^b		2.26 ^b	21.32 ^a	0.98	1.64	13.98 ^a
ΔGDP	0.21	-	2.17 ^b	3.01 ^b	3.79 ^b	3.27 ^b	3.79	-	79.91 ^a	13.67 ^b	3.73 ^b	141.64 ^b
ΔLAB	2.15 ^c	0.02	-	0.03	0.22	0.42	0.48	4.16 ^a	-	0.46	0.47	0.46
ΔNUC	1.80	4.14 ^a	0.21	-	0.13	0.32	1.02	5.27 ^a	0.54	-	1.16	0.99
ΔREW	1.46	0.91	3.22 ^b	3.38 ^b	-	0.42	0.99	0.26	1.38	0.98	-	0.97
ΔFOS	2.78 ^b	0.12	0.58	2.69 ^b	0.25	-	10.16 ^a	2.74 ^b	0.23	1.64	10.23 ^a	-
Energy importers												
ΔCO_2	-	3.11 ^b	2.46	3.22 ^b	0.16	2.21 ^c	-	4.28	13.57 ^a	0.55	0.95	12.99 ^a
ΔGDP	2.29 ^b	-	0.34	2.91 ^a	0.30	2.55 ^b	3.52 ^a	-	47.79 ^a	8.94 ^b	3.37 ^a	7.49 ^a
ΔLAB	0.55	0.08	-	0.33	0.28	0.32	0.73	0.29	-	0.48	0.77	0.73
ΔNUC	0.82	0.18	0.18	-	0.18	0.10	1.89	3.53 ^c	0.50	-	1.73	0.79
ΔREW	2.86	-0.52	2.53	0.36	-	0.14	1.44	0.29	1.14	0.57	-	0.13
ΔFOS	0.75	0.66	0.35	0.91	0.36	-	10.91 ^a	3.86 ^a	0.61	5.57	9.68 ^a	-
Energy exporters												
ΔCO_2	-	1.15	0.39	1.49	0.57	3.34 ^b	-	0.32	5.58 ^b	1.16	1.61	6.27 ^b
ΔGDP	2.19 ^c	-	1.89 ^c	2.46 ^b	0.23	2.53	3.53	-	17.51 ^b	5.54 ^a	4.22 ^a	3.38 ^c
ΔLAB	0.52	0.06	-	0.93	0.29	0.73	0.79	0.58	-	0.28	1.36	0.22
ΔNUC	3.19 ^c	0.45	0.55	-	0.68	0.88	0.86	0.28	1.86	-	0.54	0.19
ΔREW	0.27	0.82	0.09	0.17	-	0.17	0.13	0.43	0.74	0.15	-	0.16
ΔFOS	0.56	5.16 ^a	1.28	0.18	0.64	-	7.84 ^a	2.06	0.78	1.18	5.60 ^a	-

108 NOTE: a, b, c indicates level of significance at 1% , 5% and 10%

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Figures

Figure 1

Graphical representation of the econometric approach.

Figure 2

Graphical representation of two-sided and one sided causal affiliations among variables in different country group.