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RESEARCH ARTICLE

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Assessing the drivers of (non)conventional energy portfolios in the South Asian economies: The role of technological innovation and human development

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Abstract

Energy is a vital component of economic development process, but part of the energy system including production and consumption of non-renewable energy sources largely constitute environment setback. Interestingly, this research contributes to the growing debate on understanding the factors contributing to energy consumption portfolios using the case of five major South Asian economies including Bangladesh, India, Nepal, Sri Lanka, and Pakistan from 1990 to 2018. Crucial factors like trade flow, human development index, technological innovations, and urbanization were controlled for while examining the roles of economic expansion on the disaggregated energy consumption portfolios (renewable and non-renewable energy sources) of these countries. The empirical dissection revealed that economic growth and the duo of trade and innovation are inimical to environmental sustainability as they trigger nonrenewable energy consumption while suppressing cleaner energy usage in the South Asian bloc. Urbanization on the other hand shows significant simultaneous positive impacts on the consumption of both renewables and nonrenewable energy, but its impacts are more pronounced on the latter than the former. Lastly, the study posits that human development and urbanization are major drivers of clean energy among the countries. Thus, strategic investment plans for human development enhancements and greener urban infrastructures are recommended for environmental sustainability goals in the region.

KEYWORDS
environmental sustainability, non-renewable energy, renewable energy, South Asian economies

1 | INTRODUCTION

Energy resources remains a vital component for economic development of countries. Without the input of energy, production activities are often hindered thus leading to impediments on countries' economic growth paths. World Bank estimates that the global energy consumption, in terms of energy rent, has continued to increase significantly in the last four decades, across all economic development levels. For instance, in high-income countries, total energy rent has grown more than double from about 0.77% of Gross Domestic Product (GDP) in 1970 to 1.57% of GDP in 2018 (World Bank, 2020). Similarly, in middle-income countries, the rent increases from 2.43% to 4.18% of GDP during the same period amounting to almost a double increase while the rent also doubled from 5.28% to 10.84% of GDP during the same period in the low-income countries. However, this increasing trend of natural resource rents and energy consumption is in line with the welfare gain given the steady rise in per capita income over the years. Evidently, the World Bank estimates show that the world's GDP per capita has tripled in the years between 1990 and 2019 as the figure averagely increased from $5551 in 1990 to $17,811 in 2019 (World Bank, 2020).

Nevertheless, utilization of natural resources such as the energy consumption may not necessarily be beneficial to the environment. Specifically, for non-renewable energy, which is mainly derived from fossil resources, often raises major concerns in the minds of environmentalists about its destructive externality in terms of carbon emissions generations. The World Bank estimates revealed that carbon dioxide emission at the world level grew by about 11.37% between 1970 and 2016 following the increase in per capita emissions from 4037 tons to 4555 tons within the periods. Of course, the negative impacts of the increasing emissions are multidimensional as they do not only widen production costs through environmental taxation and other environmental-related charges (He et al., 2015; Song et al., 2017), but also harm the quality of life thereby creating impediments to human development (Ahmad et al., 2020; Alimi et al., 2020; Cao et al., 2019; Jiang et al., 2022; WHO, 2012). Declining quality of life also has the potential of dragging an economy backward since it can influence the overall productivity of labor (Albouy et al., 2013; Ma et al., 2020). Hence, this calls for more effective policies to minimize the dependency of the global economy on non-renewable energy, and instead, increase clean energy production and consumption.

However, formulating effective policies to minimize emissions require sufficient knowledge regarding factors affecting energy consumption. In this regard, attention must be paid to the renewable portfolios as well as the non-renewable component. Focusing on both energy sources is critical since understanding the determinants of non-renewable energy cannot be separated from renewable energy. While several studies have investigated the factors driving energy portfolios, some of the studies have come up with mixed findings. For instance, many studies that considered income per capita as a determinant of renewable and non-renewable energy consumption have delivered mixed findings. Some studies argued that growing economic affluence vis-à-vis increasing income per capita positively affects non-renewable consumption (Ali et al., 2021; Ansari et al., 2020; Sebri & Ben-Salha, 2014) among others. Likewise, some studies also agree with the existence of positive relationship between income per capita and renewable energy consumption, as demonstrated in Sebri and Ben-Salha (2014), Apergis and Payne (2011), and Sharif et al. (2019), among others. However, while Ansari et al. (2020) further argued that income per capita negatively affects renewable energy consumption, the study of Adom et al. (2012) found that income per capita has no significant link with both forms of energy.

Other studies have also considered many other potential determinants while investigating factors affecting renewable and non-renewable energy consumption, such as technological innovation, human development, urbanization, and trade. In terms of technological innovation, the findings are generally mixed. While Santra (2017), Yu and Du (2019), among others, argue that innovation is environmentally destructive and has no significant impact on energy consumption, Fisher-Vanden et al. (2004), Hang and Tu (2007), and Khan et al. (2021), among others, argued that innovation is positively correlated with renewable energy consumption. Furthermore, Sawada and Managi (2014), Khan et al. (2021), and Rasoulinezhad and Saboori (2018), among others, argue that innovation also increases non-renewable energy consumption. Additionally, other studies considering human development as a determinant of energy usage also deliver mixed findings. For example, some studies consider that human development index (HDI) is positively associated with renewable energy consumption, such as demonstrated in Sasmaz et al. (2020), Kazar and Kazar (2014), Sanchez-Loor and Zambrano-Monserrate (2015), among others. However, Wang et al. (2018) argue that non-conventional energy use and human development are not associated. The mixed findings are also found in the studies utilizing urbanization as a determinant (Jones, 1991; Parikh & Shukla, 1995; Shahbaz & Lean, 2012; Poumanyvong & Kaneko, 2010). Another variable commonly considered as a determinant is trade (Aydin & Turan, 2020; Hdom & Fuinhas, 2020; Khoshnevis Yazdi & Shakouri, 2017).

Given the mixed results that are produced in the literature thus far, this research aims to contribute to the debate in understanding factors affecting renewable and non-renewable energy consumption in five popular South Asian countries including Bangladesh, Nepal, Sri Lanka, India, and Pakistan for 1990–2018. To the best of our knowledge, this is the first study to address these factors for the specific bloc. The current study unlike extant literature focuses on the simultaneous interaction among income per capita, technological innovation, human development index, trade, and urbanization in relation to both energy use (renewable and non-renewable) portfolios in the South Asian bloc. Furthermore, while conducting the analysis for this group of countries, the current study also contributes to the literature in terms of the use of newly developed empirical methodology such as the cross-sectional autoregressive distributed lag (CS-ARDL) technique for the panel analysis.

About the significance of the study, addressing the energy dynamics in these groups of middle- and low-income countries will provide economic benefits to policymakers, authorities, and other stakeholders in terms of ensuring sustainable energy generation for production activities. Furthermore, given that about 88% of the estimated over 300 million environmental pollution-related deaths are generally recorded among the low-income and middle-income countries, according to World Health Organization (WHO) report (WHO, 2012), addressing the energy dynamics in the understudied countries will also help to address health-related environmental pollution challenges. Additionally, this study is differed from past literature as this study critically controls the effect of some crucial factors such as human development, technological innovations, trade, and urbanization, while examining the role of economic progress on disaggregated energy portfolios of the South Asian countries in terms of both the clean energy and non-renewable energy consumption.

This article is organized as follows. Section 2 presents a broad literature review. Section 3 provides the methodology and model information. Section 4 describes the parameters and analyses the empirical findings. Section 5 concludes the study.

2 | LITERATURE REVIEW

Since the pioneering work the empirically examine the association between energy use and economic growth in Kraft and Kraft (1978), studies aiming to understand the factors influencing energy consumption are now widely covered in the literature. Factors like economic growth and innovations are among the major determinants of energy use that have gained substantial focus in the growing literature lately. In most of the studies that focused on technological innovation as a major determinant of energy use, innovation is often proxied by the number of environmental-related patents produced in the country and several studies have come up with divergent findings on the innovation-energy consumption nexus (Alam & Murad, 2020; Hang & Tu, 2007; Khan et al., 2021; Santra, 2017). Some of these studies demonstrated that technology innovation increases non-renewable energy consumption, others revealed that the relationship is negative, while the rest of the studies also demonstrate that the relationship between the two follows the upside "U-curve" of the famous Environmental Kuznets Hypothesis (EKC). In the case of the Organization for Economic Co-operation and Development (OECD) countries, Alam and Murad (2020) noted that the impact of technological innovation on countries' renewable energy consumption varies significantly. Santra (2017) also noted that although innovation has a significant impact on aiding economic growth, it however portends no significant positive impact as far as the environment is concerned. Yu and Du (2019) also shared the same view with Santra (2017). They noted that innovation is the source of environmental degradation. Notwithstanding, some studies have argued that innovation is necessary to improve energy consumption efficiency (Fisher-Vanden et al., 2004). For instance, the study of Hang and Tu (2007) revealed a positive impact of innovation on renewable energy in six major developed countries throughout 1980–2010. The study also showed that the observed positive relationship between innovations and the renewable energy consumption is bidirectional. This conclusion goes in line with the evidence from Khan et al. (2021). The latter study investigated the impact of technological innovation on non-renewable energy across 69 countries of the Belt and Road initiative for 2000–2004 using robust standard error regression and dynamic generalized method of moments (GMM) estimators. They discovered that renewable energy and technological innovation are positively and causally related.

In different perspectives, many studies likened non-renewable energy consumption by carbon emission following the assumption that non-renewable energy, which is mainly based on fossil fuels, corresponds with rising carbon emission. For example, Sawada and Managi (2014) examine the relationship between technological change and non-renewable resource extraction and exploration. The study demonstrates that innovative technological change can help in improving the efficiency of non-renewable energy exploration, which consequently implies that the greater supply of non-renewable energy stimulates its consumption thereof. Similarly, the results of Khan et al. (2021) unveil that innovation contributes substantially to the rise of non-renewable energy consumption. These findings are further supported by those of Rasoulinezhad and Saboori (2018); Khan et al. (2020), and Cai et al. (2018) that have also argued a positive relationship between technological innovation and non-renewable energy consumption.

On the income aspect as a determinant of energy consumption, higher income tends to trigger more consumption due to income effect as supported by some studies in the literature. For example, Ansari et al. (2020) investigated the relationship between renewable energy, non-renewable energy, and economic growth in the case of the top energy-consuming countries for 1991–2016. Renewable energy consumption was proxied by the sum of hydro, modern and traditional biomass wind, solar, liquid biofuel, biogas, geothermal, marine, and waste resource, while non-renewable energy was proxied by the sum of coal, oil, and gas consumption in terms of million tons of oil equivalent (MTOE). Economic growth in the study was proxied by gross domestic product per capita. The study applies the fully modified ordinary least square (FMOLS) and the dynamic modified ordinary least square (DOLS) alongside the standard OLS for the empirical analysis. The study demonstrates that both non-renewable energy consumption and income per capita positively contribute to the rising carbon emission. This finding implies that income per capita positively affects non-renewable energy consumption. On the contrary, renewable energy consumption is negatively correlated with income per capita, implying that higher income per capita does not necessarily correspond to higher energy consumption. This finding also supports the findings from the study of Ali et al. (2021) for Pakistan using ARDL method and the study of Sebri and Ben-Salha (2014) for the case of the (Brazil, Russia, India, China, and South Africa) BRICS countries. Both Ali et al. (2021) and Sebri and Ben-Salha (2014) revealed that there is a mutual relationship between income per capita and renewable energy.

On the other hand, Apergis and Payne (2011) showed that the relationship between non-renewable energy and income per capita is positive and bidirectional based on the examination of 11 different economies during the period of 1992–2004. These findings have been corroborated by findings from Sharif et al. (2019) for 74 countries from 1990 to 2015 using the FMOLS and DOLS methods. The finding indicates that income per capita and non-renewable energy are positively correlated. On the contrary, the study shows that renewable energy is negatively associated with income per capita. In another study, Bilgili et al. (2016) also obtained a positive relationship between non-renewable energy and income per capita, but a negative relationship between renewable energy and income per capita for the OECD countries. However, despite the evidence in support of income as a determinant of energy consumption from various economies, the study of Adom et al. (2012) for the case of the Iranian economy concluded that GDP expansion has no significant nexus with the two energy forms (renewable and non-renewable).

The Human Development Index (HDI) has been proxied as another energy consumption determinant in other studies. It is assumed that a more civilized society would be wiser in utilizing energy, minimizing the use of non-renewable energy, hence reducing carbon emission via the use of cleaner energy (Martínez-Guido et al., 2019; Razmi et al., 2021; Roy & Dalei, 2019). The study of

Soukiazis et al. (2019) revealed that renewable energy is a significant determinant of human and physical capital include research and development (R&D), and vice versa. Additionally, Razmi et al. (2021) investigated the relationship between non-renewable energy and human development index in the case of Iran by using the non-linear ARDL model. The study showed that non-renewable energy consumption is negatively correlated with the human development index while renewable energy consumption is positively correlated with the index. Ouedraogo (2013) examined the relationship between non-renewable energy consumption (in the form of electricity) and human development index using an error correction model and revealed that the relationship is not significant on the short-term basis, however, it is negative based on a long-term analysis. The study of Sasmaz et al. (2020) for OECD countries also revealed the presence of a causal relationship between HDI and renewable energy consumption. Kazar and Kazar (2014) are also in support of this finding, based on the study of a sample of 154 countries, arguing that renewable energy has a bidirectional causal effect on human development in the short term. In the long term, the study argues that a higher level of human development index can promote renewable energy production. However, this finding contradicts the conclusion from Wang et al. (2018) that there is no relationship between human development and renewable energy.

Urbanization is another determinant of energy use that is often considered in the literature. Demands on energy are expected to increase with rising urban population and this can cover either the demand for renewable or non-renewable energy (Poumanyvong & Kaneko, 2010; Jones, 1991; Onifade, Gyamfi, et al., 2021; Onifade, Alola, et al., 2021; Shahbaz & Lean, 2012). Following the examination of 59 developing countries using 1980 as a single year of observation, Jones (1991) argues that the increase in population size by 10% corresponds to the rise of per capita energy consumption by 4.5%–4.8%. This finding is similar to that of Parikh and Shukla (1995). The study which demonstrates the case of the developing countries over the period 1965–1987 argued that a ten percent growth in population size corresponds to around 4.7 percent expansion in per capita energy in take. Furthermore, in addition to a positive relationship between energy consumption and urbanization, some studies have even revealed a unidirectional causal nexus originating from urbanization to energy use. For instance, Shahbaz and Lean (2012) and Mishra et al. (2009) found unidirectional causality from urbanization to energy consumption in the short run.

As for the roles of trade, the empirical evidence is mostly tilted toward the positive roles of trade on energy consumption. Akbar et al. (2021) asserted that openness to foreign trade will not only positively trigger non-renewable energy use but also the consumption of renewables. Khoshnevis Yazdi and Shakouri (2017) also obtained a positive relationship between trade and energy consumption for both renewable and non-renewable in the case of African countries. Other studies such as Parsa and Sajjadi (2017) and Hdom and Fuinhas (2020) have also corroborated the positive impacts of trade openness on energy consumption. The understudied South Asian countries in the current study are yet to receive adequate attention in the growing literature. Hence, based on the comprehensive review of the related literature, this study focuses on the impacts of potential energy consumption determinants like technological innovation, income, trade flow, urbanization, and human development on both the renewable and non-renewable energy consumption in the South Asian bloc.

3 | DATA AND EMPIRICAL APPROACH

This part of the investigation documents information about the dataset and the empirical approaches leading to the findings.

3.1 | Data description

The present research assesses the effects of the drivers of per capita income (Y), trade flow (TF), urban population (URB), Technological innovation (TI), and human development index (HDI) on renewable energy (REU) and non-renewable energy use (NR) for the case of South Asian nations. The dependent variables used for this study are both renewable energy and nonrenewable energy whiles the independent variables are per capita income, trade flow, urban population, Technological innovation, and human development index. The dataset for this empirical analysis stretches between 1990 and 2018. Moreover, Table 1 reports the summary description of the examined variables.

3.2 | Empirical model

Meanwhile, all the variables investigated are logged transformed to ensure conformity to normality and to safeguard the homoscedasticity of the variables. Given the pioneering work of Kraft and Kraft (1978), the empirical models (for renewable and non-renewable energy forms) are illustrated accordingly:

$$REU_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 TF_{it} + \beta_3 URB_{it} + \beta_4 TI_{it} + \beta_5 \mathrm{HDI}_{it} + \varepsilon_{it}, \tag{1}$$

$$NR_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 TF_{it} + \beta_3 URB_{it} + \beta_4 TI_{it} + \beta_5 \mathrm{HDI}_{it} + \varepsilon_{it}, \tag{2}$$

where REU, Y, TF, URB, TI, HDI, and NR stands for renewable energy, income, trade flow, urban population, technological innovation, human development index, and nonrenewable energy.

The long-term influence of income, trade flow, urban population, technological innovation, and human development index on renewable energy and nonrenewable energy in South Asia countries is the goal of the research. The coefficients and units of evaluation are compatible with previous literature Khan et al. (2021) Grabara et al. (2021) and Fan and Hao (2020). Specifically, we are concerned with the effective use of energy provided, improving access to alternative energy suppliers, offering environmentally sustainable preservation, and conserving ecological integrity. All these constitute significant priorities in our society today.

TABLE 1 Description of variables

Name of indicator	Abbreviation	Proxy/scale of measurement	Source
Technological innovation	TI	Patent (residents and non-residents)	World Bank
Income	Y	it is proxied by the gross domestic product per capita (2010 Constant USD)	World Bank
Nonrenewable Energy	NR	Fossil fuel energy consumption (% of total)	British Petroleum
Renewable energy	REU	% of total final energy consumption	British Petroleum
Technological Innovation	TI	% of total population with access to mobile communication	World Bank
Trade flow	TF	Import + Export	World Bank
Urban population	URB	(% of total population)	World Bank
Human development index	HDI	Human development index in relation to schooling years and returns on different education levels	World Bank

Source: Authors' compilation.

3.3 | Methodology pathway

Series of empirical approaches are implemented in this part. These approaches begin with the necessary pre-test for cross-sectional inference, stationarity, and cointegration to the main coefficient estimation.

3.3.1 | Cross-section dependence

To establish the suitable methodological approach(s) for this investigation, we used the cross-section dependency (CD) approach. The findings of the CD approach could help us decide whether to utilize first-generation or second-generation panel data estimate approaches. The research may be biased, inappropriate, and conflicting if the CD evaluation is not conducted (Gyamfi et al., 2021; Gyamfi et al., 2022). We utilized a robustness evaluation utilizing three-CD tests: the Pesaran (2007) CD, Pesaran (2015) scaled LM, and Breusch and Pagan (1980) approaches, to ensure that the aforesaid difficulties do not emerge. The CD test is depicted as follows:

$$CD = \sqrt{\left(\frac{2T}{N(N-1)}\right)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{p}_{ij}\right). \tag{3}$$

Whereas from Equation 3, $\widehat{p}_{ij}$ identifies the indicators of the remaining evaluation of ADF regarding the pairwise cross-sectional interconnection. N and T are the panel range and model specifically for the time and cross-section.

3.3.2 | Stationarity approach

It is vital to identify stationarity attributes of indicators under investigation before moving to further analysis. Moreover, if there is an indication of CD, utilization of the first-generation unit root test will produce outcomes that are misleading. Based on this knowledge we utilize unit root tests that can identify variables stationarity feature amidst CD. Thus, we utilized 2nd generations stationarity test to identify variables of the investigation stationarity attribute. We utilized both CIPS and CADF to catch the order of the variables of integration. Equation presents the CADF as follows:

$$\Delta Y_{i,t} = \gamma_i + \gamma_i Y_{i,t-1} + \gamma_i \overline{X}_{t-1} + \sum_{l=0}^{p} \gamma_{il} \Delta \overline{Y_{t-l}} + \sum_{l=1}^{p} \gamma_{il} \Delta Y_{i,t-l} + \varepsilon_{it}. \tag{4}$$

In Equation 8, $\overline{Y}_{t-1}$ and $\Delta \overline{Y_{t-l}}$ shows the cross-section average. The value of CIPS is derived as follow:

$$\widehat{\mathrm{CIPS}} = \frac{1}{\mathrm{N}}\sum_{i=1}^{n} \mathrm{CADF}_{\mathrm{i}}. \tag{5}$$

The cross-section augmented Dickey-Fuller test derived from Equation (4) is denoted by the term CADF in Equation (5).

3.3.3 | Cointegration approach

If there is a presence of CD, utilization of first-generation cointegration such as Pedroni and Kao cointegration tests will produce misleading outcomes since they do not consider CD. Based on this knowledge, we utilized Westerlund cointegration initiated by Westerlund (2007) to catch the long-run association between energy intensity and the regressors. Unlike both Pedroni and Kao cointegration tests, Westerlund (2007) considers CD. The Equation below presents Westerlund (2007).

$$G_t = \frac{1}{N}\sum_{i-1}^{N} \frac{\acute{\alpha}_i}{SE(\acute{\alpha}_i)}. \tag{6}$$

$$G_\alpha = \frac{1}{N}\sum_{i-1}^{N} \frac{\mathrm{T}\acute{\alpha}_i}{\acute{\alpha}_i(1)}. \tag{7}$$

$$P_T = \frac{\acute{\alpha}}{SE(\acute{\alpha})}. \tag{8}$$

$$P_\alpha = T\acute{\alpha}. \tag{9}$$

The test alternative and null hypotheses are "there is cointegration" and "no cointegration" accordingly.

3.3.4 | Cross-section augmented auto-regressive distributed lags (CS-ARDL)

To analyze and present the long-run technique centred on the MG method, the research uses the CS-ARDL methodology (Chudik et al., 2016; Chudik & Pesaran, 2015) since it is the most accurate and efficient optimal in terms of sample accuracy and effectiveness. The CS-ARDL method effectively handles cross-sectional reliance when describing heterogeneous time effects. Additionally, the CS-ARDL holds the following merits namely (i) it makes available the best possible option in terms of accuracy, efficiency, and robust outcomes in panel data analysis (ii) it eliminates the need to pre-test the integration order, deals effectively with CS-ARDL issues and describes heterogeneous time series (iii) it addresses the problem of slope homogeneity issues and feedback effects between the indicators (iv) it extracts both the long and short-haul effects (Chudik et al., 2016; Chudik et al., 2016; Chudik & Pesaran, 2015; Pesaran & Smith, 1995). The equation below depicts the CSARDL method:

$$Y_{it} = \sum_{i=1}^{py} \pi_{it} Y_{i,t} + \sum_{i=0}^{pz} \theta_{i1}^{\iota} Z_{i,t-1} + \sum_{i=0}^{pT} \phi_{i1}^{\iota} Z_{i,t-1} + e_{it}, \tag{10}$$

where, $\overline{X}_{\mathrm{t}} = (\overline{Y}_{\mathrm{t\text{-}1}}, \overline{Z}_{\mathrm{t-1}})$ $I =$ average cross-reliance's are proved by $\overline{Yt}$, as well as Zt. Moreover, $\overline{X}_{\mathrm{t-1}}$ stand for averages of both regressors and dependent variable. The coefficients of the average group and long period are exemplified as follows in (Equations 10 and 11) requirement, $\mathrm{p_y = 2}$ and $\mathrm{p_x = 1}$, and ARDL (1, 0) requirement, $\mathrm{p_y = 1}$ and $\mathrm{p_x = 0}$. The CS-ARDL evaluations of the separate mean equal coefficient are then assumed by Equation 12:

$$\widehat{\vartheta}_{CS-ARDL,i} = \frac{\sum_{i=0}^{pz} \widehat{\widetilde{\theta}}_{il}^{\iota}}{1 - \sum_{l=1}^{py} \widehat{\pi}_{il}}. \tag{11}$$

$$\widehat{\vartheta}_{meangroup(MG)} = \frac{1}{N} \sum_{i=1}^{N} \widehat{\vartheta}_i. \tag{12}$$

The current study again employs the FMOLS technique as a robustness for the CS-ARDL test.

4 | EMPIRICAL OUTCOMES AND INTERPRETATION

As a first step, the descriptive statistics are checked in Table 2 where it can be observed that both positive and negative skewness is obtained from the analysis. Nonrenewable energy, trade flow, and urbanization have negative skewness while renewable energy, income, technological innovation, and human development index also have positive skewness. However, it is observed that all variables

TABLE 2 Descriptive statistics and correlation matrix analysis

	LREU	LEU	LY	LTF	LURB	LTI	LHDI
Mean	4.0596	5.8682	6.8175	3.7088	3.1453	2.8756	−0.6270
Median	4.0174	6.0194	6.7164	3.7358	3.2495	2.8527	−0.6481
Maximum	4.5453	6.5155	8.2569	4.4845	3.5957	4.1167	0.0000
Minimum	3.5480	4.7782	5.9056	2.8324	2.2170	1.5621	−0.9519
Std. Dev.	0.2757	0.4192	0.5751	0.3744	0.3452	0.6291	0.1907
Skewness	0.2355	−0.1234	0.0217	−0.0315	−0.0954	0.0630	0.0373
Kurtosis	2.1566	3.3530	2.7802	2.4907	2.5162	2.1076	2.7205
Jarque-Bera	5.2493^{c}	29.099^{a}	8.9697^{b}	1.4810^{c}	9.2947^{a}	4.5689^{a}	6.9360^{b}
Probability	(0.0724)	(0.0000)	(0.0112)	(0.0768)	(0.0095)	(0.0018)	(0.0311)
Observations	145	145	145	145	145	145	145
LREU	1						
LNR	−0.1532c	1					
LY	−0.4090^{a}	0.5853^{a}	1				
LTF	0.2628^{a}	0.3176^{a}	0.4649^{a}	1			
LURB	−0.8895^{a}	0.1311	0.1960^{b}	−0.4589^{c}	1		
LTI	−0.1490^{c}	0.6114^{a}	0.1848^{b}	0.0983	0.0698	1	
LHDI	−0.2058^{a}	0.3909^{a}	0.8646^{a}	0.5794^{a}	−0.0149	0.1099	1

Note: a < 0.01, b < 0.05, and c < 0.10.

TABLE 3 Cross-sectional dependency (CD) and slope homogeneity (SH) examinations

Model	Pesaran CD test	*p*-value	Pesaran LM test	*p*-value	Breuch-Pagan LM	*p*-value
LREU	13.952[a]	(.000)	40.495[a]	(.000)	196.099[a]	(.000)
LNR	14.243[a]	(.000)	42.604[a]	(.000)	205.529[a]	(.000)
LY	16.209[a]	(.000)	55.402[a]	(.000)	262.767[a]	(.000)
LTF	12.539[a]	(.000)	11.932[a]	(.000)	68.361[a]	(.000)
LURB	4.052[a]	(.000)	49.657[a]	(.000)	237.073[a]	(.000)
LTI	−2.376[a]	(.008)	18.951[a]	(.000)	99.751[a]	(.000)
LHDI	11.841[a]	(.000)	31.474[a]	(.000)	155.755[a]	(.000)
Slope homogeneity (SH)						
	Coefficient	***p*-value**				
SH ($\tilde{\Delta}$ test)	5.765[a]	(.001)				
SH ($\tilde{\Delta}$ adj test)	6.159[a]	(.003)				

[a]<0.01.

TABLE 4 Panel IPS and CIPS unit root test

	CIPS				
	I (0)		I (1)		
Variables	C	C&T	C	C&T	Decision
LREU	−1.978	−2.082	−4.883[a]	−4.841	I (1)
LNR	−1.555	−1.018	−3.952[a]	−4.776[a]	I (1)
LY	−2.041	−2.474	−4.392[a]	−4.756[a]	I (1)
LTF	−1.924	−1.915	−4.216[a]	−4.670[a]	I (1)
LURB	−1.972	−0.175	−4.209[a]	−5.526[a]	I (1)
LTI	−2.033	−2.514	−5.285[a]	−5.794[a]	I (1)
LHDI	−0.006	−0.101	−2.642[a]	−3.617[a]	I (1)

Note: significance level, while C = constant and C&T = constant and trend.
[a]<0.01.

TABLE 5 Westerlund cointegration test

	Model a		Model b	
Statistics	Value	*p*-value	Value	*p*-value
Gτ	−3.822[a]	(.009)	−2.586[a]	(.001)
Gα	−2.691[a]	(.009)	−2.042[a]	(.008)
Pτ	−2.070[a]	(.000)	−2.500[a]	(.009)
Pα	−3.703[a]	(.000)	−3.339[a]	(.000)

[a]<0.01.

have a negative correlation with renewable energy except trade flow which has a positive correlation with renewable energy.

Based on the findings of the empirical research, individual time series are first analyzed to determine whether or not there is cross-sectional dependence (CSD). This is done by applying the Breusch-Pagan LM test, the Pesaran scaled LM test, and the Pesaran CD techniques, all of which can be found in Table 3. The cross-sectional link demonstrates that the null hypothesis CSD outcome can be rejected at the one percent level of significance for all the techniques utilized in this study. This implies that the panel unit root analysis must consider the connection among cross-sectional individuals. However, the Pesaran and Yamagata (2008) SH techniques on the other hand produced a 1% siginficat level. This indicates that a shock appears to be transmitted to other nations within the panel in each of the South Asia countries. The findings proceed to demonstrate that neither multicollinearity nor serial autocorrelation can be found among the datasets under consideration. The results of the CIPS unit root technique by Pesaran (2007) presented in Table 3 provide evidence in favor of this assumption for the coefficients that were investigated, and Table 4 contains the outcomes of the panel cointegration investigation. The CIPS outcomes validate that all variables are stationary after difference.

Subsequently, outcome of the Westerlund (2007) Cointegration test shown in Table 5 traces a long run equilibrium relationship between the highlighted variables in the panel analysis. The conclusion was supported by the evidence of rejecting the null hypothesis.

4.1 | Panel coefficient estimation results

Tables 6 and 7 (CS-ARDL and FMOLS) give the long-run equilibrium analysis for the study. The CS-ARDL technique was utilized for the combined panel analysis of the South Asia countries while the FMOLS gives country by country analysis for the study.

4.1.1 | Panel results

From Table 6, Model A (renewable energy as dependent variable), it was observed that income is significantly negatively related to renewable energy for the South Asia countries which are in line with the findings of Khan et al. (2021). The significant negative connection among the two coefficients is understandable because maintaining income growth is a major objective of emerging economies which is

TABLE 6 CS-ARDL technique

	Model a			Model b		
Variables	**Coefficient**	**t-statistics**	***p*-value**	**Coefficient**	**t-statistics**	***p*-value**
LY	−0.332[a]	[−4.223]	(.000)	0.688[a]	[4.239]	(.000)
LTF	−0.259[a]	[−5.638]	(.000)	0.123[a]	[3.430]	(.001)
LURB	0.411[c]	[1.421]	(.059)	3.890[a]	[4.483]	(.000)
LTI	−0.025[c]	[−1.426]	(.057)	0.128[a]	[5.326]	(.000)
LHDI	0.030[b]	[0.092]	(.027)	−3.427[a]	[−7.870]	(.000)
F-STAT	0.154[a]		(.000)	0.234[a]		(.001)
Short-Run						
ECM	−0.352[b]	[−2.526]	(.013)	−0.209[b]	[−1.996]	(.049)
D(LY)	−0.065	[−0.457]	(.649)	0.073	[0.229]	(.820)
D(LTF)	0.062[c]	[1.816]	(.073)	0.004	[0.098]	(.922)
D(LURB)	4.101	[0.659]	(.511)	−2.256	[−0.664]	(.508)
D(LTI)	0.007	[0.720]	(.474)	−0.014	[−0.661]	(.510)
D(LHDI)	−0.025	[−0.805]	(.423)	0.764[b]	[2.092]	(.039)

Note: [] for standard error, () for *p*-value, D for short-run coefficients, optimal lags for CS-ARDL by using AIC.

[a]<0.01.

[b]<0.05.

[c]<0.10.

often anchored on nonrenewable energy resources. As such, the driving force for most of the economic expansion is fossil fuel-based energy. Furthermore, most of the available renewable energy means are comparatively capital intensive and much more expensive for the huge energy demands of the South Asian countries. As a result, nonrenewable energy resources are seen as cheaper alternatives to sustain the huge energy demand for the needed economic expansion despite being at the detriment of the environment. Our findings differ from the study conducted by Sadorsky (2009), which showed that a rise in income is likely to result in a rise in the usage of renewable energy.

Moreover, the effects of trade inflow are negative for renewable energy consumption, and it is a major driver of nonrenewable energy intake for South Asian countries. This is in support of the panel study of Khan et al. (2020) and Wang and Zhang (2021). This sort of interaction exists because the actions of trade inflows are not focused on clean and alternative energy supplies. To redirect trade inflows from the nonrenewable to the renewable energy sectors, attractive compensation programs to promote clean trade in these nations need to be implemented. Similarly, technological innovations have a negative significant influence on renewable energy use. This result cannot be separated from the preceding observed roles of trade inflows that were previously analyzed. A major reason for this negative link among the two coefficients is due to trade liberalization that has enhanced the diffusion of nonrenewable energy technology throughout the understudied South Asian economies. These findings are in line with the observation of Khan et al. (2021). But the results oppose the results by Bamati and Raoofi (2020) who concluded that for developed economies, technological innovation has a positive impact on renewable energy.

Again, there is a positive relationship between urbanization and renewable energy in the long run which affirms the finding of Yang et al. (2016). The demographic architecture, employment profile, consumption habits, economic segmentation, and main sectors of a nation may all be influenced by urbanization. The influence of urbanization on renewable energy consumption may be separated into two phases: the initial phase and the later phase. First and foremost, urbanization alters the methods of manufacturing and living, which in turn alters the need for energy sources. The desire for energy resources is typically comprised of both direct and indirect components because what is a product in one industry may be natural resources in another. In general, there are three phases to the urbanization process: the initial stage, the accelerative stage, and the final stage. The beginning stage is the most basic level and the influence of urbanization on renewable energy usage varies depending on where you are in the process of urbanization.

Moreover, a percentage rise in the human development index will increase renewable energy by 0.030% which is in line with the finding of Hashemizadeh and Ju (2021). Efficient energy management forecasts based on the human development index, which include social, economic, environmental, and technological components, necessitate the use of decision-making approaches that are capable of balancing numerous objectives at the same time. Furthermore, policymakers must be able to evaluate such investments while taking into consideration the imprecision and uncertainty of the data, as well as the fact that they are pursuing many (and sometimes contradictory) agendas. For the short-run analysis, it is observed that income has a negative significant interaction with renewable energy which trade inflow also has a positive connection with renewable energy for the South Asia countries.

TABLE 7 FMOLS for the countries

Countries	LY	LTF	LURB	LTI	LHDI	R²	ADJ R²
Model A							
Bangladesh	−0.148[a]	−0.057[c]	0.738[b]	0.043[a]	−0.385[b]	0.993	0.991
India	−0.101[b]	−0.085[b]	4.364[c]	−0.115[c]	2.406[c]	0.970	0.962
Nepal	−0.064[c]	−0.044[b]	0.024[b]	−0.022[c]	−0.098[b]	0.801	0.746
Pakistan	0.375[c]	−0.072	4.262[b]	−0.105	1.541	0.880	0.848
Sri Lanka	−0.463[a]	−0.309[a]	0.540	−0.131[b]	0.029	0.900	0.875
Model B							
Bangladesh	0.364[b]	0.097[b]	0.786[c]	−0.036[b]	−0.352[b]	0.994	0.992
India	0.443[c]	0.055[b]	4.545[b]	0.091[c]	−3.049[b]	0.987	0.984
Nepal	1.189[a]	−0.092[a]	0.182[b]	0.015	−1.446[a]	0.978	0.972
Pakistan	−0.365	−0.003	5.213[b]	0.138[a]	−2.448[b]	0.774	0.714
Sri Lanka	0.396[a]	0.371[a]	−11.481[a]	−0.028	0.403[c]	0.949	0.936

[a]<0.01.
[b]<0.05.
[c]<0.10.

For Model B where nonrenewable energy is the dependent variable, it is observed that a 1% increase in income will increase nonrenewable energy use by 0.6884%. This outcome shows that the more income rises, the more they consume energy by buying items like cars, washing machines, and other appliances which are energy intensive. Again, trade flow also has a positive significant association with nonrenewable energy consumption for the South Asia countries. Moreover, both urbanization and technological innovation also increase nonrenewable energy use while the human development index is the only variable that decreases nonrenewable energy use in the long run. As many individuals within these countries advance their knowledge, the awareness of the environmental damages the use of nonrenewable energy creates becomes pronounced thus, helping to create a gradual shift of attention from nonrenewable to cleaner forms of energy. Moreover, the outcomes affirm the finding of Tang and Tan (2013), Shahbaz et al. (2017), Arminen and Menegaki (2019), Kwakwa et al. (2020), and Khan et al. (2021). The environmental benefits of human development in this study essentially come up in the long run. These beneficial impacts are not applicable in the short run as seen in the short-run results in model B meaning that the investments in human development carry numerous long-run environmental benefits.

4.1.2 | Country-specific results

For the country-specific analysis for the south Asia countries where the authors utilized the FMOLS technique, the outcome which is presented in Table 7 largely aligns with the panel results in Table 6. For instance, in the panel investigation, the variables (with the exemption of only urbanization and HDI) exhibit a negative effect on renewable energy sources while HDI is seen to hinder non-renewable energy utilization. Therefore, for Mode A where renewable energy is the dependent variable, it is observed that there is a negative relationship between income and renewable energy for all countries except Sir Lanka which has positive relations. Moreover, trade flow and technological innovation also have a negative association with renewable energy for all the South Asia countries except for Bangladesh which the relationship involving technological innovation and renewable energy proof to be positive. Urbanization, however, shows a positive link with renewable energy whiles for human development, Bangladesh and Nepal obtain a negative connection with the dependent variable and the remaining countries had a positive relationship with the dependent variable.

Furthermore, for Model B where energy use is the dependent variable, there is a positive relationship between income and energy use except Pakistan which show a negative relationship among the variable. Moreover, apart from Nepal and Pakistan which obtain a negative connection between trade flow and energy use, the reaming countries had a positive connection between these two variables. For urbanization, the result shows a positive relationship with energy use for all the countries except Sir Lanka. However, there of the countries (India, Nepal, and Pakistan) show positive while the two countries (Bangladesh and Sir Lanka) obtain a negative connection between technology innovations with energy use. Lastly, the result obtained from human development and energy use shows a negative connection except for Sir Lanka which obtain a positive interplay between the two variables.

5 | CONCLUSION AND POLICY IMPLICATIONS

The impacts of the control variables were accessed on both clean energy and non-renewable energy for South-Asian countries including Bangladesh, Nepal, India, Sri Lanka, and Pakistan between 1990 and 2018. The current study critically controls for crucial factors like human development index, technological innovations, trade flow, and urbanization, while examining the roles of economic expansion on the disaggregated energy portfolios of the south Asian countries in terms of both clean energy and non-renewable energy. By incorporating the variables, the study renders contributions to the literature toward understanding the puzzle on the influential factors for renewable and non-renewable energy consumption through the combination of techniques including the novel CS-ARDL method and FMOLS. Using the cross-sectionally augmented autoregressive distributed lag (CS-ARDL), some findings stand out. Economic growth boosts non-renewable energy use while it reduces renewable energy use in South Asia. Trade reduces renewable and increases non-renewable. Urbanization increases both renewable and nonrenewable but the magnitude of impact on renewables is quite low almost about nine times higher than the observed positive impacts on non-renewable energy consumption. Innovation reduces renewable but increases non-renewables and the magnitude of its impacts on non-renewables is more pronounced than on renewable energy use. HDI boosts renewable but reduces non-renewable.

5.1 | Policy implication

These results are indicative of important Policy directions for the authorities in the South Asian bloc. The countries need to further strategize on the pathway to improving the share of renewables in their energy portfolio by investing more in cleaner energy production systems to advance it energy transition plan and improve environmental sustainability. In addition, considering the revealed impacts of innovations in triggering nonrenewable energy use, this is indicative that the South Asian countries are yet to harness the rising trends in trade volumes in the regions for environmental benefits. Trade regulations can be designed to promote and facilitate trade in green energy technologies with the rest of the world. In this regard, the countries can offer tax incentives on the import of green technologies. However, while doing so, the authorities should also strive to provide a thriving production or business environment to boost the efforts of the local green energy entrepreneurs or investors in environmentally friendly technologies.

Moreover, more strategically designed investment plans for human development enhancements and green infrastructural investments to support sprawling urbanization are suggested to the authorities. In addition to the economic benefits of more investments in human development for the bloc, more commitments to investments in human development would also help to further produce a highly enlightened society about the needs for cleaner energy consumption and this would help to further facilitate the actualization of sustainable environment and related SDGs goals in the South Asian economic region. In spite the policy relevance of this investigation, future study can better guide decision makers when updated dataset is implemented. It is also important that the energy mix of each of the renewable (i.e., wind, solar, hydro, and biomass) and non-renewable energy sources (i.e., coal, natural gas, oil) are considered in future investigation.

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