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Abstract
This paper makes a novel attempt to model the non-linear association between renewable energy consumption and crude oil prices across four net oil-importing South Asian economies namely Bangladesh, India, Pakistan and Sri Lanka. Using annual data from 1990 to 2018, the results from the panel data regression analyses confirm the non-linear nexus and show that although rising crude oil prices do not facilitate renewable energy consumption initially, in the latter phases higher crude oil prices are associated with higher levels of renewable energy consumption. The similar non-linearity is also confirmed in the context of the renewable energy share in total final energy consumption and crude oil prices. Moreover, the nexus between renewable electricity share in aggregate electricity output and crude oil prices is also found to be non-linear in nature. However, rising crude oil prices were not found to enhance the share of renewable electricity. The causality results, overall, implicates that movements crude oil prices do influence the renewable energy transition within the concerned South Asian economies. Thus, these results impose critically important policy implications with respect to attainment of energy security and environmental sustainability across South Asia, particularly via reducing the imported crude oil-dependencies of these nations.

Keywords: renewable energy; crude oil price; renewable energy transition; South Asia; cross-sectional dependency; net oil-importing economies

JEL classifications: F64; O13; P18; P28; Q4; Q43

1. Introduction

Deteriorating environmental quality and aggravation of climate change adversities worldwide have sparked the determination in aligning the global development policies to simultaneously safeguard the environmental wellbeing as well. Although in the past there had been a mass consensus on the concept of '*growing now and cleaning up later*,' thus, traditionally accepting the trade-off between economic and environmental welfares, the contemporary development policies tend to focus more on greening of the global production processes to curb the carbon and other greenhouse emissions that stem from the predominant combustion of the fossil fuels. Hence, it is pertinent for the world economy to undergo a transition from the use of non-renewable to renewable energy resources, keeping environmental sustainability into cognizance (Murshed 2018). In the same vein, the Sustainable Development Goals (SDG) agenda of the United Nations has called out for global commitment to augment Renewable Energy (RE) into the global energy-mix for ensuring energy security and environmental sustainability worldwide. Precisely, the 7th SDG specifically stresses on substantially elevating the share of renewables in the global energy consumption figures by 2030 (Villavicencio Calzadilla and Mauger 2018).

The benefits of enhancing the levels of Renewable Energy Consumption (REC) can take multidimensional forms. For instance, incorporating RE technologies within the economy is likely to facilitate the global energy security policies which seem to be at risk following the depletion of the Non-Renewable Energy (NRE) reserves worldwide (Valentine 2011). Thus, augmentation of RE into the global energy-mix would not only relieve pressures off the fossil fuel demand but it would also complement the NRE in significantly improving the reliability of the overall energy supply (Zemin 2008). Besides, REC can also exhibit a pivotal role in curbing the intensities of greenhouse emissions to improve environmental quality and slow down the climate change phenomenon as well (Perry, Klemeš and Bulatov 2008). Consumption of renewables has also been appropriately acknowledged, in the 2015 Paris climate change conference, to play a defining role in keeping the global temperature rise below the critical level of 2 degrees Celsius per annum which is pertinent in combating climate change adversities to a large extent.[1] Among the other positive impacts, REC is hypothesized to reduce the vulnerability of economies against volatility of crude oil supplies (Rentschler 2013), stabilize energy prices (Shen *et al.* 2010), enhance energy-use efficiency levels (Murshed 2019), expand electricity-access rates (Oseni 2012), attribute to rural electrification (Urmee, Harris and Schlapfer 2009), facilitate off-grid electrification (Sen and Bhattaccharya 2014) and also create job opportunities within the local community (Sari, Ewing and Soytas 2008; Llera *et al.* 2013).

However, in spite of such advantageous features, the adoption of RE technologies is not so straightforward due to the generation, storage and transmission of both primary and secondary sources of RE being highly conditional on the use of appropriate technology (Painuly 2001). Thus, technological backwardness, within developing economies in particular, often upholds the substitution of the fossil fuels for the renewable alternatives. Besides, the underdeveloped energy infrastructure within these nations is also proclaimed to be one of the major hindrances bottlenecking the prospects of undergoing the Renewable Energy Transition (RET) (Murshed 2020). Moreover, implementation of the RET policies is comparatively more difficult in the context of Net Oil-Importing Countries (NOIC) courtesy of their acute vulnerability to exogenous shocks to the world crude oil prices (Gupta 2008). A particular reason behind this could be interpreted in terms of the predominant reliance of these nations on crude oil imports, mostly for domestic power generation purposes. Moreover, inadequate natural RE endowments often compel these nations to rely on the imported oils. As a result of such monotonic dependence, switching from the use of NRE to RE is often deferred, thus, attributing to the adverse environmental complications stemming from the obligatory combustion of the imported oils. Furthermore, these economies are also referred to be highly susceptible to other multifaceted macroeconomic adversities, following the impulsive movements in world crude oil prices, as well (Cunado, Jo and Gracia 2015).

Against this background, this paper aims to probe into the dynamic impacts of world crude oil price shocks on the RET process across four major NOIC across South Asia namely Bangladesh, India, Pakistan and Sri Lanka. The fact that all these nations have traditionally been vastly reliant on crude oil imports, investigation of the cross-price elasticity of RE demand becomes a pertinent topic of research, keeping South Asia's prospects of RET into consideration. Although existing studies have probed into the impacts of oil prices on REC using a linear framework, in the context of South Asia, the possible non-linearity of the REC-crude oil price nexus is yet to be explored. It is germane to address the quadratic association between these variables from the notion that oil price movements may not be able to induce RET instantaneously, following the inability to undergo RET due to being a large share of their national outputs being generated using power sourced from the imported crude oils. Thus, REC in the initial stages can be expected to pretty inelastic to rising crude oil prices in the world market. However, alongside substantial economic development of these economies with time, the barriers to RE adoption could be expected to reduce whereby the elasticity of REC with respect to further hikes in crude oil prices could be anticipated to improve to facilitate the RET process. This paper contributes to the literature in this regard by modeling the non-linear association between REC and movements in the prices of crude oil. Addressing this non-linearity is of relative significance in the context of NOIC since these economies are highly rigid to RET in the short-run following their extensive reliance on imported crude oils.

[1] For more information on the Paris climate change Conference of Parties 21 (COP21) see Rhodes (2016) and Robbins (2016).

This paper specifically addresses the following questions in the context of the selected NOIC across South Asia:

1. Is the relationship between REC and crude oil prices non-linear in nature?
2. Does an increase in world crude oil prices facilitate RET in these net oil-importing economies?
3. Is there any causal impact of crude oil price movements on REC?

The remainder of the paper is organized as follows. Section 2 provides an overview of the state of RE use within the four South Asian economies. A review of the relevant theoretical and empirical literature is put forward in section 3. Section 4 presents the empirical model and chalks down the attributes of the dataset used. The methodological approach is explained in section 5 while section 6 discusses the findings from the econometric analyses. Finally, section 7 concludes and highlights the potential policy implications.

2. An overview of the trends in REC across South Asia

Apart from belonging to the same lower-middle-income category and being net importers of crude oil, all these four South Asian economies have sourced a major share of the respective national outputs employing non-renewable energy resources, imported crude oils in particular. Table 1 presents the trends in REC between 1990 and 2018. As far as the employment of RE is concerned, Sri Lanka can be seen to head the list in terms of recording the highest per capita REC figures among the four South Asian economies considered in this paper. A particular reason behind this phenomenon could be attributed to nation's indigenous biomass energy resources accounting for a dominant share of the aggregate primary energy consumption figures (Nissanka and Konaris 2003). In contrast, Bangladesh accounts for the lowest per capita REC levels among the four South Asian nations. This can largely be credited to the nation's insufficient natural endowments of primary RE resources (Amin and Murshed 2016). Between 1990 and 2018, the per capita REC, in terms of kilograms of oil equivalent, in India and Sri Lanka rose on average by 8.33% and 18.91%, respectively while that in Bangladesh and Pakistan declined by 6.10% and 5.66%, respectively. It is also evident from Table 1 that all the four nations have performed miserably in improving the RE shares in their respective total final energy consumption levels as well. Over the same time period, the average RE share of Bangladesh has gone down by almost 33 percentage points followed by India, Sri Lanka and Pakistan registering declines in their RE shares by 19.79, 18.45 and 8.75 percentage points, respectively. These adverse trends seem to portray ominous signals concerning the attainment of RET across South Asia. Hence, it is critically important to identify the factors inhibiting consumption of renewables from policy perspectives.

Table 1: Trends in REC across the selected South Asian economies

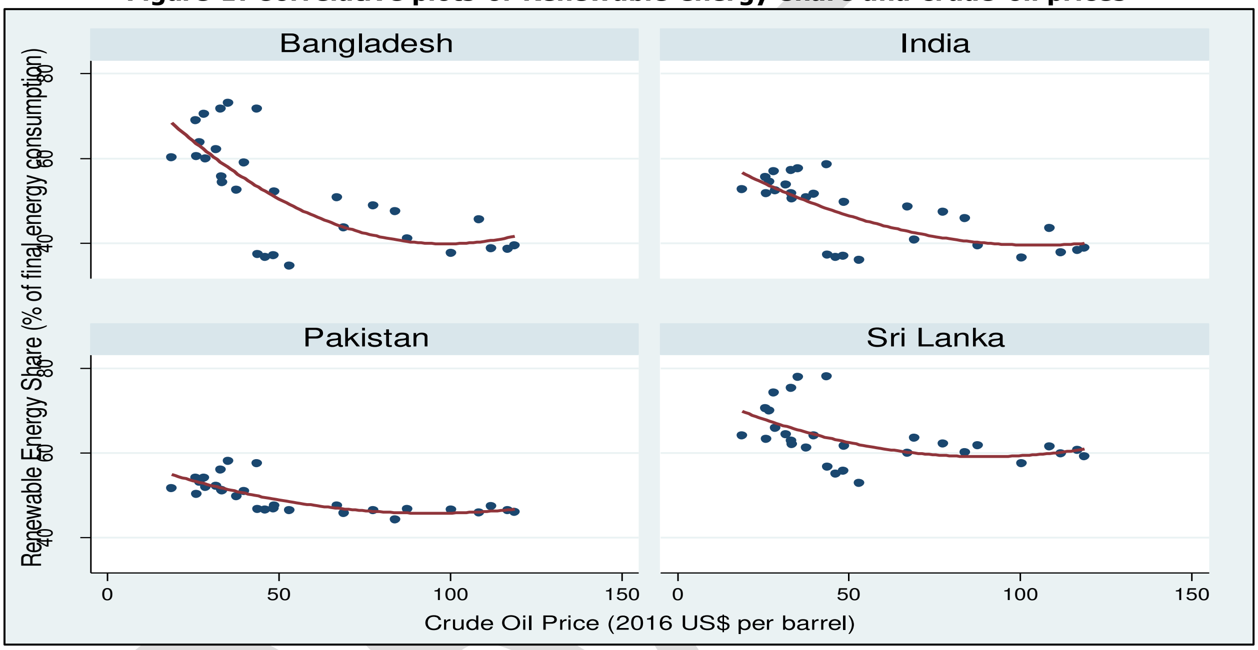
Renewable Energy Consumption (kg of oil equivalent per capita)				
Period	**Bangladesh**	**India**	**Pakistan**	**Sri Lanka**
1990-95	88.40	207.13	229.73	241.54
1996-00	84.62	211.68	228.33	253.90
2001-05	84.10	216.26	225.57	273.60
2006-10	84.70	221.26	221.76	286.26
2011-15	83.53	226.48	216.33	300.00
2016-18	83.00	224.37	216.73	287.21
Renewable Energy Share (% of Total Energy Consumption)				
Period	**Bangladesh**	**India**	**Pakistan**	**Sri Lanka**
1990-95	69.97	56.75	55.51	74.34
1996-00	60.37	52.45	51.38	64.37
2001-05	53.13	50.30	49.43	61.60
2006-10	45.34	43.44	45.86	61.86
2011-15	37.84	37.57	46.63	58.05

2016-18	37.11	36.96	46.75	55.89

Note: The figures are given in terms o period averages
Source: World Development Indicators (World Bank 2019)

Figure 1 depicts the correlative plots of RE shares in total energy consumption figures and real crude oil prices across the selected South Asian economies over the time period spanning from 1990 to 2018. The inverted-U shapes of the fitted lines, as shown in figure 1, portrays the dependence of these nations on crude oil imports since rising crude oil prices are initially accompanied by lower RE shares which, after a threshold level, elevates the RE shares. Hence, these interesting trends further stresses on the need to investigate the potential non-linearity of the REC-crude oil price nexus in the context of these South Asian NOIC.

Figure 1: Correlative plots of Renewable energy share and crude oil prices



Source: Author's own

3. Literature Review

This section is subdivided into two subsections in which the former discusses the theoretical framework engulfing the REC-crude oil prices nexus while the latter sheds light on the empirical evidence in this regard.

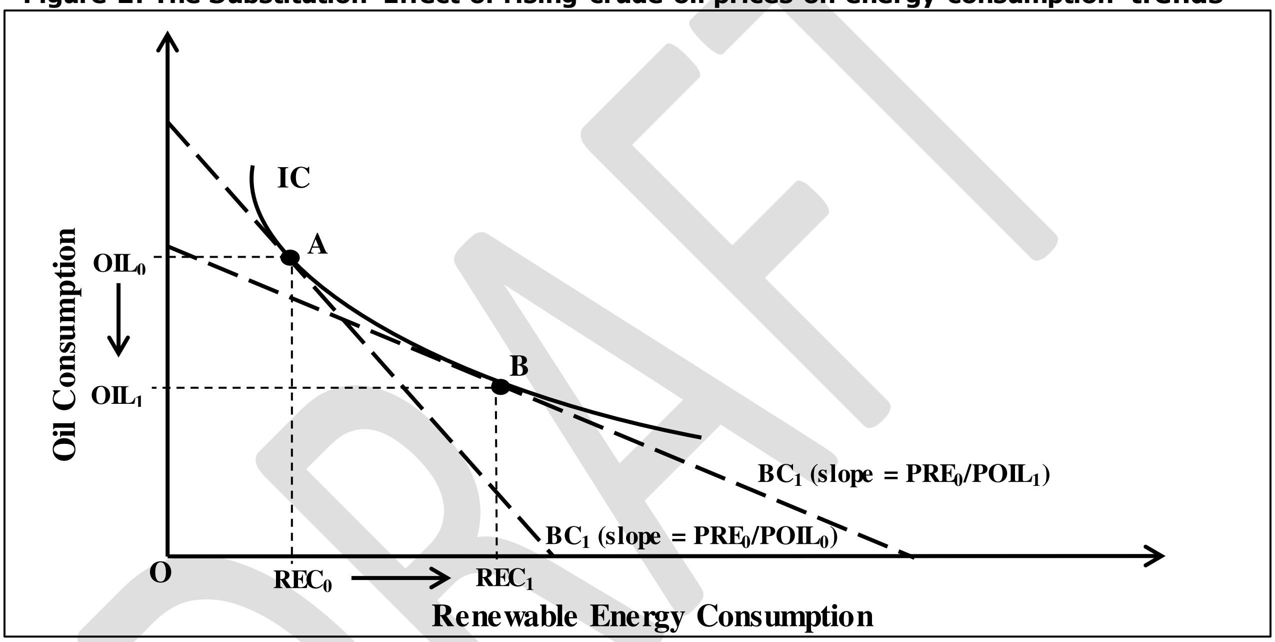
3.1. Theoretical Framework

The impacts of exogenous shocks to world crude oil prices on REC can be explained using the concept of Substitution Effect (SE) of a price change.[2] Usually, the total impact of a change in the price of a commodity can be expressed as a sum of the substitution and income effects. However, this paper confines the discussion to explaining the REC-oil price nexus using the SE stemming from a rise in the crude oil prices. Several studies have referred to RE resources as substitutes for the NRE resources such as crude oil, coal and natural gas (Kruger 2006). Hence, assuming RE resources as perfect substitute for fossil fuels, a rise in world crude oil prices is likely to induce a SE whereby the volume of REC can be anticipated to go up. Figure 2 illustrates the dynamics in this regard. Prior to the rise in the crude oil prices, across the world market, the optimum level of REC takes place at point A where

[2] For more information on substitution effects see Ashenfelter and Heckman (1974).

the indifference curve (IC) is tangential to the slope of the budget constraint (BC_0). The slope of this budget constraint is given by the relative price ratio of RE resources and crude oil ($PRE_0/POIL_0$). At point A, the optimum levels of REC and oil consumption are respectively shown as RE_0 and OIL_0. Now assuming that the price of crude oil, which is determined in the world market, goes up (from $POIL_0$ to $POIL_1$) while the price of renewables, which is locally determined, is assumed to stay put (at PRE_0). Hence, the relative price ratio would decline resulting in the slope of the budget constraint being flatter. The new budget constraint can be shown as BC_1 and the corresponding relative price ratio is given by $PRE_0/POIL_1$. Under such circumstances, there will be a movement along the indifference curve, from point A to point B, whereby the consumption of renewables can be expected to rise while oil consumption is likely to decline. The SE of the rise in world crude oil prices can, therefore, be shown as the increase in the levels of REC from RE_0 to RE_1 and the decrease in oil consumption levels from OIL_0 to OIL_1.

Figure 2: The Substitution Effect of rising crude oil prices on energy consumption trends



Source: Author's own

However, this mechanism is strongly grounded on the assumption of RE resources and fossil fuels being perfect substitutes. In the case of these two variables not being perfect substitutes, the SE could be negligible whereby the impact of rising crude oil prices on the level of REC may not be as pronounced. Under more adverse scenarios, in which the RET is not possible due to certain macroeconomic limitations, particularly in the form of predominant oil-dependencies, rising crude oil prices may even foster higher consumption of crude oils to meet the aggravating demand for energy to produce the national outputs. As a consequence, the share of NRE in aggregate energy consumption levels can be anticipated to rise along with the rise in crude oil prices. Hence, it can be said that the exact nature of the REC-crude oil price nexus depends on the possibility of the substitution between the NRE and RE resources and also on the extent of crude oil-dependency of the concerned economy.

3.2. Empirical Evidence

A plethora of studies have attempted to model the impacts of oil prices on the demand for RE in the context of both developed and developing economies. In a country-specific study by Sadorsky (2009), the author probed into the factors attributing to REC within the Group of Seven (G7) economies using annual data from 1980 to 2005. The short-run results from the error-correction model approach revealed that rising oil prices increased REC in France while reducing it in the context of the United Kingdom (UK). However, no statistical short-run impact could be established for the rest of the G7 nations. The long-run findings, tapping the fully-modified and dynamic ordinary least squares approach, showed that rising oil prices ultimately increased REC within France, Germany and Italy but led to declines in the REC levels in the context of Canada, Japan, the UK and the United States of America (USA). However, the results also showed that REC is pretty elastic to changes in oil prices across Germany, the UK and the USA while for France, Italy, Canada and Japan evidence of an inelastic association between REC and oil price movements was ascertained. For the pooled data of all the G7 nations, a negative correlation between oil price and REC was also evidenced from the statistical significance of the long-run elasticity estimate.

Azad *et al.* (2014) used annual time-series data spanning across 1990 and 2011 to conduct simulation exercises for assessing the impacts of oil price shocks on Australia's RE demand. The results from the Generalized Method of Moments (GMM) regression approach provided statistical evidence regarding RE resources being substitutes for fossil fuels in the context of Australia. The corresponding elasticity estimate denoted that the marginal effect of a rise in the price of crude oil attributed to a rise in the volume of REC by 0.14%, on average, *ceteris paribus*.

The causal linkage between REC and real oil prices for the USA, over the period 1949 to 2009, was estimated by Payne (2014). Results from the Toda-Yamamoto long-run causality approach suggested no causation between the two variables. Moreover, the impulse response function analyses revealed that unexpected shocks to real oil prices could not establish a statistically significant impact on the country's REC over a 10-year time period. Instead, the statistical estimates revealed that REC in the USA responds positively to positive shocks to the country's real GDP and carbon emissions figures.

In a recent study by Ji and Zhang (2019), the factors affecting REC growth in China, between 1992 and 2013, were explored using variance decomposition techniques within a Vector Autoregressive (VAR) model framework. The corresponding results indicated that changes in crude oil prices accounted for almost 20% of the total variations in China's RE share in aggregate final energy consumption figures. Moreover, upon checking for the robustness of the findings using an alternate indicator of RE use within the Chinese economy, the findings revealed that oil prices explained almost one-fourth of the total variations in China's volumes of non-hydroelectric power. The overall results highlighted that the movements in oil prices were second to financial development in explaining the changes in the growth of the RE sector of China.

Shah, Hiles and Morley (2018) analyzed the impacts of oil price shocks and other macroeconomic aggregates on RE investment trends in Norway, the USA and the UK. The study utilized annual data stemming from 1960 to 2015 to perform the forecast error variance decomposition analysis within a VAR framework. The results showed that shocks to both real and nominal prices of oil failed to exert much impact on the trends in RE investments in the UK. In contrast, positive shocks to oil prices were found to trigger positive movements in the RE investment figures of Norway and the USA. The authors referred to state intervention in the UK as the core reason behind the ineffectiveness of oil price shocks to explain movements in the nation's RE investment trends. The causality estimates revealed that only in the context of the USA, a unidirectional causality was found to be stemming from oil prices and investment in the nation's RE sector. Furthermore, the authors concluded that the impacts of oil price shocks on development of the RE sector depend on whether an economy is a net importer or a net exporter of oil. The fact that the USA was a net importer of oil across a lion's share of the study period was claimed to be the reason behind the nation's RE investment trends being responsive to oil price shocks.

Amongst the various cross-country examinations documented in the literature, Omri and Nguyen (2014) used annual data in the context of 64 global economies, from 1990 to 2011, to model the elasticity of REC with respect to changes in real prices of crude oil. Results from the dynamic system-GMM regression analyses revealed that rising crude oil prices reduced the volume of per capita REC across the entire panel of 64 countries. Moreover, up classifying the countries in terms of their respective income group, the regression estimates revealed that a rise in the real values of crude oil prices by 1% was accompanied by a reduction in the per capita REC figures for the panel of the middle-income economies by 0.34%, on average, *ceteris paribus.* However, no statistically significant impact could be ascertained in the context of the low-income and the high-income panels. Thus, the authors opined in favor of the heterogeneity of the REC-oil price nexus across economies with respect to the income group they belong to.

The REC-oil price nexus in the context of seven Central American nations was explored by Apergis and Payne (2014a). The authors used annual data for all the seven economies over the period 1980 to 2010. The regression analysis was conducted using the fully modified ordinary least squares estimator. The elasticity estimates showed that the per capita REC within the selected Central American economies responded to changes in both real prices of oil and coal. In particular, a 1% rise in the real oil prices was found to elevate the per capita REC figures by 0.29%, on average, *ceteris paribus*, thus, implicating the substitutive properties between RE and fossil fuels in the context of the selected nations. Moreover, the authors also concluded that real oil prices, over the entire study period, does not exert a causal impact of the per capita REC figures. However, allowing for regime shifts in the year 2002, the causality findings during the pre-2002 period revealed statistical evidence regarding unidirectional short-run causal impacts of real oil prices on per capita REC while in the long-run a bidirectional causation between the variables was observed. On the other hand, in the post-2002 period, bidirectional causalities between real oil prices and REC per capita were found in both the short- and the long-runs.

Marques and Fuinhas (2011) assessed the drivers of RE use across 24 European Union nations between 1990 and 2006. The uniqueness of this study involved the consideration of prices of disaggregated NRE resources to estimate their conditional impacts on the demand for RE. The regression results from the difference-GMM, system-GMM and the least squares dummy variable correlated estimators unanimously suggested that oil prices are statistically insignificant in explaining the changes in the shares of renewable in the total energy consumption figures of the European Union member countries. In a similar study, Damette and Marques (2019) also probed into the drivers of REC within the 24 European Union nations. Upon controlling for the problem of dependencies across the cross-sections, the authors employed the pooled mean group panel data estimator to deduce the long-run elasticities. The results showed that oil prices exhibited a positive and statistically significant impact on the share of renewables in total energy production levels. Moreover, the authors also opined that rising dependency on energy imports also contributed to a higher RE shares in total energy supplies.

The dynamics engulfing the REC-oil price nexus in the context of 25 member states under the Organization for Economic Co-operation and Development (OECD) were examined by Apergis and Payne (2014b). The study employed annual data from 1980 to 2011 to predict the long-run associations. The results advocated in favor of the long-run cointegrating associations between per capita REC and real oil prices. Moreover, the long-run elasticity between these variables, as predicted using the panel fully modified ordinary least squares estimator, showed that the marginal impact of a rise in real oil prices triggered a simultaneous increase in the per capita REC figures by 0.45%, on average, *ceteris paribus.* Moreover, the causality estimates from the panel error-correction method revealed a bidirectional causal association between per capita REC and real oil price both in the short- and long-runs.

In a similar study, Apergis and Payne (2015) employed panel cointegration techniques to predict the long-run determinants of REC in the context of 11 South American nations, using yearly data between 1980 and 2010. The results from the fully modified ordinary least square technique indicated that REC per capita is positively influenced by rising real oil prices, thus, referring to RE resources as alternative sources of energy to the fossil fuels. A 1% rise in the real price of oil was found to be accompanied by a 0.37% escalation in the per capita REC figures, on average *ceteris paribus.* Hence, these findings suggested that REC in the context of the concerned South American economies is inelastic to changes in world oil prices. Moreover, the causality estimates from the vector error-correction model approach discovered bidirectional short-run causation between per capita REC and real oil prices. However, in the long-run real oil price was found to causally impact the per capita REC figures without the feedback.

Hence, it is apparent from the equivocal conclusions made in the aforementioned country-specific and cross-country empirical studies that rising crude oil prices do not guarantee the replacement of fossil fuel consumption via the RE alternatives. Moreover, considering country-specific features, a great deal of heterogeneity concerning the nature of the REC-oil price nexus is also evident. More importantly, the existing literature has overlooked the possible non-linearity between these variables which could be effective in reasoning the ineffectiveness of higher crude oil prices in instigating the RET phenomenon, particularly from the perspectives of the NOIC. This paper attempts to address this gap in the literature by modeling the REC-crude oil price relationship in a non-linear framework in the context of the four NOIC across South Asia.

4. Empirical Model and Data

The selection of the empirical models is based on the underlying economic theories. In order to model the possible non-linear association between crude oil prices and consumption of RE resources across the selected South Asian nations, the level of REC within the concerned economies is expressed as a quadratic function of real crude oil prices and controlled for key macroeconomic aggregates that may affect the overall nature of the REC-crude oil price nexus. The corresponding empirical model can be specified as:

$$\boldsymbol{lnREC_{it} = \beta_0 + \beta_1 lnROILP_{it} + \beta_2 lnROILP_{it}^2 + \beta_3 lnRGDP_{it} + \beta_4 lnRGDP * lnROILP_{it} + \beta_5 DEPEND_{it} + \beta_6 lnCO2_{it} + \beta_7 lnTO_{it} + \varepsilon_{it}} \quad \textbf{(1)}$$

where the subscripts i and t respectively denote the individual cross-sectional units and the time period. β_i (i = 1, …, 7) are the elasticity parameters to be estimated while ε is the error-term. The variable *REC* is per capita consumption of RE, measured in terms of kilograms of oil equivalent. *ROILP* and *ROILP*^{2} stand for the real prices of crude oil and its squared term, respectively. The unit of measurement of real crude oil prices is in terms of US dollars per barrel in constant 2016 prices. It is worth noting that the statistical significance of the elasticity parameters attached to ROILP and ROILP^2 would portray a non-linear association between REC and real crude oil prices in the context of the selected South Asian nations.

Among the other key variables controlling the econometric framework, *RGDP* abbreviates for the real Gross Domestic Product which is included to account for the possible effects of economic growth on the facilitation of REC across the concerned economies. Economic growth can be anticipated to exert a positive impact on the REC figures via empowering the concerned nations to overcome the limitations restraining the RET phenomenon (Murshed 2020). In addition, *RGDP* is interacted with *ROILP* and included in the model to account for the joint impacts of economic growth and crude oil price shocks on the movements in the REC levels. The rationale behind the inclusion of this interaction term could be explained in the sense that as an economy, particularly the one that is a net importer of crude oil, experiences growth it can gradually lessen its dependence on the oil-imports which, in turn, can be expected to elevate its REC levels. In the same vein, the econometric model is also controlled for the imported oil-dependency, abbreviated by *DEPEND,* within the selected South Asian economies. Following Damette and Marques (2019), imported oil-dependency is proxied by the share of energy imports in the total merchandize imports figures of the respective economies. A rise in the share of energy imports in aggregate merchandise import figures can be interpreted as a simultaneous increment in the degree of oil-dependency which, in turn, can be associated with lower REC within the economies.

In addition, the econometric model is also controlled for carbon-dioxide emissions. The variable CO_2 stands for the volume of carbon-dioxide emissions measured in terms of kg per 2010 US dollars' worth of GDP. It is pertinent to include carbon-dioxide emissions in modeling the trends in REC since rising apprehensions regarding the air-pollution induced climate change adversities are likely to facilitate the substitution effect between the consumption of fossil fuels and the renewable alternatives (Omri and Nguyen 2014). Finally, TO denotes the trade openness index, measured in terms of the sum of imports and exports as a percentage of the GDP. The relevance of considering openness to trade for modeling the REC trends can be justified in the sense that a rise in the trade openness indices can be interpreted as a reduction in the trade barriers which can be anticipated to facilitate cross-border flows of renewable power, thus, boosting the REC levels (Murshed 2018).

For the robustness check of the REC-crude oil price nexus, model (1) is re-estimated using two alternate indicators of REC, namely the share of renewables in total final energy consumption figures and the share of renewable electricity in aggregate electricity output levels. The corresponding models can be specified as:

$$\boldsymbol{lnRES_{it} = \alpha_0 + \alpha_1 lnROILP_{it} + \alpha_2 lnROILP_{it}^2 + \alpha_3 lnRGDP_{it} + \alpha_4 lnRGDP * lnROILP_{it} + \alpha_5 DEPEND_{it} + \alpha_6 lnCO2_{it} + \alpha_7 lnTO_{it} + \varepsilon_{it}} \quad \mathbf{(2)}$$

$$\boldsymbol{lnRELEC_{it} = \delta_0 + \delta_1 lnROILP_{it} + \delta_2 lnROILP_{it}^2 + \delta_3 lnRGDP_{it} + \delta_4 lnRGDP * lnROILP_{it} + \delta_5 DEPEND_{it} + \delta_6 lnCO2_{it} + \delta_7 lnTO_{it} + \varepsilon_{it}} \quad \mathbf{(3)}$$

where RES and RELEC stand for the shares of renewable energy and renewable electricity respectively in the total final energy consumption and aggregate electricity outputs. All the variables have been transformed into their natural logarithms for the ease of the long-run elasticity estimation and also to minimize the sharpness of the annual data series to generate consistent and reliable estimates. The time period of the dataset used in this paper stretches from 1990 to 2018. The real crude oil price data is sourced from the British Petroleum's Statistical Review of World Energy 2019 (British Petroleum 2019) while data for all the other variables are retrieved from the World Development Indicators website of the World Bank (2019). Table 2 in the appendix provides the descriptive statistics of all the variables considered in the econometric analyses.

5. Methodology

The econometric analyses begin with the Cross-sectional Dependency (CD) analysis. The problem of CD is claimed to generate biased and inconsistent stationarity and cointegrating properties (Dong *et al.* 2018). Thus it is pertinent to investigate whether the panel series in the dataset are independent or not. CD usually stems from spatial effects whereby a particular economic data of two or more economies exert an impact on one another, thus, the associating the countries globally or regionally (Pesaran and Chudik 2013). This paper primarily employs the Breusch-Pagan (1980) Lagrange Multiplier (LM) test to identify the possible CD issues in the panel data series. The LM test statistic can be specified as:

$$\boldsymbol{LM = \sum_{i=1}^{N-1}\sum_{j=i+1}^{N} T_{ij}\, \hat{\rho}_{ij}^2 \rightarrow \chi^2 \frac{N(N-1)}{2}} \quad \mathbf{(4)}$$

where N is the number of countries, T is the time period and $\hat{\rho}_{ij}^2$ is the predicted correlation coefficient sourced from the residuals of the econometric model. Besides, the Pesaran (2004) CD test, ideally suited for handling datasets with small cross-sections and short time dimensions, is also employed. The Pesaran CD test statistic can be specified as:

$$\boldsymbol{CD} = \sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}T_{ij}\,\hat{\rho}_{ij}^{2} \rightarrow N(0,1) \qquad \textbf{(5)}$$

Both these test statistics are respectively estimated under the null hypothesis of cross-sectional independence against the alternative hypothesis of CD. The results from the CD analyses for all the three models are displayed in Table 2 in the appendix. The statistical significances of the Breusch-Pagan LM and the Pesaran CD test statistics reject the null hypotheses of cross-sectional independence, for the respective models, to validate the existence of the CD among the panel series. Hence, the application of the conventionally used first-generation panel unit root and cointegration techniques is no longer valid since these methods fail to account for the CD issues in the dataset.

In addition to CD analyses, it is pertinent to check the slope heterogeneity issue as well since ignoring the possible heterogeneity of the slope coefficients across the cross-sections could result in the estimations being biased. Thus, this paper uses the slope heterogeneity test proposed by Pesaran and Yamagata (2008) which estimates two test statistics, $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$, under the null hypothesis of slope homogeneity against the alternative hypothesis of slope heterogeneity. The corresponding results from the slope heterogeneity test, for models (1), (2) and (3), are reported in Table 2 in the appendix. The statistical significance of the test statistics, at 1% level, rejects the null hypothesis to suggest the slope heterogeneity issues.

5.1. Second generation Panel unit root analysis

The second generation panel unit root techniques are claimed to generate estimates via addressing the CD issues, much unlike the conventionally used first-generation panel unit root tests that assume cross-sectional independence. Thus, upon confirmation of the CD problem, the second generation panel unit root tests are employed. This paper uses the Cross-sectionally Augmented Dickey-Fuller (CADF) and the Cross-sectionally Augmented Im, Pesaran and Shin (CIPS) panel unit root estimation techniques proposed by Pesaran (2007). The CADF test statistic can be obtained from the generalized regression given below:

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i\bar{y}_{t-1} + \sum_{j=0}^{s} d_{ij}\,\Delta\bar{y}_{t-j} + \sum_{j=1}^{s}\delta_{ij}\,\Delta\bar{y}_{i,t-j} + e_{it} \qquad \textbf{(6)}$$

where $\bar{y}$ and $\overline{\Delta y}$ are the cross-sectional averages of lagged levels and first differences, respectively, at time T for all cross-sections. The estimated t-statistic from equation (6) is then used to compute the CIPS statistic which can be specified as:

$$CIPS = N^{-1}\sum_{i=1}^{N} CADF_i \qquad \textbf{(7)}$$

where $CADF_i$ is the t-statistic estimated from the CADF regression model shown in equation (6). Both the CADF and CIPS tests are performed under the null hypothesis of non-stationarity of the respective variable against the alternative hypothesis of stationarity.

5.3. Second generation panel Cointegration analysis

The popularly used panel cointegration methods namely the Pedroni (1999) residual-based cointegration technique does not take the CD among the panels into account. Thus, the Westerlund (2007) panel cointegration analysis, which is robust to handling cross-sectionally dependent panel datasets, is employed to investigate the long-run associations between the concerned variables included in the econometric models. The CD is accounted under the Westerlund (2007) cointegration approach via estimation of the probability values of the test statistics using bootstrapping methods. A total of two group-mean tests and two panel tests are performed under the null hypothesis of no cointegration against the alternative hypothesis of cointegration among at least one cross-sectional unit or cointegration among the whole panel, respectively. The four tests under the Westerlund (2007) panel cointegration approach are structured in the context of an error-correction model which can be expressed as:

$$\Delta y_{it} = \delta_i' d_t + \alpha_i\left(y_{i,t-1} - \beta_i' x_{i,t-1}\right) + \sum_{j=1}^{p_i}\alpha_{ij}\Delta y_{i,t-j} + \sum_{-q_i}^{p_i}\gamma_{ij}\Delta x_{i,t-j} + e_{it} \qquad \textbf{(8)}$$

where d_t stands for the deterministic components and p_i and q_i are the lag lengths and lead orders which are allowed to vary across individual cross-sections. The two group-mean test statistics G_t and G_a and the two panel test statistics P_t and P_a within the Westerlund (2007) cointegration analysis can be specified as:

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\widehat{\alpha_\iota}}{SE(\widehat{\alpha}_i)} \quad (9)$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\widehat{\alpha_\iota}}{\widehat{\alpha}_i(1)} \quad (10)$$

$$P_t = \frac{\widehat{\alpha_\iota}}{SE(\widehat{\alpha}_i)} \quad (11)$$

$$P_a = T\widehat{\alpha} \quad (12)$$

The statistical significance of these test statistics rejects the null hypothesis to suggest long-run associations between the variables included in the model. The presence of cointegrating relationships is a pre-requisite to estimating the long-run estimates using appropriate regression methods.

5.3. Panel regression analysis

The presence of CD issues in the dataset is likely to be translated into misspecification problems resulting in biased regression outputs (Damette and Marques 2019). Similarly, the slope heterogeneity issues are also likely to generate similar problems as well (Pesaran and Yamagata 2008). Although the conventionally used panel data estimation techniques namely the Fully-Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) are claimed to be able to handle the cross-sectional correlations among the panels, such methods overlook the slope heterogeneity issues by inappropriately assuming the existence of the homogeneous slope coefficients across all the cross-sections. To account for this problem, this paper uses three panel data regression estimators which, in addition to handling the CD issues, allow for the slope coefficients to vary across the cross-sectional units (Damette and Marques 2019).

The first of the three panel data regression techniques used in this paper is referred to as the Mean Group (MG) estimator developed by Pesaran and Smith (1995). The MG estimation primarily involves the estimation of the slope coefficients for each of the cross-sections, within the panel dataset, using the Ordinary Least Squares (OLS) method and then averaging them across the panel units. This allows for the possible heterogeneity of the slope coefficients across the different cross-sections to overcome the inefficiencies of the FMOLS and the DOLS techniques. The MG estimator can be specified as:

$$\widehat{\beta}_{MG} = N^{-1}\sum_{i=1}^{N}\widehat{\beta}_i \quad (13)$$

where $\widehat{\beta}_{MG}$ is the simple mean of the individual slope estimators from each cross-sectional unit. However, a major limitation of this technique is that it fails to account for the CD in the data. Thus, the Common Correlated Effects Mean Group (CCEMG) estimator, proposed by Pesaran (2006), is tapped which is basically a cross-sectionally augmented version of the MG estimator to handle the CD issues as well. The CCEMG corrects the limitations of the MG estimator by incorporating the time-variant unobserved common factors stemming from the CD issues into the estimation process via augmenting these unobserved common factors into the regression model before estimating the individual slope coefficients for each of the cross-sections and then averaging them across the panel units. Likewise the MG estimator, the CCEMG estimator can also be specified as:

$$\widehat{\beta}_{CCEMG} = N^{-1}\sum_{i=1}^{N}\widehat{\beta}_i \quad (14)$$

where $\widehat{\beta}_{CCEMG}$ is once again the mean of the individual slope estimates from each cross-sectional unit. The only difference between the MG and the CCEMG estimators, respectively expressed in equations (13) and (14), is that the CCEMG estimator estimates and averages the individual slope coefficients via augmenting the common factors across the cross-sections into the empirical model which is not the case in the context the MG estimator.

Finally, for robustness check, the Augmented Mean Group (AMG) estimator proposed by Bond and Eberhardt (2013) is used for the regression analyses. The AMG estimator, much like the CCEMG estimator, also allows for slope heterogeneity and CD issues in the data. However, the AMG estimator augments the year dummies into the model and refers the time-variant unobserved common factors to exhibit a dynamic process whereas the CCEMG estimator includes the unobserved common factors in the error term (Mrabet *et al.* 2019).

5.4. Panel causality analysis

Finally, the causality analyses are performed to understand the pairwise causal dynamics between the variables of concern. The newly developed Dumitrescu-Hurlin (DH) panel causality estimation technique developed by Dumitrescu and Hurlin (2012) is applied in this paper. Application of the conventionally used Granger (1969) causality test is inappropriate following the slope heterogeneity issues in the data since this technique assumes the slopes to be homogeneous across the cross-sectional units. The Granger (1969) causality test statistic is estimated under the null hypothesis that causality does not exist between a pair of stationary variables belonging to all the cross-sections, against the alternative hypothesis of causality existing between these variables homogenously across all the cross-sections. In contrast, the DH causality technique allows for heterogeneity across the cross-sections to estimate the z-bar statistics using the null hypothesis that causality does not exist between a pair of stationary variables in all the cross-sections, referred to as the Homogenous Non-Causality (HNC) null hypothesis, against the non-homogenous alternative hypothesis of causality existing between these variables in at least one of the cross-sections. The mean statistic used to test the HNC null hypothesis can be specified as:

$$\boldsymbol{W^{HNC}_{N,T} = \frac{1}{N}\sum_{i=1}^{N} W_{i,T}} \qquad \textbf{(15)}$$

where $W^{HNC}_{N,T}$ is the mean value of the individual Wald statistics $W_{i,t}$. According to Dumitrescu and Hurlin (2012), under the assumption that the individual residuals are independently distributed across all the cross-sections and their covariances are equal to zero, the mean statistic sequentially converges to the equation below when T and N tend to approach infinity:

$$\boldsymbol{Z^{HNC}_{N,T}} = \sqrt{\frac{\boldsymbol{N}}{\boldsymbol{2K}}}\left(\boldsymbol{W^{HNC}_{N,T} - K}\right)^{\vec{\boldsymbol{d}}}_{\boldsymbol{T,N\to\infty}} \boldsymbol{N(0,1)} \qquad \textbf{(16)}$$

where $Z^{HNC}_{N,T}$ is the z-statistic, N is the number of cross-sections and K is the optimal lag length. Moreover, Dumitrescu and Hurlin (2012) also argue that if T tends to infinity, the individual Wald statistics are independently identically distributed with the mean individual Wald statistic being equal to K and its variance being equal to 2K. A standardized Z-statistic ($\bar{\boldsymbol{Z}}^{\boldsymbol{HNC}}_{\boldsymbol{N,T}}$) is then approximately calculated for the mean Wald statistic of the HNC null hypothesis which can be specified as:

$$\boldsymbol{\bar{Z}^{HNC}_{N,T}} = \frac{\sqrt{\boldsymbol{N}}}{\sqrt{\boldsymbol{Var(\widetilde{W}_{i,T})}}}\left[\boldsymbol{W^{HNC}_{N,T} - E\widetilde{W}_{i,T}}\right] \qquad \textbf{(17)}$$

6. Results and Discussion

The results from the second generation panel unit root tests are reported in Table 4. It is apparent from both the CADF and the CIPS test results that all the variables are non-stationary at their respective level forms. The statistical insignificance of the corresponding test statistics fails to reject the null hypothesis of non-stationarity in this regard. However, all the variables do become stationary at their first differences, thus, indicating a common order of integration [i.e., I(1)] which can be perceived from the statistical significance of the corresponding test statistics under both the unit root estimation techniques.

Table 4: Panel unit root test with cross-sectional dependency results

Variable	Level		1st difference		Order of Integration
	Intercept	Intercept & trend	Intercept	Intercept & trend	
Pesaran CADF Test					
lnREC	-1.488	-2.429	-2.519*	-3.220**	I(1)
lnRES	-1.116	-.1717	-0.453	-3.204**	I(1)
lnRELEC	-1.823	-2.511	-3.133*	-3.072**	I(1)
$lnROILP^2/lnROILP^2$	-1.610	-1.700	-2.819*	-3.700*	I(1)
lnRGDP	-1.691	-2.222	-2.281	-3.979*	I(1)
lnROILP*lnRGDP	-1.283	-1.586	-2.456***	-3.998*	I(1)
lnDEPEND	-1.919	-2.283	-3.892*	-3.794*	I(1)
$lnCO_2$	-1.849	-2.721	-3.216*	-3.209**	I(1)
lnTO	-1.969	-1.806	-2.435***	-3.983*	I(1)
Pesaran CIPS Test					
lnREC	-2.001	-2.129	-6.001*	-6.084*	I(1)
lnRES	-2.068	-1.954	-4.945*	-5.023*	I(1)
lnRELEC	-2.101	-2.023	-5.682*	-5.678*	I(1)
$lnROILP^2/lnROILP^2$	-1.610	-1.700	-3.320*	-3.952*	I(1)
lnRGDP	-1.677	-2.113	-4.417*	-4.389*	I(1)
lnROILP*lnRGDP	-0.552	-1.895	-3.709*	-3.764*	I(1)
lnDEPEND	-1.995	-1.942	-5.183*	-5.165*	I(1)
$lnCO_2$	-2.139	-2.019	-5.445*	-5.541*	I(1)
lnTO	-1.615	-1.849	-5.295*	-5.288*	I(1)

*Notes: The optimal lags are chosen based on the Akaike Information Criterion (AIC); *, ** & *** indicate statistical significance at 1%, 5% and 10% levels, respectively*

The Westerlund (2007) panel cointegration test results in the context of models (1), (2) and (3) are presented in Table 5. The statistical significances of the test statistics reject the null hypothesis of no cointegrating relationships between the variables in the respective models. Hence, in the context of model (1), it can be said that REC across all the four South Asian economies has long-run associations with real crude oil prices and other macroeconomic aggregates controlled for in the empirical modeling. Similarly, in the context of model (2), it can also be asserted that there are long-run associations between the shares of RE in aggregate final energy consumption figures and crude oil prices and all the other control variables for all the four South Asian economies. Finally, the statistical significances of the test statistics in the context of model (3) also provide statistical validity regarding long-run associations between the renewable electricity share in aggregate electricity outputs and the other independent variables. Thus, the confirmation of the long-run associations calls for further investigation of the long-run conditional elasticities between the concerned variables.

Table 5: Westerlund cointegration test results

Test Statistic	Model (1)		Model (2)		Model (3)	
	Value	p-value	Value	p-value	Value	p-value
Gt	-3.101*	0.000	-3.286*	0.000	-2.714***	0.100
Ga	-4.645*	0.000	-4.883*	0.000	-5.019*	0.000
Pt	-6.145	0.200	-7.836*	0.000	-5.664***	0.100
Pa	-5.111***	0.100	-4.660***	0.100	-2.975	0.300

*Notes: The bootstrapping regression is conducted with 100 replications; The optimal lag selection is based on AIC; * and *** denote statistical significance at 1% and 10% levels, respectively.*

Table 6 displays the long-run elasticity estimates from the MG, CCEMG and the AMG regression analyses. It is apparent from the overall results that the elasticity estimates, in the context of the three models, are robust across the alternate panel data regression techniques with respect to the predicted signs and their corresponding statistical significance. In the context of model (1), the statistical significances of the elasticity parameters attached to *lnROILP* and *$lnROILP^2$* confirm the non-linearity of the REC-crude oil price nexus in the context of the selected net oil-importing South Asian economies. Moreover, the negative signs of the elasticity parameters attached to *lnROILP* advocate in favor of positive shocks to real crude oil prices, initially, not being able to facilitate REC across the concerned economies. The corresponding elasticity estimates implicate that a 1% rise in real crude oil prices is accompanied by a fall in the REC levels on average by 2.35% to 3.59%, *ceteris paribus.* The negative REC-crude oil price nexus was also reported in the study by Sadorsky (2009) for Canada, Japan, the UK and the USA. It is worth mentioning that Japan, the UK and the USA are all net-importers of crude oils which further justify our results in the context of the four South Asian net oil-importers.

However, although initially the REC-crude oil price nexus is found to be negative, the statistical significance and the positive signs of the estimated elasticity parameters attached to $lnROILP^2$ suggest that beyond a threshold level of real crude oil price the relationship reverses to induce greater consumption of RE resources within the South Asian nations. The corresponding elasticity estimates show that, beyond the threshold level of crude oil price, a further rise in the real price of crude oil by 1% is accompanied by increments in the REC levels by 0.10% to 0.14%, on average, *ceteris paribus.* Therefore, it can be asserted that initially following a rise in crude oil prices the substitution of the imported crude oils via the RE alternatives, within the selected South Asian nations, may not be possible due to the predominant reliance of these nations on oil imports to source energy for generating their respective national outputs. A particular reason behind such imported oil-dependence can largely be attributed to the unavailability of indigenous natural oil endowments across South Asia. This, coupled with the limited opportunities to locally generate power from renewables in most of the selected South Asian countries, tends to restrain the RET process in the short-run. However, a persistent rise in crude oil prices and economic development over time does induce the RET phenomenon in these economies which possibly could be due to the gradual phasing out of the imported-oil dependencies of these economies over time. This mechanism can be explained using the estimated economic growth elasticities of REC. The positive signs of the statistically significant elasticity parameters attached to *lnRGDP* suggest economic growth does exhibit favorable impacts to facilitate RET within the economies which could be playing a key role in reducing their imported-oil dependencies. Moreover, the positive signs of the statistically significant elasticity parameters attached to the interaction term further advocates in favor of the joint favorable impacts of economic growth and rising crude oil prices concerning the facilitation REC within the four South Asian nations. Furthermore, dependency on imported oils is also found to dampen the prospects of RET across South Asia. The negative signs of the statistically significant elasticity parameters attached to *lnDEPEND* denote that a 1% rise in the volume of energy imports leads to a fall in the REC levels on average by 0.17% to 0.24%, *ceteris paribus.* Thus, reducing oil imports, which can be said to be synonymous with a reduction in imported-energy dependencies, is key to boosting REC within the South Asian countries.

The other important findings include the positive association between CO_2 emissions and REC which explicitly points out towards the REC being triggered by environmental adversities stemming from air pollutions which, in turn, can largely be attributed to the combustion of the imported oils. Thus, rising CO_2 can be claimed to instigate the substitution between imported oils and the RE alternatives. The positive CO_2-REC nexus is parallel to the findings by Sadorsky (2009) in the context of the G7 countries. On the other hand, the regression results also imply that liberalizing trade barriers generate favorable outcomes concerning the facilitation of the RET phenomenon within the selected economies. This is evident from the positive signs of the statistically significant elasticity parameters attached to *lnOPEN* which imply that a 1% rise in the trade openness indices enhances REC by 0.23% to 0.29% on average, *ceteris paribus.* A specific reason behind this finding could be interpreted as lower trade barriers facilitating the cross-border flows of renewable power within the concerned economies whereby the levels of REC can justifiably be expected to go up. Similar findings were reported in the study by Murshed (2018) which included Nepal as an additional South Asian economy along with the four nations considered in this paper.

As far as the shares of renewables in total final energy consumption figures are concerned, the elasticity estimates in the context of model (2), as reported in Table 6, also confirms the non-linear association between renewable energy shares and real crude oil prices. The negative and the positive signs of the statistically significant estimated elasticity parameters attached to *lnROILP* and $lnROILP^2$, respectively, provide support to this claim. The results show that a 1% rise in real crude oil prices initially curbs the shares of renewables by 0.61% to 0.99% on average, *ceteris paribus.* The small magnitudes of the predicted elasticities imply that the share of renewables in aggregate final energy consumption figures is pretty inelastic to changes in crude oil prices. However, beyond a certain threshold level of real crude oil price, a further increase in the crude oil prices by 1% enhances renewable energy shares on average by 0.01% to 0.07%, *ceteris paribus.* Hence, once again it can be concluded that the rising price of crude oil in the international markets does not instantaneously lead to the substitution of crude oil via the RE alternatives. However, beyond a certain price level, the substitution does take place to some extent whereby the RET phenomenon can be expected to take off.

Among the other key findings in the context of model (2), economic growth, although attributing to higher REC levels, does not simultaneously guarantee a rise in the share of RE in the total final energy consumption figures. A 1% rise in the real value of crude oil prices is found to reduce the RE shares by 0.10% 0.12%, on average, *ceteris paribus.* Hence, it can be said that the national outputs of these nations are relatively more intensive in use of the NRE resources which further implicates towards the imported oil-dependency of the concerned South Asian nations. Moreover, quite expectedly, the marginal impacts of imported-oil dependency are also found to dampen the RE shares as perceived from the negative and statistically significant estimates of the elasticity parameters attached to *lnDEPEND* in the context of model (2). On the other hand, rising carbon-dioxide emissions, in spite of accounting for higher REC levels, actually lead to lower shares of renewables in aggregate final energy consumption figures across the concerned South Asian countries. This implies that although environmental pollution does trigger REC to some extent it does not undermine the use of the NRE resources, thus, inhibiting the overall RET phenomenon. Finally, openness to trade is also found to exert adverse impacts on RE shares which corroborates to the findings by Murshed (2018). A 1% rise in the trade openness indices of the selected South Asian economies is found to reduce the RE shares by 0.14% to 0.18%, on average, *ceteris paribus.* The negative trade openness-renewable energy share nexus in the context of middle-income economies was also highlighted in the study by Murshed (2020).

Finally, the regression results in the context of model (3), as reported in Table 6, also confirm the non-linear association between movements in real prices of crude oil and the shares of renewable electricity in aggregate electricity output levels within the selected South Asian economies. The statistical significances of the estimated elasticities of REC with respect to changes in real crude oil price and its squared term affirm the quadratic association between these two variables. However, the negative signs of the elasticity parameters attached to both *lnROILP* and $lnROILP^2$ explicitly points out towards the fact that rising crude oil prices do not stimulate the transition from non-renewable to renewable primary energy use for electricity generation purposes in the selected NOIC across South Asia. This is a pretty concerning finding in the context of energy security within these nations. However, it is to be noted that the magnitudes of the estimated elasticities of the parameters attached to $lnROILP^2$ are relatively lower, and less than one, in comparison to the predicted elasticities of the parameters attached to *lnROILP*. This implies that as the real price of crude oil increases to a large extent, its dampening impact on renewable electricity shares seems to gradually diminish. Hence, it can be expected that at extremely high crude oil prices, the marginal negative impact on the renewable electricity share can be anticipated to be completely phased out which, in turn, could go on to raise the share in the near future.

The other key results in the context of model (3) reveal that higher economic growth elevates the share of renewable electricity within the selected South Asian economies. A 1% rise in the real GDP figures is found to increase the shares by 1.35% to 2.59%, on average, *ceteris paribus.* This implies that the growth of the economy empowers the concerned economies to get over the dependency on imported oils for generating electricity, thus, lessening the shares of non-renewable electricity. Moreover, imported oil-dependency is found to undermine the renewable electricity share within the four NOIC within South Asia. Furthermore, rising carbon-dioxide emissions are found to ineffective in enhancing the share of renewables in aggregate electricity outputs which tends to suggest that there has somewhat been an acceptance regarding the trade-off between economic growth and environmental pollution. As a result, rising carbon-dioxide emissions across these South Asian economies inhibit the overall prospects of transition from non-renewable to renewable electricity generation.

The regression analyses are followed by the DH causality examinations. The results from the causality tests are reported in Table 7. It is evident from the statistical significance of the z-bar statistics that there is a bidirectional causal association between real crude oil price and REC. This finding is parallel to the findings by Apergis and Payne (2014a) in the context of the Central American economies. Moreover, findings from the causality analyses also reveal unidirectional causations stemming from real crude oil prices to the shares of RE and renewable electricity in total final energy consumption and aggregate electricity output levels, respectively. Hence, keeping the long-run elasticity estimates into consideration, the overall findings from the causality analysis advocate in favor of movements in real prices of crude oil, in the international market, influencing the overall prospects of RET within the selected NOIC across South Asia. Thus, safeguarding the concerned economies to overcome the predominant dependence on their oil imports is key to undergoing the non-renewable to RET within these economies.

Table 6: Long-run elasticity estimates from the panel regression analyses

	Model (1)			Model (2)			Model (3)		
Dep. Var.	***lnREC***			***lnRES***			***lnRELECS***		
Estimator	**MG**	**CCEMG**	**AMG**	**MG**	**CCEMG**	**AMG**	**MG**	**CCEMG**	**AMG**
lnROILP	-3.200*	-2.347*	-3.593*	-0.988**	-0.610*	-0.912**	-2.123*	-3.167*	-2.644*
	(0.729)	(0.566)	(0.710)	(0.415)	(0.021)	(0.450)	(0.324)	(1.012)	(0.412)
lnROILP²	0.140**	0.096***	0.112**	0.057**	0.009**	0.067*	-0.024**	-0.048**	-0.171*
	(0.069)	(0.054)	(0.509)	(0.025)	(0.005)	(0.012)	(0.013)	(0.023)	(0.024)
lnRGDP	0.491*	0.637*	0.487**	-0.112**	-0.099*	-0.121**	1.851*	2.592*	1.347***
	(0.081)	(0.062)	(0.243)	(0.045)	(0.014)	(0.059)	(0.420)	(0.991)	(0.807)
lnROILP*lnRGDP	0.073*	0.053*	0.080*	0.015	0.001	0.013	1.016	1.029	1.332
	(0.019)	(0.015)	(0.012)	(0.011)	(0.001)	(0.015)	(0.729)	(1.023)	(1.000)
lnDEPEND	-0.211*	-0.169*	-0.239**	-0.154*	-0.134*	-0.160*	-0.458**	-0.229*	-0.477*
	(0.047)	(0.024)	(0.124)	(0.027)	(0.015)	(0.031)	(0.231)	(0.088)	(0.114)
lnCO₂	0.678*	0.605*	0.722*	-0.229*	-0.245*	-0.232**	-1.312*	-0.747**	-0.992**
	(0.062)	(0.037)	(0.090)	(0.028)	(0.022)	(0.110)	(0.503)	(0.036)	(0.462)
lnTO	0.281*	0.232*	0.292*	-0.177*	-0.135*	-0.180**	-0.353	-0.538	-0.217
	(0.071)	(0.044)	(0.065)	(0.041)	(0.023)	(0.053)	(0.291)	(0.393)	(0.259)

*Notes: The standard errors are reported within the parentheses; *, ** and *** denote statistical significance at 1%, 5% and 10% levels, respectively.*

Table 7: The Dumitrescu-Hurlin panel causality test results

Model (1)		Model (2)		Model (3)	
Null Hypothesis (H_o)	**Z-bar stat.**	**Null Hypothesis (H_o)**	**Z-bar stat.**	**Null Hypothesis (H_o)**	**Z-bar stat.**
lnROILP → lnREC	8.382* (0.000)	***lnROILP → lnRES***	4.649* (0.000)	***lnROILP → lnRELEC***	6.071* (0.003)
lnREC → lnROILP	2.296** (0.030)	***lnRES → lnROILP***	1.192 (0.231)	***lnRELEC → lnROILP***	1.874 (0.382)
lnRGDP → lnREC	9.841* (0.000)	***lnRGDP → lnRES***	3.351* (0.002)	***lnRGDP → lnRELEC***	3.298* (0.001)
lnREC → lnRGDP	2.113** (0.035)	***lnRES → lnRGDP***	1.034 (0.300)	***lnRELEC → lnRGDP***	5.570* (0.000)
lnDEPEND → lnREC	1.147 (0.684)	***lnDEPEND → lnRES***	6.112* (0.000)	***lnDEPEND → lnRELEC***	3.396* (0.001)
lnREC → lnDEPEND	3.083* (0.002)	***lnRES → lnDEPEND***	8.222* (0.000)	***lnRELEC → lnDEPEND***	0.684 (0.297)
lnCO₂ → lnREC	1.271 (0.682)	***lnCO2 → lnRES***	6.671* (0.000)	***lnCO2 → lnRELEC***	7.487* (0.000)
lnREC → lnCO₂	2.708* (0.007)	***lnRES → lnCO2***	4.019* (0.000)	***lnRELEC → lnCO2***	0.912 (0.306)
lnTO → lnREC	11.286*	***lnTO → lnRES***	6.993*	***lnTO → lnRELEC***	2.335**

	(0.000)		(0.000)		(0.020)
lnREC* → *lnTO	2.228* (0.006)	***lnRES* → *lnTO***	0.442 (0.341)	***lnRELEC* → *lnTO***	2.347** (0.018)

*Notes: → indicates does not Granger cause; The p-values, computed using 100 bootstrap replications, are reported within the parentheses; *, ** and *** denote statistical significance at 1%, 5% and 10% levels, respectively.*

7. Conclusions and policy implications

Rising apprehensions in the context of energy insecurity and environmental degradation, on a global scale, in the future has sparked the need to undergo RET worldwide. The importance of transitioning from consumption of non-renewable to RE resources is of greater relevance in the context of the NOIC since predominant dependency on imported oils often goes on to bottleneck their prospects of RET. Against this milieu, this paper attempted to investigate the impacts of exogenous shocks to real crude oil prices on the RET phenomenon within four net-oil importing South Asian economies namely Bangladesh, India, Pakistan and Sri Lanka. The overall results from the econometric analyses provided statistical validity regarding the non-linear U-shaped association between crude oil price and REC. Moreover, statistical evidence regarding a similar non-linear association between crude oil prices and RE share in total final energy consumption figures was also ascertained. Furthermore, the results also suggested that the relationship between crude oil prices and the share of renewable electricity in aggregate electricity outputs is also non-linear; however, higher crude oil prices were not found to enhance the renewable electricity share in the context of the concerned South Asian economies. Finally, the causality findings revealed that changes in the crude oil prices influence movements in REC and the shares of RE and renewable electricity in total final energy consumption and aggregate electricity outputs, respectively.

Therefore, in line with these aforementioned findings, it is ideal for the associated governments to adopt appropriate strategies to gradually phase-out the conventional imported-oil dependency of these South Asian economies which, in turn, is likely to facilitate the overall RET phenomenon to a large extent. More importantly, keeping the immense potentials of cross-border RE trade within South Asia into cognizance, it is recommended to liberalize the corresponding trade barriers to facilitate the flows of renewable power into the four net-oil importing South Asian economies considered in this paper. For instance, these economies can look forward to import hydroelectric power from Nepal while importing geothermal energy from Bhutan. Although the prospects of power-trade across South Asia are often marginalized due to acute geopolitical and other macroeconomic issues, it is absolutely pertinent to overcome these hindrances keeping the attainment of the SDG into cognizance, particularly via the implementation of public policies that are precisely designed to foster RET within the South Asian region.

As part of the future scope of research, this paper can be replicated individually for the all the four net oil-importing South Asian economies to identify the possible heterogeneous impacts of crude oil prices on the REC levels. Moreover, this investigation can also be performed in the context of the net oil-exporting nations to understand the contrasting dynamics of the REC-crude oil price nexus ignoring the imported-oil dependency issues.

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Appendix

Table 2: Descriptive Statistics

Variable	*lnREC*	*lnRES*	*lnRELEC*	*lnROILP*	*lnRGDP*	*lnDEPEND*	*ln*CO_2	*lnTO*
Mean	24.002	3.954	2.873	3.883	25.762	2.847	-0.549	3.656
SD	1.455	0.195	1.132	0.528	1.314	0.582	0.601	0.408
Minimum	22.136	3.548	0.115	2.930	23.749	1.583	-1.672	2.741
Maximum	26.437	4.358	4.604	4.777	28.675	3.761	0.256	4.485
Skewness	0.492	-0.156	-0.877	0.289	0.678	-0.256	-0.320	0.155
Kurtosis	1.841	2.409	2.922	1.910	2.414	1.782	2.627	2.410
Observations	116	116	116	116	116	116	116	116

Table 3: Cross-sectional dependency and Slope heterogeneity test results

	Model (1)		**Model (2)**		**Model (3)**	
CD Tests	**Statistic**	**p-value**	**Statistic**	**p-value**	**Statistic**	**p-value**
Breusch-Pagan LM	133.345*	0.000	107.05*	0.000	121.02*	0.000
Pesaran CD	3.112*	0.002	1.851**	0.045	1.911**	0.039
Slope Heterogeneity Test	**Statistic**	**p-value**	**Statistic**	**p-value**	**Statistic**	**p-value**
$\tilde{\Delta}$	15.041*	0.000	14.021*	0.000	15.449*	0.000
$\tilde{\Delta}_{adj}$	15.019*	0.000	14.392*	0.000	16.012*	0.000

*Notes: * and ** indicate statistical significance at 1% and 5% levels, respectively.*