Energy Reports 7 (2021) 808–821

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Can regional trade integration facilitate renewable energy transition to ensure energy sustainability in South Asia?

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ARTICLE INFO

Article history:
Received 19 October 2020
Received in revised form 2 January 2021
Accepted 21 January 2021
Available online xxxx

Keywords:
Renewable energy transition
Renewable energy
Energy sustainability
Intra-regional trade
Cross-sectional dependency
Slope heterogeneity
South Asia

ABSTRACT

This paper primarily aimed to assess the impacts of regional trade integration on the prospects of undergoing renewable energy transition in selected South Asian economies between 1992 and 2015. The overall results from the econometric analyses, controlling for the cross-sectional dependency and slope heterogeneity issues, highlight the importance of promoting intra-regional trade among the South Asian economies to boost the renewable energy consumption shares and renewable electricity output shares in the total final energy consumption and aggregate electricity output figures, respectively. Besides, the non-linearity of the nexuses between intra-regional trade shares and renewable energy consumption shares and between intra-regional trade shares and renewable electricity output shares are also ascertained. The threshold intra-regional trade shares concerning the renewable energy consumption and renewable electricity output shares are predicted at 20.53% and 17.50%, respectively. However, the predicted threholds are significantly higher than the current average intra-regional trade share in South Asia. Moreover, the panel causality analysis reveals unidirectional causal relationships stemming from intra-regional trade shares to renewable energy consumption and renewable electricity output shares. Besides, greater FDI inflows are found to reduce the overall use of renewable energy while higher levels of economic growth and CO_2 emissions are found to catalyze renewable energy use in South Asia. Furthermore, the results also implicate a non-linear U-shaped association between positive crude oil price shocks and renewable energy consumption and renewable electricity output shares. Therefore, these findings impose critically important policy implications for liberalizing the intra-regional trade barriers, reducing dirty foreign direct investment inflows, expediting economic growth, reducing fossil fuel dependency and abating carbon dioxide emissions to facilitate renewable energy transition in South Asia.

1. Introduction

South Asia has been recognized as one of the rapidly emerging global regions. The South Asian countries have collectively sustained a rock-solid average annual growth rate of around 7% over the last couple of years (World Bank, 2019a). However, despite persistently growing over the years, these nations have predominantly remained energy-constrained (Murshed, 2020a). Hence, it can be hypothesized that the growth achievements of these economies have been below their potential capacities amidst the traditional energy constraints. The energy crises of the South Asian nations can primarily be credited to a great deal of heterogeneity in the nature of their indigenous energy endowments (Nandy, 2019). Consequently, the majority of these nations have failed to meet their respective energy demand with domestic energy supplies. Consequently, the unreliability of energy supplies across this region is also believed to have underpinned the growth momentum of the South Asian countries (Zhang, 2019). Furthermore, the low electrification rate, especially across rural neighborhoods, is also a common feature of these countries, which further reflects the energy crisis scenario in South Asia.

The energy crisis faced by the South Asian countries is asserted to be detrimental to their prospects of achieving the Sustainable Development Goals (SDG) agenda of the United Nations. In particular, the low electrification rates are often alleged to be the central factor impeding the attainment of the SDG (UN-ESCAP, 2018). In 2017, almost 1.62 billion people in South Asia had no access to in-grid electricity supply which accounted for more than 24% of the global population with no grid-connectivity (World Bank, 2019b). Thus, it is imperative for these South Asian economies to substantially improve their overall grid connectivity. The low electrification rates can largely be accredited to the monotonic fossil fuel dependencies of the South Asian nations. The predominant reliance on the finite fossil fuel supplies,

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https://doi.org/10.1016/j.egyr.2021.01.038

Nomenclature

SDG	Sustainable Development Goals
RE	Renewable energy
FDI	Foreign Direct Investment
RET	Renewable energy transition
SAARC	South Asian Association for Regional Cooperation
RES	Renewable energy shares
REOS	Renewable electricity output shares
CO_2	Carbon dioxide
SASEC	South Asia Subregion for Economic Cooperation
BBIN	Bangladesh–Bhutan–India–Nepal
ASEAN	Association of Southeast Asian Nations
ACEC	Africa Clean Energy Corridor
GMM	Generalized Method of Moments
CCEMG	Common Correlated Effects Mean Group
PMG	Pooled Mean Group
MG	Mean Group
DFE	Dynamic Fixed Effects
OECD	Organization for Economic Cooperation and Development
VECM	Vector Error–Correction Model
PCSE	Panel Corrected Standard Errors
FMOLS	Fully Modified Ordinary Least Squares
DOLS	Dynamic Ordinary Least Squares
SUR	Seemingly Unrelated Regression
G7	Group of Seven
2SLS-IV	Two-Stages Least Squares-Instrumental Variable
IRT	Intra-regional trade shares
GDP	Gross Domestic Product
RGDPPC	Real Gross Domestic Product per capita
OIL	Real crude oil price
CO2PC	Carbon dioxide emissions per capita
SAPTA	SAARC Preferential Trade Agreement
SAFTA	South Asian Free Trade Area

particularly for electricity generation purposes, has not only compromised the overall reliability and sustainability of the energy supplies, fossil fuel combustion has also jeopardized the environmental well-being to a large extent (Murshed, 2020b). Therefore, since socioeconomic and environmental development without ensuring energy security is doubtful to be sustained over time, achieving energy sustainability has become the utmost prioritized agenda of the South Asian governments.

Among the several means of ensuring energy sustainability, integration of Renewable Energy (RE) resources into the national energy-mix is hypothesized to be the most important one. Besides, enhancing the use of RE would not only complement the non-renewable energy resources to reduce the energy crisis, but it would improve the environmental quality. However, undergoing Renewable Energy Transition (RET) to phase-out the fossil fuel-dependency is not an easy task to accomplish, especially for the underdeveloped economies that are predominantly technologically backward (Murshed et al., 2020a). Besides, the poor energy infrastructure within these countries is also not conducive to generate electricity using renewable resources (Murshed, 2018). Similarly, several of the South Asian countries are no exception to these aforementioned constraints (Murshed et al., 2020b). Consequently, the larger South Asian economies, in particular, have remained predominantly reliant on non-renewable energy resources (World Bank, 2019b). Hence, from the perspective of achieving energy sustainability, it is critically important for the South Asian nations to identify the factors that can enable them to undergo RET.

Although these RET-inhibitory factors can be overcome through technological spillovers particularly from Foreign Direct Investment (FDI) inflows, such channels to facilitate the RET phenomenon is subject to time lags. Thus, it is pertinent to look for interim and immediate solutions that would ensure greater consumption of RE within the South Asian economies. In this regard, intra-regional energy trade could be ideal in boosting the RE consumption levels across South Asia (Dhungel, 2008; Singh et al., 2018; Saklani et al., 2020; Sarker et al., 2020). The smaller South Asian economies like Nepal and Bhutan have conventionally generated a significant proportion of their respective national outputs using RE resources. Besides, both these economies have surplus amounts of RE due to their respective energy demands being significantly smaller than their capacities to generate electricity from renewables. In contrast, the comparatively larger South Asian economies like India, Bangladesh and Pakistan have been largely reliant on both local and imported non-renewable fossil fuels (World Bank, 2019b; Zhang et al., 2017; Ali et al., 2017). Hence, these contrasting scenarios make South Asia a hub for intra-regional energy trade whereby both Bhutan and Nepal can export hydroelectricity to the other fossil fuel-dependent South Asian nations (Timilsina, 2018). Consequently, the overall use of RE across this region can be amplified to a large extent which, in turn, can be hypothesized to ensure energy sustainability in South Asia.

However, despite the promising prospects, intra-regional energy trade among the South Asian economies is yet to take giant strides. A particular reason behind this phenomenon is the fact that the overall volume of trade among the South Asian neighbors has traditionally remained significantly below par (Shah, 2020). In 2015, intra-regional trade in South Asia accounted for merely 5% of the total international trade in South Asia (Kaushik, 2015). Recently, intra-regional trade in South Asia was estimated to be worth 23 billion US dollars which is barely one-third of what it should potentially be (Kathuria, 2018). These depressing trends can be due to multifaceted factors such as inappropriate tariff measures, high costs of intra-regional connectivity, and, most importantly, geopolitical tensions among the South Asian economies that have impeded trade engagements among the South Asian neighbors (Kathuria, 2018). Besides, the ineffectiveness of the South Asian Association for Regional Cooperation (SAARC) agreement has further dampened intra-regional trade across South Asia (Ashraf et al., 2017). However, resolving these issues would effectively boost intra-regional trade in South Asia which, in turn, could also facilitate the RET phenomena across this region.

Against this backdrop, this paper aims to empirically assess the importance of promoting intra-regional trade in South Asia in respect of facilitating RET within selected South Asian economies namely Bangladesh, India, Pakistan, Sri Lanka, Nepal and Bhutan. This current study contributes to the relevant literature in fourfold. Firstly, this is the seminal contribution that attempts to empirically explore the regional trade-RET nexus in the South Asian context. The previous studies have primarily focused on the overall impacts of international trade on RE consumption in South Asia (Murshed, 2018). However, since the intra-regional trade baskets of the South Asian economies are likely to include renewable electricity, the intra-regional trade shares are hypothesized to be a relatively more relevant proxy of international trade compared to using the overall openness index to trade to assess the trade-RE consumption nexus. Besides, some of the previous studies tried to qualitatively examine this relationship (McBennett et al., 2019; Alam et al., 2019); however, none have attempted to empirically analyze this relationship. Secondly, since the objective of this paper is to predict the impacts of intra-regional trade on the RET phenomenon, this study uses the Renewable Energy Shares (RES) and the Renewable Electricity Output Shares (REOS) to proxy for RET across South Asia. The preceding studies have emphasized the impacts of international trade on the absolute volumes of RE consumption in South Asia. However, simply increasing the RE consumption volumes is not sufficient to understand the RET phenomenon. Rather, increasing the RE consumption shares in the total final energy consumption levels is more important since a rise in the RES is analogues to a decline in the dependency on fossil fuels.

Thirdly, this paper employs the Augmented Mean Group (AMG) panel data regression approach of Bond and Eberhardt (2013) to ascertain the long-run elasticities. As opposed to the conventionally used methods that are robust to handling cross-sectionally dependent panel data sets, the AMG estimator alongside addressing the issues of cross-sectional dependence also accounts for the slope heterogeneity issues. The existing studies have popularly used regression methods that do not accommodate the slope heterogeneity problems within the estimation process (Omri and Nguyen, 2014; Zeren and Akkuş, 2020). Thus, the findings in these existing studies are likely to be inefficient and biased. Hence, this current study addresses this gap in the literature by using the AMG estimator in the South Asian context. Finally, this current study further contributes to the literature by probing into the non-linear association between international trade and RE consumption. The non-linearity of the trade-RE consumption nexus has been overlooked in the existing literature which has considered a linear model instead (Dogan and Seker, 2016). However, addressing this non-linear relationship is critically important from the understanding that lower levels of intra-regional trade may not be efficient in facilitating the RET phenomenon due to the predominantly fossil fuel-dependencies of the South Asian economies. However, persistently enhancing the intra-regional trade integration can be anticipated ease-out the fossil fuel-dependency to trigger RET across South Asia.

The following questions are specifically addressed in this paper:

1. Does higher regional integration facilitate RET in South Asia?
2. Is the intra-regional trade-RET nexus non-linear?

The remainder of the paper is arranged as follows. Section 2 reviews the relevant literature that has probed into the relationship between international trade and renewable energy consumption. The econometric model and the attributes of the data set considered in this paper are provided in Section 3. The methodology is outlined in Section 4 while section reports and interprets the findings from the econometric analyses. Finally, Section 6 concludes with key policy implications.

2. Literature review

This section is divided into two sub-sections in which the former outlines the theoretical framework concerning the impacts of intra-regional trade and other macroeconomic aggregates on RE use while the latter reviews the relevant literature in this regard.

2.1. Theoretical framework

The linkage between international trade and RET can be understood from the theoretical underpinnings postulated by Heckscher (1919) and Ohlin (1933) which suggested that a country is better off being a net-importer of commodities in which it has a comparative disadvantage in producing them. Linking this to the intra-regional trade and the RET phenomenon, it can be said that regional trade integration among the South Asian economies can be a medium to promote cross-border energy trade among themselves. Most of the South Asian economies are technologically unequipped to integrate renewable energy into their respective energy systems (Murshed, 2020c). Besides, these economies are also constrained in terms of the scarcity of natural endowments that are needed to generate electricity using renewable resources. For instance, the flat geographic terrain of Bangladesh makes it difficult for the nation to generate electricity from hydropower (Murshed and Dao, 2020). In contrast, Nepal and Bhutan are thought to have a comparative advantage over most of the other South Asian economies in this regard. Consequently, these nations meet a lion's share of their local energy demand using locally generated hydroelectricity. Hence, as per the theoretical framework under the Heckscher–Ohlin model of international trade, Nepal and Bhutan are likely to be net-exporters of hydropower while the other South Asian economies can be expected to be net-importers. Thus, promoting intra-regional trade within South Asia can be hypothesized to trigger RET across this region.

Apart from intra-regional trade, RE consumption depends on a variety of other macroeconomic factors including financial globalization, economic growth, energy prices and environmental pollution. As far as financial globalization is concerned, it is hypothesized that attracting FDI can lead to technological spillovers necessary for relieving the technological constraints inhibiting the RET within the developing (Liu et al., 2016). On the other hand, since it is relatively difficult for the developing economies to undergo RET, it is vital for these economies to enhance their growth rates to become economically empowered enough to overcome RET-restraining factors further. Besides, high-income nations are often believed to undergo RET at a faster rate compared to low-income nations (Chang et al., 2009). Moreover, exogenous shocks to energy prices are also said to induce a substitution effect whereby consumption of a particular energy resource can be expected to be replaced by a relatively cheaper alternative. In this regard, positive shocks to oil prices can trigger the RET phenomenon, especially across the net oil-importing South Asian economies (Murshed and Tanha, 2020). Finally, RET can also be motivated by the exacerbation of environmental quality. Since enhancing RE consumption is often acknowledged to reduce Carbon dioxide (CO_2) emissions (Dong et al., 2018, 2020), a surge in such greenhouse gas emissions is likely to motivate greater use of RE while simultaneously reducing non-renewable energy.

2.1.1. The literature on regional trade and RET

Several preceding studies have used qualitative methods to analyze the potential channels through which regional trade integration can foster intra-regional energy trade across South Asia (Dhungel, 2008; Rahman et al., 2011). In a paper by Srivastava and Misra (2007), the authors reviewed the historical developments and the ongoing efforts concerning regional energy cooperation among Bangladesh, Bhutan, India and Nepal under the South Asia Subregion for Economic Cooperation (SASEC). The authors also recommended some interventions that can be useful in enhancing the efficiency of the SASEC to promote cross-border energy trade among these four South Asian countries. Using a similar approach, Singh (2013) highlighted the opportunities for boosting regional energy cooperation in South Asia. The author claimed that it is impossible for the South Asian nations to meet their energy demands using their respective energy supplies unless there is cooperation among the neighbors to develop the energy sectors in South Asia. Singh (2013) asserted that intra-regional import of hydropower by India could be a win-win scenario for both the exporting and importing South Asian economies in respect of mitigating their energy crises. In addition, this paper also recommended some future energy cooperation initiatives that can be undertaken to boost intra-regional power trade in South Asia. On the other hand, Huda and McDonald (2016) described the political challenges concerning regional energy cooperation through the implementation of pipelines and electricity grids across South Asia. The authors also attempted to explain the channels of energy cooperation in South Asia in light of the theoretical frameworks of international cooperation. Besides, the geopolitical barriers impeding intra-regional energy trade in South Asia were also put forward from a political economics perspective.

In a recent report by McBennett et al. (2019), the authors reviewed the opportunities for enhancing hydropower trade between Nepal and India. Also, the potential channels through which energy cooperation by Nepal can curb the energy deficiency in Bangladesh was put forward. Besides, regional energy trade arrangements like the Bangladesh–Bhutan–India–Nepal (BBIN) energy dialogs and the India–Sri Lanka–Sampur Thermal Power Project were discussed in the study by Paul (2020). In another study, Ogino et al. (2019) commented on the surplus supply of hydropower in Bhutan. The authors also highlighted the nation's comparative advantage, over the other South Asian economies, in hydroelectricity generation to explain how Bhutan has emerged as a net-exporter of hydropower within South Asia. Apart from elevating the renewable energy consumption levels only, Alam et al. (2019) showed that regional trade of non-renewable energy, particularly oil, gas and coal, can also be efficient in mitigating the prevalent energy shortages faced by the South Asian nations. Moreover, the prospects of energy trading within South Asia through the execution of the Bhutan–India additional grid enhancement project, the construction of the India–Nepal 400 kilovolts transmission link, the proposed India–Sri Lanka high-voltage electricity transmission project, the Bangladesh–India high voltage direct electricity transmission project, the India–Pakistan 220 and 400 kilovolts transmission link construction project and the India–Pakistan 400 kilovolts and CASA 1000 transmission links projects were evaluated in the study by Wijayatunga et al. (2015).

Among the relevant studies that have explored the regional trade-RET in the context of other regions, Nangia (2019) stressed on encouraging greater regional trade integration for safeguarding energy security in Asia. The authors asserted that due to the Asian energy markets being largely fragmented, the cross-border transmission of energy, particularly through intra-regional energy trade, could be effective in enhancing the Asian regional grid-connectivity. Similarly, Zaman and Kalirajan (2019) predicted that regional trade integration among the South, East and Southeast Asian countries can account for up to 41.6% of primary energy trade. Besides, it can also boost renewable energy trade by 34.6%. In another study by Shi et al. (2019), the authors recommended regional trade integration among the Association of Southeast Asian Nations (ASEAN) states for enhancing power connectivity. Besides, the authors also pointed out the possibility of regional integration among the ASEAN members and the BBIN countries which could be ideal in enhancing energy trade across Asia and the Pacific. Saadi et al. (2015) analyzed the regional renewable energy trading prospects, under the Africa Clean Energy Corridor (ACEC), between the African economies. Moreover, Patt et al. (2011) asserted that regional integration among the European counties is key to achieving the 2050 agenda of generating 100% of total electricity outputs from renewable energy resources. Likewise, Gulagi et al. (2017) revealed the channels through which Australia, through regional renewable energy trade, can power the energy-deficient Asian economies. Therefore, once again it is evident that promoting regional integration has been acknowledged in the literature to play critically important roles in facilitating RET within the integrated economies. Thus, it is pertinent to empirically explore this relationship to comment on the validity of the preceding qualitative assessments.

Although empirical studies are yet to document the intra-regional trade-RET nexus, several existing studies did attempt to explore the relationship between international trade openness and RE consumption nexus. Using a linear system Generalized Method of Moments (GMM) model for 64 low-, middle- and high-income nations, Omri and Nguyen (2014) found higher openness to trade to increase the RE consumption growth rates. Furthermore, the authors argued that the positive impacts of international trade on RE consumption are comparatively higher for low-income countries. On the other hand, enhancing participation in international trade was found to be ineffective in influencing the RE consumption growth rates of the high-income countries. Zeren and Akkuş (2020) employed the Common Correlated Effects Mean Group (CCEMG) model to handle cross-sectional dependent data concerning 15 emerging economies including India. The results indicated that higher openness to trade resulted in lower RE consumption levels while enhancing the non-renewable energy consumption levels. In another study on 43 developed and developing nations, Uzar (2020) considered the Pooled Mean Group (PMG) model to ascertain the short- and long-run impacts of international trade on the RE consumption levels. The findings revealed that although enhancing openness to international trade in the short-run increases RE consumption levels, it does not affect the RE consumption levels in the long-run. Similarly, Alam and Murad (2020) used the PMG, Mean Group (MG) and Dynamic Fixed Effects (DFE) models to evaluate the short- and long-run determinants of RE consumption in 25 Organization for Economic Cooperation and Development (OECD) nations. The findings certified that enhancing trade openness reduced RE consumption levels in the short-run. However, in the long-run, a positive relationship between trade openness and RE consumption was ascertained. Hence, it is evident that the impacts of international trade on RE consumption are uncertain.

2.1.2. The literature on FDI inflows and RET

FDI is referred to as a stimulant of economic development for the underdeveloped nations. FDI induce technological spillover within the host economies which, in turn, can be linked to the RET phenomenon (Doytch, 2020). Among the existing studies that have focused on the FDI inflow–RE consumption nexus, Doytch and Narayan (2016) ascertained the impacts of FDI inflows on RE consumption across 74 global economies. The authors used the system GMM model to tackle endogeneity issues and found higher FDI inflows to increase the industrial levels of RE use while simultaneously decreasing non-renewable energy use. The authors argued that FDI inflows lead to technological innovation which is imperative in triggering RET across the host economies. In another study on 31 Chinese provinces, Fan and Hao (2020) employed a Vector Error–Correction Model (VECM) and found per capita FDI inflows to be effective in boosting the per capita RE consumption levels in the long-run but not in the short-run. Besides, the results from the Granger causality analysis revealed evidence of unidirectional causality running from RE consumption to FDI inflows. The positive impacts of FDI inflows on the RE consumption levels were also highlighted in the studies by Paramati et al. (2016) and Kutan et al. (2018) for emerging market economies. In contrast, some studies have also documented the evidences regarding FDI inflows dampening the RE consumption levels of the host nations. Employing a panel fixed effects with Driscoll-Kraay standard errors model to control for cross-sectional dependence, Anton and Nucu (2020) found that a rise in the FDI inflows within 28 European Union members led to a decline in the RE consumption levels. On the other hand, Murshed et al. (2020a) used the Panel Corrected Standard Errors (PCSE) model and found FDI inflows to be ineffective in explaining the variations in the RE consumption levels and RES in Bangladesh, India, Pakistan and Sri Lanka. Therefore, it can be said that the impacts of FDI inflows on RE use are uncertain.

2.1.3. The literature on economic growth and RET

According to the International Energy Association, economic growth rate is a major determinant of energy demand (IEA, 2006). Hence, it is imperative to control for economic growth when modeling the RE demand. The nexus between economic growth and RE consumption can be evaluated in terms of four hypotheses. Firstly, the *growth hypothesis* refers to RE use contributing to economic growth. Secondly, the *conservative hypothesis* refers to economic growth affecting the RE consumption levels. Thirdly, the *feedback hypothesis* claims economic growth and RE consumption to be interdependent. Finally, the *neutrality hypothesis* states no relationship between economic growth and RE consumption levels. The preceding studies have mainly evaluated the economic growth–RE consumption nexus in respect of these four hypotheses. In a recent study on 21 African nations, Ergun et al. (2019) use fixed and random effects models and found economic growth to reduce the RES. Besides, the authors also found evidence of a bidirectional causal association between these variables to validate the *feedback hypothesis*. In another study on five South Asian economies (Bangladesh, India, Pakistan, Sri Lanka and Nepal), Rahman and Velayutham (2020) used the panel Fully-modified Ordinary Least Squares (FMOLS) and the Dynamic Ordinary Least Squares (DOLS) panel data models and found unidirectional causality stemming from economic growth to per capita RE consumption level. The country-specific results also showed that the *conservative hypothesis* was valid for India, Pakistan, Sri Lanka and Nepal. However, in the context of Bangladesh, the *neutrality hypothesis* was found to be valid since no causal association between these variables could be established. In contrast, the *growth hypothesis* was validated by the statistical evidence of unidirectional causality running from RE consumption to economic growth in the study by Aïssa et al. (2014) for 11 African nations. In another relevant study on 18 emerging market economies including India, Sadorsky (2009a) used the panel FMOLS model and found higher economic growth per capita to lower the RE consumption levels.

2.1.4. The literature on oil prices and RET

Fossil fuels, especially crude oil, and RE resources are often considered as substitutes (Sadorsky, 2009b). Thus, exogenous oil price shocks are expected to induce movements in the RE consumption levels. In a study by Sadorsky (2009b), the author used a Seemingly Unrelated Regression (SUR), FMOLS and DOLS models for the Group of Seven (G7) countries and found higher oil prices to reduce the long-run RE consumption levels of German and Italy. Conversely, for Canada, Japan, the United Kingdom, the United States and the G7 panel, higher oil prices were found to reduce the long-run RE consumption levels. Besides, in the short-run, higher oil prices were seen to increase the REC levels of France while reducing the RE consumption levels in Japan and the United Kingdom. Similarly, Omri and Nguyen (2014) used the system GMM model to evaluate the oil price–RE use nexus in the context of 26 high-income, 26 middle-income and 12 low-income countries. The authors found that a growth in the real price of oil reduces the growth rate of RE consumption for the whole panel as well as for the middle-income countries panel. However, no statistically significant impact of oil price on RE use was ascertained. Although most of the existing studies have looked into the linear impacts of oil price shocks on RE consumption, Murshed and Tanha (2020) recently explored the non-linear relationship between these variables. The authors found that since the large South Asian economies are overwhelmingly dependent on fossil fuels, positive shocks to oil prices initially are not effective in triggering the RET phenomenon. However, a persistent rise in oil prices eventually inflicts a substitution effect to facilitate RET in South Asia.

2.1.5. The literature on CO_2 emissions and RET

Since RE resources are environmentally-friendly, enhancing the consumption of renewables has been acknowledged in the literature to mitigate CO_2 emissions (Shafiei and Salim, 2014; Dong et al., 2020). However, several studies have also highlighted the impacts of CO_2 emissions on the RE consumption levels. Sharif et al. (2019) used FMOLS and DOLS models and found statistical evidence of a bidirectional causal association between RES and per capita CO_2 emissions in the context of a panel of 72 global economies. The authors asserted although enhancing the RE consumption levels is necessary for abating CO_2 emissions, higher emissions of CO_2 can also help to the mitigate CO_2 emissions for ensuring environmental welfare. In another study on five North African nations, Jebli and Youssef (2017) also employed the FMOLS and DOLS models and found unidirectional causality running from CO_2 emissions to RE consumption in the long-run. On the other hand, Murshed (2020c) used Two-Stages Least Squares-Instrumental Variable (2SLS-IV) model to evaluate the impacts of CO_2 emissions on the RE consumption levels and RES of 71 middle- and low-income nations. The results confirmed that rising levels of per capita CO_2 emissions reduced both the RE consumption levels and RES. Similarly, the CO_2 emission-inhibiting impacts of RE use in the South Asian context have also been documented in the literature (Murshed et al., 2020c). Besides, the results were found to be homogeneous for both the middle-income and low-income panels. Attiaoui et al. (2017) used the PMG model and found higher levels of CO_2 emissions to increase the short-run RE consumption levels and decrease the long-run RE consumption levels in selected African nations.

Hence, based on the review of the aforementioned studies, several gaps in the literature can be identified. First, it is evident that many preceding studies have used qualitative methods to explain the expected benefits of enhancing intra-regional energy trade with regards to facilitating the RET phenomenon in South Asia. However, there is no single study that has attempted to use quantitative methods to empirically examine the intra-regional trade-RET nexus in the South Asian context. Besides, as opposed to the previous studies that have primarily explored the overall impacts of international trade on the RET phenomenon in South Asia (Murshed, 2018), this is a seminal study that evaluates the specific effects on intra-regional trade integration on RET in South Asia. It is expected that the findings from the analysis can motivate the policymakers in adopting relevant strategies that can boost regional trade of renewable energy in South Asia which, in turn, can assist in ensuring energy sustainability across this region. Second, the empirical models like fixed effects, random effects, GMM, MG, CCEMG, VECM, PCSE, FMOLS, DOLS, SUR and 2SLS-IV used in the preceding relevant studies have controlled for cross-sectional dependence in the data. However, these models have largely overlooked the slope heterogeneity concerns whereby the findings from the associated studies can be expected to be biased. Hence, this current study attempts to resolve this methodological issue by using the AMG estimator which is robust to handling cross-sectionally dependent and heterogeneous panel data sets. Third, the majority of the existing studies have modeled RET using linear model specifications. However, this current study also checks the robustness of the findings using non-linear model specifications. It is pertinent to assess the possible non-linearity of the relationships between the variables for key policy implications.

3. Econometric model and data

The impacts of regional trade integration on the RET phenomenon across South Asia are modeled using both linear and non-linear model specifications. Firstly, the linear model can be specified as:

$$RES_{it} = \partial_0 + \partial_1 IRT_{it} + \partial_2 FDI_{it} + \partial_3 \left(IRT * FDI\right)_{it} + \partial_4 lnRGDP_{PC_{it}} + \partial_5 lnOIL_{it} + \partial_6 lnCO2_{PC_{it}} + \varepsilon_{it} \quad (1)$$

where i and t refer to the individual South Asian country (cross-section) and the time period, respectively. ε_{it} is the error-term. The parameters ∂_0 and $\partial_i (i = 1, \ldots, 6)$ are the intercept and the elasticities to be estimated. The dependent variable *RES* abbreviates for the percentage shares of RE in the total final energy consumption level for the respective South Asian nations. The RES are used to proxy the RET phenomenon since a rise in this share, which is synonymous with a decline in the share of non-renewable energy in the total energy consumption figure, can be interpreted as a transition from the use of non-renewable energy to the consumption of RE alternatives (Murshed, 2018). The principal regressor of interest, as denoted by *IRT*, stands for the intra-regional trade shares (in percentage) of each South Asian economy in their respective total international trade figures. The intra-regional trade shares proxy for the degrees of regional trade integration of the selected South Asian nations. Higher intra-regional trade shares imply greater integration in regional trade and vice-versa.

Besides, the econometric model is controlled for the FDI inflows into South Asia. The variable *FDI* abbreviates for the percentage shares of net FDI inflows in the Gross Domestic Product (GDP) of the respective countries. The justification of its inclusion into the model is based on the understanding that FDI inflows can be expected to stimulate technological spillovers and energy-infrastructural development that are necessary for the adoption of RE generation technologies in South Asia (Murshed, 2020d; Doytch and Narayan, 2016). Although the direct impacts of intra-regional trade on the RET phenomenon are assessed from the sign of the elasticity parameter attached to *IRT*, it is also pertinent to evaluate the indirect channels as well. Thus, an interaction term between intra-regional trade shares and net FDI inflow shares, denoted by (*IRT**FDI*) is augmented into the model. The sign of the elasticity parameter attached to the interaction term would depict a joint impact of these variables on the RES.

The econometric model also controls for the per capita national income levels of the South Asian economies which are used to proxy for the level of economic growth of the respective nations. The variable $lnRGDP_{PC}$ refers to the natural logarithm of real GDP per capita measured in constant 2010 United States dollars. It is important to control for economic growth since higher national income levels can be expected to advance the underdeveloped energy infrastructure of the South Asian nations. This, in turn, can be expected to facilitate the RET phenomenon in South Asia (Ackah and Kizys, 2015). Besides, the cross-price elasticity of RE demand is examined by augmenting the real crude oil prices into the model. The variable *lnOIL* stands for the natural logarithm of the real crude oil prices measured in constant 2016 United States dollars per barrel. Since RE resources can be considered as substitutes for fossil fuels, the changes in the RES in response to exogenous oil price shocks can be presumed to provide an understanding of this cross-price elasticity of RE demand in South Asia. Several studies have used crude oil prices in estimating the RE demand (Murshed, 2020a; Brini et al., 2017). Finally, the model is controlled for the per capita CO_2 emissions. The variable $lnCO2_{PC}$ abbreviates for the natural logarithm of the CO_2 emissions measured in metric tonnes per capita. The justification of considering CO_2 emissions as a determinant of the RES is derived from the understanding that rising CO_2 levels are likely to induce environmental apprehensions. Consequently, there could be a tendency to phase-out the dependence on non-renewable energy resources and integrate RE into the national energy-mixes of the South Asian nations (Sadorsky, 2009b).

To account for the possible non-linearity of the intra-regional trade-RET nexus, model (1) is re-estimated using a non-linear model specification which can be shown as:

$$RES_{it} = \alpha_0 + \alpha_1 IRT_{it} + \alpha_2 (ITR^\wedge 2)_{it} + \alpha_3 FDI_{it} + \alpha_4 \left(IRT * FDI\right)_{it} + \alpha_5 lnRGDP_{PC_{it}} + \alpha_6 lnOIL_{it} + \alpha_7 (lnOIL^\wedge 2)_{it} + \alpha_8 lnCO2_{PC_{it}} + \varepsilon_{it} \quad (2)$$

where *IRT^2* is the squared term of the intra-regional trade shares of the South Asian economies. The inclusion of the squared term is rationalized in the sense that despite having immense prospects of boosting intra-regional trade, the South Asian economies have failed to strengthen their degrees of regional trade integration. Consequently, intra-regional trade accounts for a significantly small percentage of the total international trade in South Asia. Similar trends are also evident in the context of the intra-regional energy trade patterns. Hence, it can be presumed that initially, a rise in the intra-regional trade shares may not be effective in elevating the RES. However, with time, if the intra-regional trade shares persistently go up, provided the associated constraints are overcome, it can be anticipated to boost the cross-border RE flows. As a result, the higher degrees of intra-regional trade integration is likely to facilitate the RET phenomenon in South Asia. In this regard, addressing the non-linearity of the intra-regional trade shares-RES nexus is critically important in the South Asian context.

Besides, the possible non-linear nexus between crude oil prices and RES is scrutinized by augmenting the squared term of the real crude oil prices (*lnOIL^2*). The majority of the large South Asian economies have traditionally showcased their monotonic dependency on crude oil imports for electricity generation purposes (Murshed, 2020a). Thus, a small rise in the international price of crude oil may not be sufficient in inducing the substitution of the non-renewable energy resources by the RE alternatives. However, if the crude oil prices go on to rise substantially, the crude-oil dependency can be expected to subside. Consequently, the RET phenomenon can be expected to be triggered within the South Asian nations.

For the robustness check of the findings, the models are re-estimated using an alternative proxy for the RET phenomenon. Hence, the REOS are used instead of the RES. The variable *REOS* refers to the percentage shares of renewable electricity in the total electricity outputs of the respective South Asian economies. The REOS can be expected to be influenced by higher degrees of intra-regional trade openness in the sense that it could be used to import the raw materials and technology that are pertinent in generating power from renewable sources (Nuclear Asia, 2019, February 05). In contrast, inappropriate tariff policies to impede the cross-border trade of these could hurt the RET phenomenon by dampening the renewable electricity output shares ((Parvez and Adhikary, 2017), June 06). Moreover, higher REOS can also be interpreted as a transition from the use of the non-renewable fossil fuels to the utilization of renewable resources for electricity generation purposes in South Asia; thus, portraying the RET phenomenon from the perspective of the secondary energy resources. The corresponding models can be specified as:

$$REOS_{it} = \beta_0 + \beta_1 IRT_{it} + \beta_2 FDI_{it} + \beta_3 \left(IRT * FDI\right)_{it} + \beta_4 lnRGDP_{PC_{it}}$$

$$+ \beta_5 lnOIL_{it} + \beta_6 lnCO2_{PC_{it}} + \varepsilon_{it} \quad (3)$$

$$REOS_{it} = \delta_0 + \delta_1 IRT_{it} + \delta_2 (ITR^{\wedge}2)_{it} + \delta_3 FDI_{it} + \delta_4 (IRT * FDI)_{it} + \delta_5 lnRGDP_{PC_{it}} + \delta_6 lnOIL_{it} + \delta_7 (lnOIL^{\wedge}2)_{it} + \delta_8 lnCO2_{PC_{it}} + \varepsilon_{it} \quad (4)$$

Annual frequency data spanning over 1992 and 2018 is used to perform the econometric analyses. The data for the intra-regional trade shares have been retrieved from the Asia Regional Integration Center database of the Asian Development Bank (ADB, 2020). The crude oil price data is compiled from the British Petroleum's Statistical Review of World Energy (British Petroleum, 2019). The other variables have been sourced from the World Bank's World Development Indicators database (World Bank, 2019b).

4. Econometric methodology

The econometric analysis starts by checking for the cross-sectional dependence and slope heterogeneity issues. According to the results obtained, the appropriate unit root, cointegration, regression and causality estimation methods are chosen.

4.1. The cross-sectional dependency analysis

Before proceeding with the estimations, it is pertinent to evaluate whether the cross-sectional units (countries) within the panel data set are independent or not. In the case of the cross-sectional units being dependent, the Cross-sectional Dependency (CD) issues emerge (Liu et al., 2021; Nathaniel et al., 2021). A simple example of CD in a panel data set can be shown in terms of a case in which a shock in a particular macroeconomic data of one of the countries tends to influence the same macroeconomic data of the remaining countries (Munir et al., 2020). Under such circumstances, the appropriate choice of the econometric methods requires the capacity to account for the CD issues. Overlooking CD leads to the estimation of spurious elasticity estimates (Behera and Mishra, 2020). In this regard, the panel data CD method introduced by Pesaran (2004) is employed. This technique is robust in handling CD issues in data sets comprising of finite cross-sectional and time dimensions. The estimates of the test statistics under the Pesaran (2004) CD test are reported in Table 1. The statistical significance of the test statistics, for all the four models, rejects the null hypothesis of cross-sectional independence to affirm the existence of CD issues in the data.

4.2. The slope homogeneity analysis

Similar to the CD issues, it is also important to assess the slope homogeneity concerns within the data set. The presence of heterogeneous slope coefficients across the cross-sectional units results in the elasticity estimates being biased (Li et al., 2021). Hence, the slope Pesaran and Yamagata (2008) slope homogeneity test is applied in this paper. This method involves the estimation of two test statistics (Δ and Δ_{adj}) that are used to comment on whether the slope-coefficients are homogeneously or heterogeneously distributed across the cross-sectional units. The statistical significance of the estimated test statistics, as presented in Table 2, reject the null hypothesis of slope homogeneity to confirm the slope heterogeneity concerns in the data set.

Following the confirmation of the CD and slope heterogeneity problems in the data set, the use of the first-generation panel data unit root and cointegration techniques is no longer appropriate. Thus, the second-generation alternative methods, that are robust to accounting for these problems, are considered.

4.3. The second-generation panel unit root analysis

Identification of the order of integration among the variables augmented into the empirical models is critically important to design the regression and causality estimation approaches. This is because the non-stationarity of the variables compromises the authenticity of the regression results since the elasticity estimates are likely to be spurious (Nathaniel et al., 2019). Besides, the choice of the appropriate regression estimator is said to be conditional on the order of integration among the variables of concern. The conventionally used first-generation panel data unit root estimation methods proposed by Levin et al. (2002) and Im et al. (2003) are unable to account for the CD issues. Hence, the Smith et al. (2004) second-generation panel unit root method is used to ascertain the order of integration among the variables. The Smith et al. (2004) approach is superior to the first-generation methods since it involves a sieve sampling procedure to account for both cross-sectional and time-series dependencies in the data using a bootstrap block (Paramati et al., 2018). A total of five test statistics, $\Psi_{\text{t-bar}}$, Ψ_{Max}, Ψ_{LM}, Ψ_{Min} and Ψ_{WS}, are predicted under the null hypothesis of the presence of heterogeneous autoregressive root (non-stationarity) against the alternative hypothesis of stationarity. The unit root analysis is followed by the panel cointegration analysis.

4.4. The second-generation panel cointegration analysis

The presence of cointegrating equations within a model implies long-run associations between the outcome variable and the regressors (Murshed and Tanha, 2020). Hence, it is pertinent to evaluate the cointegrating relationships before estimating the long-run elasticities (Pedroni, 2001). The first-generation cointegration methods, such as the Pedroni (1999) residual-based test, are inappropriate in the context of this study due to these methods not accounting for CD issues (Murshed et al., 2021). Hence, this paper employs the second-generation panel cointegration approach proposed by Westerlund (2007) which is efficient in handling the CD issues in the data. This method corrects for the CD using a bootstrapped technique and predicts two group-mean, G_t and G_a, and two panel test statistics, P_t and P_a. The statistical significance of these test statistics rejects the null hypothesis of no cointegration to affirm the existence of cointegrating relationships among the variables. The test statistics are derived from an error–correction model which can generally be expressed as:

$$\Delta y_{it} = \delta_i' d_t + \rho_i \left(y_{i,t-1} - \partial_i' x_{i,t-1} \right) + \sum_{j=1}^{\mu_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{-q_i}^{\mu_i} \gamma_{ij} \Delta x_{i,t-j} + e_{it} \quad (5)$$

where d_t symbolizes the deterministic components while the parameters p_i and q_i denote the lag lengths and lead orders, respectively. The lags and lead orders are allowed to change across the different cross-sectional units. The four test statistics can be expressed as:

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{\widehat{\alpha_i}}{SE(\hat{\alpha}_i)} \quad (6)$$

$$G_a = \frac{1}{N} \sum_{i=1}^{N} \frac{T\widehat{\alpha_i}}{\hat{\alpha}_i(1)} \quad (7)$$

$$P_t = \frac{\widehat{\alpha_i}}{SE(\hat{\alpha}_i)} \quad (8)$$

Table 1
The cross-sectional dependency results.

	Model (1)		Model (2)		Model (3)		Model (4)	
	Statistic	*p*-value	Statistic	*p*-value	Statistic	*p*-value	Statistic	*p*-value
Pesaran (2004) CD stat.	3.881*	0.000	3.626*	0.000	3.912*	0.000	5.190*	0.000

*Indicates statistical significance at 1% level.

Table 2
The cross-sectional dependency results.

	Model (1)		Model (2)		Model (3)		Model (4)	
	Statistic	*p*-value	Statistic	*p*-value	Statistic	*p*-value	Statistic	*p*-value
$\tilde{\Delta}$	19.132*	0.000	19.102*	0.000	12.012*	0.000	12.121*	0.000
$\tilde{\Delta}_{adj}$	19.338*	0.000	19.211*	0.000	12.302*	0.000	12.412*	0.000

*Indicates statistical significance at 1% level.

Table 3
The Smith et al. (2004) bootstrap panel unit root test results.

	Not considering trend					Considering trend				
Level, I(0)	ψ_{t-bar}	ψ_{Max}	ψ_{LM}	ψ_{Min}	ψ_{WS}	ψ_{t-bar}	ψ_{Max}	ψ_{LM}	ψ_{Min}	ψ_{WS}
RES	−1.239	−0.344	1.334	0.466	−0.601	−1.883	−1.799	3.310	3.511	−1.995
REOS	−0.888	−0.910	1.121	1.380	−1.109	−1.790	−1.810	2.991	2.829	−1.701
IRT	−1.443	−0.236	1.178	0.663	−0.650	−1.773	−1.812	3.123	3.212	−2.103
FDI	−1.120	−1.140	1.300	2.489	−1.550	−1.700	−1.720	2.901	3.010	−1.482
$lnRGDP_{PC}$	−0.718	−0.884	1.010	1.129	−1.054	−1.889	−1.719	2.865	2.978	−1.680
lnOIL	−1.312	−0.626	1.012	0.451	−0.712	−1.656	−1.613	3.021	3.121	−2.212
$lnCO2_{PC}$	−1.221	−1.240	1.410	4.489	−1.120	−1.880	−1.920	3.191	3.314	−1.782
1st Diff., I(1)	ψ_{t-bar}	ψ_{Max}	ψ_{LM}	ψ_{Min}	ψ_{WS}	ψ_{t-bar}	ψ_{Max}	ψ_{LM}	ψ_{Min}	ψ_{WS}
ΔRES	−5.777*	−6.010*	16.221*	16.302*	−5.601*	−5.890*	−5.414*	17.419*	17.212*	−5.450*
ΔREOS	−3.989*	−3.780*	12.131*	12.334*	−5.010*	−6.102*	−6.332*	18.324*	18.411*	−5.813*
ΔIRT	−5.835*	−6.121*	15.989*	16.102*	−5.334*	−5.799*	−5.501*	17.587*	17.320*	−5.510*
ΔFDI	−5.600*	−5.591*	15.992*	16.310*	−5.001*	−6.310*	−6.401*	17.331*	17.412*	−6.910*
Δ $lnRGDP_{PC}$	−4.121*	−3.998*	12.221*	12.290*	−5.212*	−5.990*	−6.132*	−6.223*	18.120*	−5.790*
Δ lnOIL	−5.665*	−6.021*	16.012*	16.221*	−5.214*	−5.566*	−5.319*	17.001*	17.121*	−5.410*
Δ $lnCO2_{PC}$	−5.510*	−5.501*	15.782*	16.332*	−5.219*	−6.511*	−6.671*	17.515*	17.918*	−7.110*

Notes: Δ denotes first difference; The test statistics are estimated under the null hypothesis of a non-stationarity in all the cross-sections against the alternative hypothesis of stationarity in at least one cross-section; The *p*-values are predicted using 20,000 bootstrap replications with a block size equal to 30; The optimal lag selection is based on AIC.
*Denotes statistical significance at 1% level.

$$P_a = T\hat{\alpha} \tag{9}$$

Statistical evidence of cointegrating associations between the variables fulfills the pre-requisite to performing the regression analysis.

4.5. The panel regression analysis

The fixed effects, random effects, system GMM, MG, CCEMG, PCSE, FMOLS and DOLS models are widely used in the literature. However, these methods are not applied in this current study due to the following reasons: (1) The fixed effects, random effects, system GMM, FMOLS and DOLS models do not account for CD issues despite addressing the endogeneity concerns; (2) The system GMM estimator is appropriate only when the number of cross-sections is larger than the time dimension of the study which is opposite to the case of the overall dimension of the data set used in this paper; (3) The MG, CCEMG and PCSE models account for the CD issues but are unable to accommodate the slope heterogeneity concerns. Hence, considering the aforementioned limitations of the conventionally used models, the AMG model introduced by Bond and Eberhardt (2013) is chosen to ascertain the long-run elasticities. This method simultaneously accounts for the CD and slope heterogeneity concerns in the data set (Bond and Eberhardt, 2013). Besides, the choice of the AMG technique is justified from the sense that elasticity estimation using regression estimators that are unable to simultaneously handle CD and slope heterogeneity problems generates biased outcomes due to model misspecification errors (Levin et al., 2002).

This AMG technique corrects for the slope heterogeneity issues by permitting the slope coefficients to vary across the individual cross-sectional units (Damette and Marques, 2019). This estimator is a cross-sectionally augmented modified MG estimator of Pesaran and Smith (1995). The MG estimator can be specified as:

$$\hat{\beta}_{MG} = N^{-1}\sum_{i=1}^{N}\hat{\beta}_i \tag{10}$$

where $\hat{\beta}_{MG}$ is the mean of the individual slope estimator from the respective cross-sectional unit. However, this technique, although controlling for the CD issues, fails to accommodate the slope heterogeneity issues within the estimation process. To counter this limitation, the AMG estimator first integrates both the unobserved identical factors and the time-fixed dummy variables into the model before estimating the individual slope coefficients for the corresponding cross-sectional unit and then averages them. Besides, the time-variant unobserved common factors are claimed to exhibit a dynamic process through which both the CD and the slope heterogeneity issues can be accounted for in tandem. Similar to the specification of the MG estimator shown in Eq. (10), the AMG estimator can be specified as:

$$\hat{\beta}_{AMG} = N^{-1}\sum_{i=1}^{N}\hat{\beta}_i \tag{11}$$

where $\hat{\beta}_{AMG}$ is also the mean of the individual slope estimates from the respective cross-sectional unit. The dissimilarity between the MG estimator specified in Eq. (10) and the AMG estimator in Eq. (11) is in terms of the fact that the AMG estimator averages the individual slope coefficients by integrating the common factors across the individual cross-sectional units into the model. As part of the sensitivity analysis, the group-mean DOLS estimator of Pedroni (1999) is also used for the regression analysis.

Although the regression analysis predicts the long-run conditional marginal impacts of the explanatory variables on the outcome variable, it inherently condemns the possibility of marginal impacts of the outcome variable on the explanatory variable of concern. Hence, it is pertinent to conduct the causality analysis to unearth the potential reverse causations between these variables.

4.6. The panel causality analysis

A major limitation of the conventionally used Granger (1969) causality estimation technique is its failure to account for the slope heterogeneity concerns in the data set. To overcome this shortcoming, Dumitrescu and Hurlin (2012) recently introduced a bootstrapped method that predicts the causal nexus between a pair of variables. The Dumitrescu and Hurlin (2012) method relaxes the Granger (1969) approach's inappropriate assumption of slope homogeneity across the cross-sectional units. In contrast, the Dumitrescu and Hurlin (2012) technique estimates a z-bar statistic by allowing the slope coefficients to vary. This average Wald test statistic is predicted under the null hypothesis of non-causality between a pair of stationary variables as opposed to an alternative hypothesis of the presence of a causal association between those variables in at least one of the cross-sectional units. The mean Wald statistic can be shown as:

$$W_{N,T}^{HNC} = \frac{1}{N}\sum_{i=1}^{N} W_{i,T} \quad (12)$$

where $W_{N,T}^{HNC}$ is the average value of the individual Wald statistics $W_{i,t}$. Dumitrescu and Hurlin (2012) state that under the assumption of the individual residuals being independently distributed across all the cross-sectional units and the respective covariances being equal to zero, the mean Wald statistic converges to the equation below in the case of panel data sets with large time and cross-sectional dimensions:

$$Z_{N,T}^{HNC} = \sqrt{\frac{N}{2K}}\left(W_{N,T}^{HNC} - K\right)\overset{d}{\longrightarrow}_{T,N\to\infty} N(0,1) \quad (13)$$

where $Z_{N,T}^{HNC}$ is the z-bar statistic and K symbolizes the optimal lag length. A standardized z-bar statistic ($\overline{Z}_{N,T}^{HNC}$) is then approximately estimated for the average Wald statistic which can be specified as:

$$\overline{Z}_{N,T}^{HNC} = \frac{\sqrt{N}}{\sqrt{Var(\tilde{W}_{i,T})}}\left[W_{N,T}^{HNC} - E\tilde{W}_{i,T}\right] \quad (14)$$

The statistical significance of the z-bar statistic under the Dumitrescu and Hurlin (2012) approach affirms a causality running from the independent to the dependent variable.

5. Results and discussion

The results from the Smith et al. (2004) unit root analysis are reported in Table 3. It is evident from the statistical insignificance of the predicted test statistics that the variables are non-stationary at their levels. In contrast, all the variables become stationary at their first difference. Therefore, a common order of integration, at the first difference I(1), among the variables of concern is affirmed. These findings imply that the variables converge to their mean values. Thus, the stationarity properties of the variables nullify the possibility of estimating spurious elasticity estimates from the regression analysis.

Table 4
The Westerlund (2007) panel cointegration test results.

Test statistic	Model (1)	Model (2)	Model (3)	Model (4)
G_t	−2.615*	−2.220*	−2.819*	−2.888*
G_a	−9.645	−8.185	−10.112	−9.910
P_t	−20.561*	−19.399*	−21.717*	−22.189*
P_a	−12.756*	−12.553*	−13.012*	−13.101*

Notes: The four test statistics are estimated under the null hypothesis of no cointegrating relationships against the alternative hypothesis of cointegrating relationships among the variables; Both trend and intercept are considered; The optimal lag selection is based on the AIC.
*Denotes statistical significance at 1% level.

The long-run relationships between the variables are ascertained from the panel cointegration analysis in the context of all four models. The corresponding results from the Westerlund (2007) analysis are presented in Table 4. The statistical significance of the majority of the test statistics, in the context of all four models, rejects the null hypothesis of non-cointegration to confirm the existence of cointegrating equations in the respective models. Therefore, in line with these findings, it can be claimed that there are long-run associations between intra-regional trade shares, RES, REOS and the other key macroeconomic variables controlled for within the models. The affirmation of these long-run relationships fulfills the pre-requisite to estimating the long-run elasticity estimates.

The long-run elasticities are predicted using the AMG estimator which is robust to accommodating the CD and slope heterogeneity issues in the data set. The corresponding results are reported in Table 5. In the context of the linear model specification (Model 1), it can be seen that intra-regional trade integration adversely impacts the RET phenomenon across South Asia. The negative sign of the statistically significant elasticity parameter attached to *IRT* implies that a percentage rise in the intra-regional trade shares is accompanied by a reduction in the RES by 3.447%, on average, *ceteris paribus*. This implies that initially, trade among the South Asian economies tends to boost the non-renewable energy consumption levels by a relatively greater margin than the corresponding rise in the RE consumption levels in South Asia. This could be because the intra-regional trade has always been low for the majority of the South Asian nations. Hence, a small rise in the intra-regional trade shares may not enough in triggering the RET phenomenon in South Asia. However, this finding resonates with the views put forward in the study by Alam et al. (2019) in which the authors claimed that intra-regional trade in South Asia could possibly induce cross-border trade on non-renewable energy. Consequently, under such circumstances, promoting intra-regional trade may not be effective in stimulating the RET phenomenon in South Asia. Besides, the negative intra-regional trade–RES share can also be compared to the findings of Zeren and Akkuş (2020) where the authors asserted that enhancing international trade in 15 emerging economies was responsible for higher consumption of non-renewable energy and lower consumption of RE energy. As a result, it can be thought that international trade attributed to the reduction in the RES of the emerging economies.

Similar negative impacts on the RES are ascertained in the context of FDI inflows. It is apparent from the negative sign of the elasticity parameter attached to *FDI* that a 1% rise in the shares of FDI in the GDP of the South Asian economies reduces the RES by 0.797%, on average, *ceteris paribus*. Hence, it can be asserted

Table 5
The long-run elasticity estimates from the AMG regression analysis.

Model Specification Dep. Var	(1) Linear *RES*	(2) Non-Linear *RES*	(3) Linear *REOS*	(4) Non-Linear *REOS*
Regressors				
IRT	−3.447* (0.929)	−3.052* (0.933)	−1.181* (0.089)	−2.994* (0.968)
(IRT)^2		0.507* (0.115)		0.523* (0.095)
FDI	−0.797* (0.115)	−0.538* (0.116)	−1.434** (0.768)	−1.662** (0.833)
*(IRT*FDI)*	−0.404* (0.027)	−0.798* (0.030)	−0.423* (0.161)	−0.506* (0.142)
$lnRGDP_{PC}$	0.410** (0.206)	0.597* (0.105)	0.936* (0.160)	0.976* (0.176)
lnOIL	−0.141** (0.069)	−0.108** (0.053)	−0.896** (0.336)	−0.886** (0.342)
(lnOIL)^2		0.036** (0.017)		0.086* (0.009)
$lnCO2_{PC}$	0.122** (0.0633)	0.194* (0.0679)	0.264 (0.229)	0.319 (0.265)
Constant	2.225** (0.847)	4.731* (1.481)	1.121* (0.353)	1.827** (0.910)
Threshold level of *IRT*		20.353		17.501
R-squared	0.802	0.867	0.758	0.762

Notes: The robust standard errors are reported within the parentheses;
*Denote statistical significance at 1% levels.
**Denote statistical significance at 5% levels.

that the South Asian economies are transforming into pollution havens for foreign investors. This is because the FDIs flowing into South Asia are likely to be directed at the industries that specialize in producing dirty-commodities by primarily combusting the non-renewable energy resources. These findings are similar to the conclusions made by Anton and Nucu (2020) and Doytch and Narayan (2016) for selected European Union countries. In contrast, the findings in this study contradict the findings of Paramati et al. (2016) and Kutan et al. (2018) in the context of emerging market economies. Besides, the negative sign of the statistically significant estimated elasticity parameter attached to the interaction term (*IRT*FDI*) suggests higher intra-regional trade and greater FDI inflow shares in the GDP jointly declines the RES of the South Asian nations. This finding is expected given the fact that the aforementioned elasticity estimates suggested that both intra-regional trade and FDI inflows dampen the RES in South Asia.

On the other hand, economic growth is found to be ideal in promoting RET in South Asia. The corresponding elasticity estimate reveals that a 1% rise in the real GDP per capita level accounts for a rise in the RES by 0.410%, on average, *ceteris paribus*. This implies that economic growth is likely to develop the energy infrastructure of the South Asian economies which, in turn, can be expected to partially phase-out the constraints impeding the RET phenomenon in South Asia. Similar results were found in the study by Alam and Murad (2020) for selected OECD countries. However, this finding opposes the conclusions made in the study by Doytch and Narayan (2016) where the authors claimed that economic growth primarily promotes non-renewable energy consumption. Besides, the predicted cross-price elasticity of RE demand in South Asia shows that exogenous positive shocks to the real crude oil prices do not trigger the replacement of the non-renewable energy resources by renewable alternatives. A rise in the real crude oil prices by 1% is found to dampen the RES in South Asia by 0.141%, on average, *ceteris paribus*. Hence, this particular finding tends to highlight the traditional monotonic fossil fuel-dependencies of the majority of the South Asian economies. Similarly, the positive impacts of economic growth on the RE consumption levels were highlighted in the study by Sadorsky (2009a) for 18 emerging market economies including India. In contrast, Ergun et al. (2019) asserted a negative relationship between economic growth and RES in selected African countries. Finally, the elasticity estimates also reveal a negative association between per capita CO_2 emissions and RES which implies that environmental apprehensions stemming from rising CO_2 emissions tend to trigger the need for undergoing RET in South Asia. A percentage rise in the per capita CO_2 emissions levels is predicted to enhance the RES by 0.122%, on average, *ceteris paribus.* This finding is parallel to the findings of Attiaoui et al. (2017) where higher CO_2 emissions were claimed to increase the short-run RE consumption levels of 22 African nations.

Taking the possible non-linear associations into consideration, model (1) is augmented with squared terms of intra-regional trade shares and real crude oil prices. The corresponding long-run elasticity estimates in the context of model (2) confirm a U-shaped association between intra-regional trade shares and RES. The negative and positive signs of the statistically significant elasticity parameters attached to *IRT* and (*IRT^2*) denote that a 1% rise in the intra-regional trade shares initially reduces the average RES by 3.052%, but, beyond a threshold level of intra-regional trade share, it elevates the average RES by 0.507%, *ceteris paribus*. Hence, in line with these estimates, it can be asserted that it takes a substantial amount of trade integration between the South Asian nations to trigger RET in South Asia. This finding statistically supports the claims of the previous qualitative studies by Ogino et al. (2019) and Paul (2020) in which the authors suggested regional energy trade to be an effective means of increasing the RE consumption levels across South Asia. The threshold intra-regional trade share, at zero FDI inflows, is predicted at 20.35% which is significantly higher than the current intra-regional trade share of around 5%, on average, in South Asia. Hence, this finding portrays that the South Asian economies need to buck up their willingness to participate in regional trade; especially the cross-border trade of RE needs to be substantially boosted. On the other hand, the elasticity estimate in the context of model (2) also certifies the non-linear U-shaped association between real crude oil prices and RES. Hence, it can be said that a persistent rise in the real prices of crude oil, in the long-run, is effective in stimulating the RET phenomenon in South Asia. Besides, it can be said that the monotonic fossil-fuel dependency of the South Asian nations requires crude oil prices to be significantly increased to induce a substitution between non-renewable and RE use. This finding is similar to that by Murshed and Tanha (2020) for the four net oil-importers of South Asia.

For robustness check of the intra-regional trade-RET nexus in the South Asian context, models (1) and (2) are re-estimated using the REOS as an alternative proxy for the RET phenomenon. As far as the impacts of regional trade integration on the REOS are concerned, the elasticity estimates in the context of model (3) imply a negative correlation between intra-regional trade shares and REOS. A rise in the intra-regional trade shares is found to reduce the REOS by 1.18%, on average, *ceteris paribus.* In this regard, it can be asserted that the trade of inputs required for RE generation is not a prioritized tradable commodity in the intra-regional trade baskets of the South Asian nations. Consequently, regional trade integration among these economies, at the initial stages, do not facilitate the RET phenomenon by elevating the REOS. Similarly, FDI inflows are also found to dampen the REOS in South Asia. A percentage rise in the shares of FDI in the total GDP figures is estimated to reduce the REOS by 1.43%, on average, *ceteris paribus*. Therefore, these finding further implicates the specialization of the South Asian industries in the production of dirty-commodities that are intensive in non-renewable electricity use. Hence, it can once again be asserted that the South Asian nations are transforming into pollution havens for foreign investors (Murshed, 2020d). Moreover, the joint adverse impacts of intra-regional trade and FDI inflows on the REOS are also ascertained which can be perceived from negative signs of the corresponding elasticity parameter attached to the interaction term (*IRT*FDI*) in the context of model (3).

Furthermore, the favorable impacts of economic growth on the REOS are witnessed from the associated elasticity estimates. A 1% rise in the per capita real GDP levels increases the REOS by 0.94%, on average, *ceteris paribus*. In contrast, positive shocks to world crude oil prices are found to depress the REOS by 0.90%, on average, *ceteris paribus*. This finding once again highlights the fossil fuel dependencies of the South Asian economies whereby these nations cannot easily substitute non-renewable energy use for RE use. On the other hand, the per capita CO_2 emissions are found to be ineffective in influencing the REOS of the South Asian nations.

The long-run elasticity estimates in the context of model (4) confirm the non-linear association between intra-regional trade and REOS in the context of South Asia. The corresponding elasticities denote that initially as the intra-regional trade shares increase by 1%, the average REOS decline by 2.99%. However, beyond a threshold level of intra-regional trade shares, a further rise in the intra-regional trade shares is associated with an increase in the average REOS by 0.52%, *ceteris paribus*. The threshold intra-regional trade share is estimated at 17.50% which further justifies the relevance of boosting regional trade integration among South Asian economies for initiating the RET phenomenon. Besides, the monotonic fossil fuel dependency of the South Asian economies is further highlighted from the U-shaped non-linear nexus between real crude oil prices and the REOS. The negative and positive signs of the predicted elasticity parameters attached to *lnOIL* and *lnOIL^2*, respectively, affirm this claim. Similar conclusions in the context of four South Asian net oil-importers were put forward by Murshed and Tanha (2020).

For comparability purposes, the regression analysis is repeated using the panel DOLS estimator. The corresponding elasticity estimates are reported in Table 6. It is evident that, although matching in terms of the predicted signs, the elasticity estimates predicted using the DOLS estimator are mostly found to be statistically insignificant. Hence, these contrasting findings justify the choice of using the AMG estimator to ascertain the long-run elasticities since this method simultaneously accounts CD and slope heterogeneity issues in the data. In contrast, the panel DOLS estimator fails to accommodate these issues. The regression analysis is followed by the panel causality exercises.

The key results from the Dumitrescu and Hurlin (2012) bootstrapped Granger causality analysis are summarized in Table 7. The statistically significant test statistics, in the context of models (1) and (2), reveal a unidirectional causal association stemming from intra-regional trade shares to RES. Hence, this finding supports the corresponding elasticity estimate to imply that regional trade integration is an important factor that can boost the RES of the South Asian nations. This corroborates the suggestions put forward in the existing qualitative studies of McBennett et al. (2019), Ogino et al. (2019) and Paul (2020) where the authors hypothesized regional energy cooperation to be effective in enhancing RE use in South Asia.

Besides, unidirectional causalities from the share of FDI inflows in the GDP and crude oil prices to RES are also found. Hence, keeping the corresponding elasticity estimates into consideration, it can be said that the FDI flowing into the South Asian economies deter the prospects of undergoing RET in the South Asian economies. In contrast, higher oil prices are pertinent in replacing the non-renewable energy use by the RE

Table 6
The long-run elasticity estimates from the panel DOLS estimator.

Model Specification Dep. Var	(1) Linear *RES*	(2) Non-Linear *RES*	(3) Linear *REOS*	(4) Non-Linear *REOS*
Regressors				
IRT	−3.251* (1.251)	−3.121* (1.111)	−1.212* (0.412)	−3.121* (1.121)
(IRT)^2		0.317* (0.089)		0.610** (0.232)
FDI	−0.343* (0.114)	−0.201** (0.090)	−1.441 (1.193)	−1.413 (0.978)
*(IRT*FDI)*	0.020 (0.026)	0.091 (0.081)	0.423* (0.127)	0.506** (0.198)
lnRGDP$_{PC}$	0.210 (0.328)	0.517 (0.462)	0.736 (0.751)	0.776 (0.654)
lnOIL	−0.401 (0.301)	−0.833 (0.617)	−1.456 (1.315)	−0.982 (0.881)
(lnOIL)^2		0.234 (0.251)		0.086 (0.821)
lnCO2$_{PC}$	0.142* (0.035)	0.174* (0.036)	0.434 (0.410)	0.339 (0.225)
Constant	2.215** (0.965)	2.731* (1.243)	2.721* (0.523)	2.823* (1.001)

Notes: The robust standard errors are reported within the parentheses.
*Denote statistical significance at 1% levels.
**Denote statistical significance at 5% levels.

Table 7
The Dumitrescu–Hurlin panel Granger causality test results.

Model (1) and (2)			Model (3) and (4)		
Dep. Var.	Indep. Var.	Z-bar stat.	Dep. Var.	Indep. Var.	Z-bar stat.
RES	*IRT*	9.152*	*REOS*	*IRT*	2.254**
IRT	*RES*	1.510	*IRT*	*REOS*	1.231
RES	*FDI*	11.223*	*REOS*	*FDI*	11.231*
FDI	*RES*	1.420	*FDI*	*REOS*	1.213
RES	*lnGDP$_{PC}$*	8.223*	*REOS*	*lnGDP$_{PC}$*	7.342*
lnGDP$_{PC}$	*RES*	10.231*	*lnGDP$_{PC}$*	*REOS*	12.245*
RES	*lnOIL*	6.499*	*REOS*	*lnOIL*	1.132
lnOIL	*RES*	1.371	*lnOIL*	*REOS*	0.901
RES	*lnCO2$_{PC}$*	14.231*	*REOS*	*lnCO2$_{PC}$*	6.293*
lnCO2$_{PC}$	*RES*	10.222*	*lnCO2$_{PC}$*	*REOS*	9.442*

Note: The test statistics are estimated under the null hypothesis of the independent variable Granger causing the dependent variable against the alternative hypothesis of otherwise; The optimal lag selection is based on the AIC.
*Denote statistical significance at 1% levels.
**Denote statistical significance at 5% levels.

alternatives. Moreover, the causality estimates also suggest bidirectional causalities between per capita real GDP levels and RES and between per capita CO_2 emissions and RES. Therefore, these findings imply that not only do higher economic growth and environmental pollution facilitate the RET phenomenon, undergoing RET is also critically important to ensure the sustainability of economic and environmental development in South Asia. A similar bidirectional causality between economic growth and RE use in the context of Brazil and South Africa was reported by Sebri and Ben-Salha (2013). On the other hand, Ben Jebli et al. (2015) also found evidence of a bidirectional causality between CO_2 emissions and RE consumption levels in African nations.

In the context of models (3) and (4), the causality estimates reveal unidirectional causality running from intra-regional trade shares to REOS in South Asia. Therefore, this finding also highlights the importance of promoting intra-regional trade to stimulate the RET phenomenon across this region. Besides, the causal influence of FDI inflows on the REOS is also unearthed. Therefore, in line with the corresponding elasticity estimate, this unidirectional causality implies that the incoming FDIs are typically directed at the non-renewable energy-intensive industries of the South Asian countries. Moreover, the causality findings also reveal bidirectional causal associations between per capita real GDP and REOS and between per capita CO_2 emissions and REOS. Hence, similar to the case of the RES, these bidirectional causations highlight the interdependence between these variables. Hence, it is pertinent for the South Asian nations to undergo RET for attaining their respective economic and environmental sustainability goals. A similar bidirectional long-run causality between economic growth and REOS was reported in the study by Murshed and Tanha (2020) for the net oil-importing South Asian nations. However, the authors found evidence of unidirectional causality stemming from CO_2 emissions to REOS for these economies.

6. Conclusion

Energy sufficiency is believed to be a major driver of economic growth. Hence, in the contemporary era, ensuring energy sustainability has become a vital macroeconomic agenda across the globe. In this regard, undergoing RET to replace non-renewable energy use by the RE alternatives is deemed necessary. However, initiating this transition is relatively more difficult for the developing countries to which the South Asian nations are no exception. Against this background, this paper aimed to assess the importance of boosting regional trade integration to facilitate the RET phenomenon across selected South Asian economies including Bangladesh, India, Pakistan, Sri Lanka, Bhutan and Nepal. To proxy for the RET phenomenon, two alternative indicators in the form of the RES and REOS are considered. Besides, the analysis also controlled for the effects of FDI inflows, economic growth, crude oil price shocks and CO_2 emissions. The period of analysis spanned from 1992 to 2015 and involved econometric analysis using relevant estimators that are robust to handling CD and slope heterogeneity issues in the data.

The results, in a nutshell, revealed long-run associations between intra-regional trade shares, RES, REOS, net FDI inflow shares in the GDP, per capita real GDP level, real crude oil price shocks and per capita CO_2 emissions. Besides, controlling for CD and slope heterogeneity concerns in the data, the long-run elasticity estimates confirmed the non-linearity of the nexus between intra-regional trade shares and the two alternative indicators of the RET phenomenon in South Asia. The elasticity estimates revealed that a 1% rise in the intra-regional trade shares initially decreases the RES and REOS by 3.05% and 2.99%, respectively. However, beyond a certain intra-regional trade share threshold, a further 1% rise in the intra-regional trade shares was found to increase the RES and REOS by 0.51% and 0.52%, respectively. As per the estimates, the intra-regional trade share thresholds for the RES and REOS are predicted at 20.35% and 17.50%, respectively. Moreover, unidirectional causal relationships running from intra-regional trade shares to RES and REOS were also ascertained. Besides, incoming FDI inflows were found to dampen the RES and REOS in South Asia. Furthermore, higher intra-regional trade shares and net FDI inflows were ascertained to jointly reduce the RES and REOS. On the other hand, higher economic growth and CO_2 emission levels were found to boost the RES and REOS in the long-run. On the other hand, the non-linear U-shaped impacts of positive real crude oil price shocks on the RES and REOS are also found.

Therefore, the findings imply that promoting regional trade integration could be a credible means of triggering the RET phenomenon in South Asia. However, since the estimated thresholds of intra-regional trade shares (20.35% and 17.50%) are significantly higher than the current average intra-regional trade share (around 5%) in South Asia, it is imperative to adopt relevant policy measures that can substantially boost regional trade integration in South Asia. Based on the overall findings from the econometric analyses, the following policy implications can be recommended. Firstly, it is critically important for the South Asian economies to overcome the associated barriers that have traditionally inhibited intra-regional trade among the South Asian nations. In this regard, the geopolitical tensions among the South Asian nations need to be resolved in order to facilitate regional trade cooperation in South Asia. Most importantly, India and Pakistan need to settle their political disputes to boost their bilateral trade volumes. It has believed that India and Pakistan can potentially engage in trade worth 37 billion United States dollars. In contrast, bilateral trade between these nations is merely worth 2 billion US dollars. Hence, it is critically important for India and Pakistan to exploit these potential trade opportunities which, in turn, can substantially boost intra-regional trade in South Asia. Besides, it is also necessary for the South Asian economies to be involved in energy cooperation whereby the fossil fuel-dependent nations like Bangladesh, India, Pakistan and Sri Lanka can import hydropower from Nepal and Bhutan. Thus, the augmentation of RE and the associated technologies should be augmented into the intra-regional trade baskets of South Asia. Furthermore, to boost regional integration in South Asia, it is pertinent for the South Asian nations to reinstate the functionality of the SAARC which has somewhat lost its credibility in facilitating regional integration among the member nations.

Secondly, since international trade is said to be facilitated by the adoption of trade liberalization policies, it is important for the South Asian nations to reduce the tariff and non-tariff barriers that are believed to inhibit trade among these regional neighbors. In this regard, the concessional tariff structures under the SAARC Preferential Trade Agreement (SAPTA) should be further relaxed to enhance regional trade across South Asia. Besides, it is also important to include RE resources among the tradable commodities that are currently offered custom duty-free trade flows under the South Asian Free Trade Area (SAFTA). Consequently, the cross-border flows of RE can be enhanced to a large extent which, in turn, is likely to trigger the RET phenomenon across South Asia.

Finally, apart from boosting intra-regional trade, it is also recommended that the South Asian nations restrict the inflows of dirty FDI, expedite the economic growth rates, reduce the fossil-fuel dependency and mitigate CO_2 emissions to facilitate RET across South Asia. Thus, revisiting the financial globalization policies in South Asia need to be monitored whereby appropriate steps are needed to restrict the inflows of the relatively environmentally-unfriendly FDI. Rather, the South Asian nations should ideally attract FDIs that could be effective in inducing technological spillover pertinent for initiating the RET phenomenon in South Asia. On the other hand, enhancing the economic growth rates could be effective in developing the energy infrastructures in South Asia which can further facilitate RET across this region. Moreover, mitigating fossil fuel dependency could also make it easier for the South Asian nations to replace non-renewable energy consumption by the RE alternatives following positive shocks to crude oil prices. Finally, the implementation of CO_2 emission-abatement policies should prioritize the use of RE in South Asia.

Data limitation was the major constraint faced in conducting this study. Consequently, the country-specific investigations to assess the possible heterogeneity of the findings could not be performed. As part of the future scope of research, similar studies can be undertaken in the context of intra-regional trade and RET across regions other than South Asia to test the generality of the overall findings. Besides, the effects of different trade liberalization policies in respect of promoting intra-regional trade and facilitating RET in South Asia can also be evaluated.

CRediT authorship contribution statement

Muntasir Murshed: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This study received no funding.

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