Is sustainable energy consumption, technological advancement and urbanization fast addressing south Asia's green energy expansion deficits?

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Abstract

The United Nation's sustainable development goals (UN-SDGs) like accessibility to renewable energies (SDG-7), sustainable production and consumption (SDG-12), as well as stable economic growth all centre on the notion of human development (HDI) and reflected in (SDG-8). In line with this motivation, this study explores the environmental sustainability targets for a panel of South Asian economies that are disproportionately affected by a huge energy deficit i.e., energy poverty, and technological immobility. This study considers evidence from south Asian nations to provide the role of certain indicators of human development in the wake of economic development and environmental quality objectives by unraveling the complex relationships between per capita income, access to technological innovation, access to clean energy, and urbanization. Employing a balanced panel econometric model, this study investigate the hypothesized nexus between specific macroeconomic variables among South Asian economies. The empirical evidence indicates that the human development index (HDI), per capita income, accessibility to clean energy, technological innovation, as well as urbanization all exhibits a long-run equilibrium relationship over the study period. However, income per capita, accessibility to clean energy and technological innovation all exert a positive impact on HDI for the selected countries, while urbanization shows a negative impact on HDI. Furthermore, causality relationship shows a feedback causality relationship between income per capita, access to clean energy and urbanization with the human development variable, while access to technological innovation has a one-way causality with the HDI. This current study importantly extends the extant knowledge, by presenting new insights into the interaction between human development and its antecedents from a whole new contextual perspective. These outcomes will assist policymakers and stakeholders to obtain new insights into the crucial role of clean energy accessibility, technological innovation, income per capita, and urbanization on HDI processes among South Asian countries.

Keywords Sustainable development · Human development index · Clean energy · Urbanization, economic growth · Panel econometrics · South Asian countries

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1 Introduction

Planet Earth currently confronts numerous environmental challenges, stemming from anthropogenic activities driven by accelerated economic growth, technological innovations, and the complexities of climate change. These challenges necessitate modifications to the traditional economic development paradigm, as highlighted by recent studies (Akinsola et al., 2021; Soylu et al., 2021). Consequently, there is a growing recognition among countries and production units for the need to transition from conventional economic development models to newer paradigms.

This imperative for new developmental approaches has spurred a heightened competition for exploring both traditional and non-traditional economic resources to foster growth. Unfortunately, this pursuit has also contributed to increased environmental problems globally, as noted in studies by Adebayo and Kirikkaleli (2021), Soylu et al. (2021), Gyamfi et al. (2021b), Bekun et al. (2021a), and Bekun et al. (2021b). The urgency for sustainable solutions is underscored by the interconnectedness of economic activities and environmental impacts, necessitating a reevaluation of how we approach and manage our resources for future growth.

Several South Asian economies find themselves listed among the globe's 46 least developed countries (LDCs), as per the latest report from the committee for development (CDP), highlighting their status as lower-income economies (United Nations, 2020). The inclusion of many South Asian nations in the category of least developed countries is significant, considering the heightened sensitivity of LDCs to environmental and socioeconomic shocks. Operational challenges hindering stable growth have been a persistent concern in these nations (Alola et al., 2021; Bamidele et al., 2022; Gyamfi et al., 2022a, 2022b).

As these nations chart their courses toward achieving the United Nations' sustainable development goals for 2030, there is a pressing need for the swift implementation of relevant policies to prevent falling behind their global counterparts (United Nations, 2020). This pursuit aligns with the broader objective of improving human development, as the United Nations' sustainable development goals encompass key components of human existence, including income, knowledge, and health. The human development index (HDI), in contrast to GDP, offers a more holistic assessment of national development, particularly relevant for nations facing challenges such as high income disparity, short life expectancy, and high illiteracy (Alola et al., 2021).

The discussion on human development extends to diverse antecedents, including economic policy, digital technology, and ICTs, as well as institutional and economic development (Alola et al., 2021; Asongu & Le Roux, 2017; Binder & Georgiadis, 2010). Previous studies have explored the interconnectedness of these factors with environmental sustainability (Agboola et al., 2022). For instance, drivers of sustainable economic growth, such as natural resource depletion, inflation, and policy effectiveness, have been scrutinized (Alola et al., 2021). Similarly, other studies, including Bugaje (2006) and Oyedepo (2014), have attempted to establish links between these development indicators and energy utilization, with a focus on renewable or green energy sources.

Despite progress, access to energy, especially clean energy, remains a challenge in several South Asian nations (Odugbesan et al., 2021; Soylu et al., 2021; Zhang et al., 2021). This study contributes to existing literature by exploring the critical role of clean energy access in the context of urban development in South Asia. Unlike broader discussions on clean energy transition, our focus is on the specific impact of renewable energy accessibility and technological development driven by urban population growth.

In examining energy use and technological development, South Asian countries lag behind advanced economies like the United States and China by approximately 20 years, according to National Geographic. The study also statistically analyses the extent of sustainable development achieved in South Asia, considering the economic growth trajectory of selected nations in the region, contributing theoretically to fill gaps in current literature.

Importantly, this study offers fresh insights into the relationship between human development and its antecedents from a new contextual perspective. While existing studies have explored the impact of economic development indicators on human development indices, such research has been mostly focused on Africa, China, and Europe. Our study brings evidence from South Asian nations, an area with limited documentation in the existing literature, providing new validations of the role of certain human development indicators in the context of economic development and environmental quality objectives. The findings extend the existing body of knowledge on the nexus between human development, environmental quality, and economic development.

The subsequent sections of this research follow this structure: Sect. 2 provides a summary of related studies, Sect. 3 details the methodology, data, and analysis techniques, and Sects. 4 and 5 present the findings and conclusions, respectively.

2 Review of related literature

This section highlights review of related literature on the theme on HDI and its determinant. Prior to empirical review is a synopsis of energy dynamics on HDI in relation to Asian blocs.

2.1 Overview of clean energy development deficits in South Asia

The energy sector is argued to play a crucial role in economic expansion and development globally. Particularly, the effect of energy sources and utilization on macroeconomic indicators has been a vibrant topic for prior research. The relationship between various macroeconomic indicators and human development, coupled with environmental concerns and implications of economic expansion, makes the need for research into human development and economic growth indicators more paramount (Alola et al., 2021). For instance, access to affordable electric power and household heating (natural gas and oil) are broad determinants of human development among EU states. This implies that if energy prices change significantly, the change will affect household well-being (Welsch & Biermann, 2017). Empirical evidence from India in a study by Sadath and Acharya (2017) established that India suffers from energy-poverty which reveals subsequent effects on low household income and austerity. Teschner et al., (2020) bluntly concludes that clean energy access leads to economic growth and human development, however achieving this outcome remains a global challenge to be surmounted by many countries.

The race toward ensuring net-zero emissions, or a sustainable development status is captured by the SDG 7.2.1 in which countries are to transition to a higher proportion of clean energy sources in their composite energy consumption. This goal is assessed through increasing energy sources generated from solar, geothermal, wind, biogas energy among natural renewable sources. Considering this, renewable energy sources such as solar and wind sources have seen significant increase in investment (about 47% between 2012 and 2016), therefore contributing to substantial increases in the share of these energy sources

over the past decade (Narayan, 2020; Sharma et al., 2020). Similarly, other renewable energy sources like bioenergy sources including biomass and liquid biofuels have also received sufficient investment attention, although not as the case of wind and solar, because many investors perceive solar and wind energy sources as the future of renewable energy.

Among Asian states, particularly southern Asian economies, the development of renewable energy generation in the region shows a contrasting view against the backdrop of the energy mix in the region. Despite substantial efforts are being made to deploy renewable energy, actual gains are occurring at rate slower than the growth and use of non-renewable energy sources such as fossil fuels (Asia & the Pacific Renewable Energy Status Report, 2019). South Asia's renewable energy penetration in the region averages around 41.6% compared with Southeast Asia's of 46.7% (Asia & the Pacific Renewable Energy Status Report, 2019).

Southern Asian countries like Sri Lanka, Bangladesh, India, Nepal, and Pakistan, are primarily deficient in renewable energies, as most of these countries in the region rely heavily on fossil energy imports such as oil, natural gas, and coal to meet the ever-growing demand for energy (Lin & Raza, 2019). According to the Pacific renewable energy report of 2019, countries like India, Bangladesh and Pakistan the proportion of renewable energy sources in their total energy mix is estimated to be around 37%, 34% and 46% respectively (Narayan, 2020; Sharma et al., 2020). The challenge of the slow development of renewable energy development in the south Asian region hinges primarily on the lack of financial commitment (Asia & the Pacific Renewable Energy Status Report, 2019; Narayan, 2020).

Coupled with the challenge of the huge financial obligation tied to the development of renewable energy projects in the region, security challenges exist as another significant obstacle to successfully implementing these capital-intensive energy projects (Narayan, 2020; Wang et al., 2018). This security challenge does not only bother on inter-country security challenges, but also the security of the renewable energy projects over their useful life. The issue of the lack of trust has strained the cooperation for cross-country developmental projects, thus has limited such engagements to bilateral agreements, like those between India and Nepal or Bhutan and India (Sadath & Acharya, 2017). Hence, multilateral integrations required to drive the fast development of sustainable development goals like renewable energy exploration is suffering significantly in the south Asian region. Only in recent years has a project like electric-power sharing between three nations India-Nepal-Bangladesh been possible. Therefore, the reluctance of south Asian states or governments to venture out to take multilateral political risks to further the development of the region in areas like enhancing renewable energy development remains an equally herculean task to surmount, to overcome the capital inadequacy that us stalling the development of clean energy generation in the region. Narayan, (2020) perceives that the lack of trust mainly emanating from the periodic changes in leadership among all south Asian states, underpins the lack of a multilateral approach to clean energy generation in the region. Hence, the lag and deficiency in renewable energy development in south Asian states like Sri Lanka, Nepal, India, Pakistan, and Bangladesh.

2.2 Human development and renewable (green) energy expansion

Human development is essentially at the heart of sustainable economic development particularly energy consumption. Some scholars have argued that it is not possible for human development to occur without energy, because energy is a vital element in all aspects of human life (Wang et al., 2020). Thus, energy impacts all three key areas of

human development health, living standards and education. Renewable or green energy as a type of energy, has gained significant attention in recent due to its positive impacts perceived toward the environment compared with traditional energy sources. Evidence of the relationship between renewable energy expansion and human development have shown substantial inconsistent observations (2020). For instance, Pîrlogea (2012) observed positive impact of green energy expansion on human development, whereas other studies like those of Wang et al. (2018) suggest a conclusion opposed to the latter. However, an overall assertion of these studies indicate that most studies find renewable energy expansion to positively impact human development mostly through environmental quality and reduced emissions.

Thus, it is surmised that the usage of green energy sources stimulates human development, likewise green energy deficits will shrink aspects of human development (Wang et al., 2021). In line with this, Maccari (2014), established a positive link between human developments (HDI) and sustainable environment. In that evidence from 129 countries revealed a U-shaped connection between HDI and environmental performance. Maccari (2014) thus reveals that countries with medium–low environmental levels show lower human development levels compared with nations with higher environmental performance.

A cluster of studies have established significant links between economic development factors and human development. Most highlighted among these has been the role of ICT in development of human wellbeing. AICTs role in human development is widely established in the literature. For instance, Asongu and Odhiambo (2019) revealed that fixed broadband and internet use together reduced the Atkinson index and Gini coefficient while a reduction is observed in the Palma ratio by mobile phone and internet penetration in Africa. Mohamed et al. (2010) as well as Oladapo and Rahman (2016) both showed ICT diffusion enhanced human development, likewise Lee et al., (2017) found ICTs to increase civil liberties, economic freedom and political rights which are considered determinants of human development in China. Despite the existence of these studies, this nexus still requires much more validation, particularly in the context of south Asian economies, which have significant drive in ICT developments and adoption, yet not many examinations exist on discerning the impact of ICTs on human development in the region (Khan et al., 2019; Sharma et al., 2020).

Similarly, income per capita and urbanization have all been assessed to impact various factors such as economic development and environmental quality. Prior studies have mainly considered urbanization, income, and environmental quality. Urbanization for instance, has been observed to impact environmental quality negatively (Ulucak et al., 2020). Similarly increasing per capita income increases human development, hence a direct effect (Arisman, 2018; Bamati & Raoofi, 2020; Mahalik et al., 2018).

In a nutshell, this current study makes an important extension to extant works by proving new evidence or proof of the role of technology development, access to clean energy, economic growth, and urbanization on human development in South Asia. Unlike many existing studies that have examined similar variables, they were employed to discern their impact on environment quality, mainly CO_2 emissions. Human development is a composite indicator that captures forms of growth and development. Coupled with this, very few studies exist on South Asian states like this current study. Thus, except for the few studies reviewed above, this literature review reveals human development indicator as a dependent variable have only been less investigated.

3 Methodology

3.1 Theoretical framework

Numerous influential indicators, such as technological innovation, per capita income, clean energy, and urbanization, have been incorporated into the model to offer additional insights into the current theme under review. These variables are included because they are associated with both renewable energy and economic growth, exerting an impact on the process of human development. Income activity, as highlighted by Davies and Quinlivan (2006), functions as a positive mediating factor in the connection between commerce and HDI. In nations where per capita income is increasing, more job opportunities are generated due to commerce. The standard of living of the population rises with an increase in per capita income, leading to improvements in healthcare, education, and sustainability practices.

As per Asongu et al. (2018), enhanced access to information and communications technology (ICT) fosters human and economic growth. It is crucial to note that this influence is contingent on both the available components of technology and the metrics used to measure human development indicators, such as income, wealth, land resource availability, political stability, and so on. Moreover, the literature explores the relationship between clean energy, income development, and CO2 emissions, revealing a positive association among them (Danish et al., 2017).

Furthermore, Pîrlogea (2012), Kazar and Kazar (2014), and Soukiazis et al. (2017) suggest that HDI plays a mediating role in the relationship between the expansion of green energy and environmental degradation. Utilizing HDI as an indicator of sustainable development, the study findings reveal that renewable energy consumption, coupled with investments in human and physical capital, significantly influences the objectives of sustainable development in the examined nations. The results indicate that the share of clean energy in the energy mix has a substantial impact on overall development. Finally, urbanization has an impact on the process of human development. When compared to persons who live in rural areas, the urban population has greater access to health and educational resources than the latter. Furthermore, persons who live in metropolitan regions have a greater number of work options. As a result, urbanization may have an impact on the process of human development as highlighted in the study of (Wang et al., 2018).

3.2 Data and variable description

This study considers the annual observations of the measures of human development index, access to technological innovation, per capital income, access to clean energy and urbanization of selected South Asia[1] countries over annual frequency data from 1990 to 2016. The main reason for the sampled blocs i.e., South Asia countries is due to available of data limitation. A breakdown of the details appertaining to the data is summarized in Table 1.

3.3 Study context

Various frameworks, including those proposed by Lee et al. (2017), Asongu and Odhiambo (2019), and Alola et al. (2021), have explored factors contributing to comprehensive

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[1] Bangladesh, India, Nepal, Pakistan, Sri Lanka.

Table 1 Description of variables

Indicators	Abbreviation	Scale assessment	Source
Human development index	HDI	As an index in relation to schooling years and returns on different education levels	UNDP, 2018
Access to technological Innovation	ATI	% of total population with access to mobile communication	WDI, 2020
Per capital income	GDP	it is proxied by the gross domestic product per capita (2010 Constant USD)	WDI, 2020
Access to clean energy	CE	% of total final energy consumption	WDI, 2020
Urbanization	URB	% of total population	WDI, 2020

All variables are transformed to their natural logarithm form to ensure homoscedasticity of the coefficients. UNDP- United Nations Development Program, 2019: WDI-World Bank Development Indicator, 2020. Source, authors' compilation

human development. In our current study, we integrate key elements of sustainable growth, such as the Human Development Index (HDI), encompassing factors like accessibility to clean energy, technology innovation, per capita income, and urbanization. What sets this study apart from previous research is its unique focus on South Asian economies, incorporating urbanization—a pivotal antecedent of the human development index that has been largely overlooked in existing studies. The mathematical model for the foundational assessment in this study is represented by Eq. (1).

$$\text{LnHDI} = \text{f (LnGDP, LnCE, LnATI, LnURB)} \tag{1}$$

3.4 Methodological sequences

To achieve the desired results, this study harnesses the powerful predictive capabilities of multiple econometric models, in addition to other related techniques. The analysis initially performs a cross-sectional dependence analysis to estimate sectional differences, a slope homogeneity is then performed to check for the existence of heterogeneity in the dataset. To assess the intersection between error terms, the study performed a serial Autocorrelation and Multicollinearity tests. The Westerlund and Edgerton (2007) LM technique for cointegration and the Dumitrescu and Hurlin (2012) procedures were used to assess the long term relationships and causalities.

3.4.1 Cross-sectional dependency test

Often, in most cases, panels for such analysis may possess cross-sectional dependencies as a result of the interactions between the variables, this situation is catered for using a bias-corrected LM analysis of Breusch and Pagan, (1980), Pesaran, (2007), and Pesaran, (2015). This analysis procedure is mathematically expressed as:

$$y_{it} = \alpha_i + \beta'_1 X_{it} + \mu_{it} \text{ for } i = 1, 2, 3 \dots N; t = 1, 2, T \tag{2}$$

X_{it}, and β, are K×1 vector regressors or coefficients to be predicted. α_i, shows the specific time-invariant noise factors. Cross-sectional units are uniformly distributed independently (i.i.d.) under the null principle μit may be correlated by cross-sections as a substitute. Nevertheless, the circumstance that there is no serial connection remains unaffected. The denotation value, hence, is

$$H_o :_{ij} = \rho_{ji} = cor\left(\mu_i, \mu_{jt}\right) = 0 \text{ for } i \neq j$$

$$H_o :_{ij} = \rho_{ji} \neq 0 \text{ for some } i \neq j$$

where ρij is the noise variable of the product-moment connection is given as

$$\rho_{ij} = \rho_{ji} = \frac{\sum_{i=1}^{T} \mu it, \mu jt}{\left(\sum_{i=1}^{T} \mu it^2\right)^{1/2}\left(\sum_{i=1}^{T} \mu jt^2\right)^{1/2}} \tag{3}$$

The possible number of unions is represented by $N\left(u_{it}, u_{jt}\right)$ increases.

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2$$

$\hat{\rho}ij$ depicts the model estimate of the correlations in the sets

$$\hat{\rho}ij = \hat{\rho}ij = \frac{\sum_{i=1}^{T} \hat{u}it, \hat{u}jt}{(\sum_{i=1}^{T} \hat{u}it^2)^{1}/_{2}(\sum_{i=1}^{T} \hat{u}jt^2)^{1}/_{2}} \quad (4)$$

$\hat{u}it$ the assessment of *uit* in Eq. (4). This is based on the premise of null interest, where it is assessed, that LM is scattered asymptotically determined by the chi-square statistic χ^2 with N (N-1)/2 degrees of freedom. Howbeit, with a high *N* and a finite T, it is inherently important to mitigate the extent of bias in the data, a condition often presents in econometric data analysis. Primarily, the LM statistic is not always determined for a finite T, with a high N, thus determining the likelihood of high bias. Therefore, to address this condition, this analysis considers the CD analysis procedure as an alternative approach to eliminating biases in the panel data. Thus, this is expressed as:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{j=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \right) \quad (5)$$

It is shown that below the null principal CD $\to d$ N (0, 1) there is no CSD for $N \to \infty$ and T is big enough. As a robust addition to the wide range of panel data analysis technique (including non-stationary structure as well as heterogeneous dynamic models), the CD statistic possesses a precise mean, with values of T as well as N determined to be zero. This is contrary to the assumption of the LM statistics. Thus, it is argued that toward homogeneous and heterogeneous dynamic structure the usual FE/RE techniques exhibit significant biases (Nickell, 1981; Pesaran & Smith, 1995). Thus, the cross-sectional dependency techniques remain very useful. The basis of this assertion is that, considering the limitations of model bias of the factor frameworks, the FE/RE residuals will possess a zero mean even for a corrected T, so long as the instabilities are proportionally distributed. Pesaran, (2007) provides an alteration to the model (2) above for unbalanced panels. This is shown as,

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{j=1}^{N-1} \sum_{j=i+1}^{N} \sqrt{T_{ij}} \hat{\rho}_{ij} \right) \quad (6)$$

where $Tij = \# (Ti \cap Tj)$ (i.e., value of comparable notes regarding units i and j in a time series),

$$\hat{\rho}ij = \hat{\rho}ij = \frac{\sum_{t} \in T_i \cap T_j (\hat{u}it - \hat{u}i)(\hat{u}_{jj} - \hat{u}_j)}{\left\{ \sum_{t} \in T_i \cap T_j (\hat{u}it - \hat{u}i)^2 \right\}^{1}/_{2} \left\{ \sum_{t} \in T_i \cap T_j (\hat{u}it\hat{u}_{jj})^2 \right\} ss^{1}/_{2}} \quad (7)$$

and

$$\hat{u}i = \frac{\sum_{t} \in T_i \cap T_j, \hat{u}it}{\#(T_i \cap T_j)} \quad (8)$$

The revision as suggested in Pesaran (2007) mainly show that the residuals for subsets t are all non-zero. Thus, CD technique for assessing LM is an alternative procedure to evaluate the CSD (Breusch & Pagan, 1980). Therefor panel data framework proposed by Breusch and Pagan LM is expressed as:

$$y_{it} = \alpha_i + \beta_1 X_{it} + \mu_{it} \tag{9}$$

where, i goes from 1 to N and t from 1 to T means, correspondingly. The CS as well as time scopes; X_{it} signifies the explained coefficients $k \times 1$ vector, and the intercepts and variables of slope throughout nations denoted with α_i and βi. Therefore, the Breusch-Pagan LM technique is determined as:

$$LM = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} \hat{\rho}_{ij}^2 \rightarrow X^2 \frac{N(N-1)}{2} \tag{10}$$

whereas $\hat{\rho}ij$ denotes the paired correlation coefficient obtained from the OLS procedure depicted in Eq. (10). Breusch-Pagan LM research (H_0: Cov (μit, μjt) = 0 for all t and $i \neq j$), the null hypothesis of no CD was also verified alongside the alternate CD principle (H_1: Cov (μit, μjt) $\neq$ 0 for at least one pair of $i \neq j$). (Pesaran et al., 2008) hints an issue of inadequacy of the Breusch-Pagan LM method in situations where a high N exists, because such occurrences will reduce its power if the mean population association is closer to zero. To correct this situation, (Pesaran & Yamagata, 2008) propose the use of the precise mean and variance figures estimated from the Breusch-Pagan LM test, which are bias-adjusted versions of the Breusch-Pagan LM estimates. The estimation of the bias accustomed LM examination is shown as:

$$LM = \sqrt{\left(\frac{2}{N(N-1)} \right)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \frac{(T-K)\hat{\rho}_{ij}^2 - \mu}{\sqrt{v^2 T_{ij}}} \rightarrow N(0,1) \tag{11}$$

where the number of independent variables is depicted by k and the precise mean and variance of μTij and $v^2 Tij$ 2 are denoted as $(T-k)\hat{\rho}^2 ij$

3.4.2 Slope homogeneity (SH) assessment

The nations under study could show similar economic complexities due to the existence of cross sectional dependencies (Swamy, 1970). This is consistent with the notion of homoscedasticity within the panels. Considering this, a test for homogeneity of slope is required. Thus, for the panels, we set N comparative to T, and in where we consider larger panels, N and T are denoted M. Thus, in line with Swamy, (1970) this slope homogeneity test is modelled as follows:

$$\tilde{S} = \sum_{(i=1)}^{N} \left(\hat{\beta}i - \hat{\beta}_{WFE} \right) \cdot \frac{X_i' M \tau X_i}{\sigma_i^2} \left(\hat{\beta}i - \hat{\beta}_{WFE} \right) \tag{12}$$

whereas $\tilde{S}$ is the accustomed Swamy test (i.e., Pesaran and Yamagata SH test) statistic, $\beta\hat{i}$ stipulates the coefficient of joint OLS, $\tilde{\beta}_{WFE} = \sum_{i=1}^{N} \left(X_i' M \tau X_i / \tilde{\sigma}^2 \right)^{-1} \sum_{i=1}^{N} \left(X_i' M \tau X_i / \tilde{\sigma}^2 \right)$ designates the weighted fixed-effect pooled estimator, $\tilde{\sigma}^2 = ((yi - Xi\tilde{\beta}i)\prime M\tau(yi - Xi\tilde{\beta}i))/(T-k-1)$ embodies the evaluation of $\sigma^2 i$, xi denotes to the matrix covering the explained factors in mean nonconformities, and the uniqueness

matrix is signified by $M\tau$. Moreover, the null statement of slope homogeneity is ($H0: \beta i = \beta j$ *for all i*). The Pesaran and Yamagata SH test is compared to the alternative assertion of slope heterogeneity ($H1: \beta i \neq \beta j$ *for all i*). The normal dispersal statistics can be as:

$$\tilde{\Delta} = \sqrt{N\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}\right)} \tag{13}$$

The bias-adjusted form of the $\tilde{\Delta}$ exam can be structured as surveys:

$$\tilde{\Delta}_{adj} = \sqrt{N}\left[\frac{N^{-1}\tilde{S} - E(\tilde{Z}_i T)}{\sqrt{\text{Var}(\tilde{Z}_i T)}}\right] \tag{14}$$

where $E(\tilde{z}iT) = k$ and $Var(\tilde{z}iT) = (2\ k(T\text{-}k\text{-}1))/(T+1)$ stipulate the mean and variance, compatibly.

3.4.3 Panel unit root test

This test procedure is considered where the order of the cross-section dependency and the heterogeneous conventional panel stationarity technique like the ADF, are sometimes criticized to be ineffective. Thus, a combination of the classic ADF and the CD procedure, with lagged phases is suggested to be helpful procedure to overcome the challenge of ineffectiveness (Pesaran, 2007). Thus, by ordering the distinct structures, the result is a new panel unit root test that accounts for CD and heterogeneity. Thus, the CADF regression function becomes a more robust procedure. This expressed as.

$$\Delta y_{it} = \alpha_i + b_i\bar{y}_{i,\,t\text{-}1} + c_i y_{i,\,t\text{-}1} + d_i\Delta\bar{y}_t + e_{it} \tag{15}$$

While subscript $i = 1, 2, \ldots$ n and t = 1, 2, … *t* shows the measurement of CS and time, individually, $y_{t\text{-}1} = N^{-1}\sum_{i=1}^{N} yi, t\text{-}1$ depicts the mean of the CS as $y_{i,t\text{-}1}$. $\Delta yt = N\text{-}1 \sum N\ i = 1$ Δy_{it} all show the 1st order of Δy_{it}. The null hypothesis of ($H0\ \beta i = 0$ *for all i*) highlights the stationarity principle, whereas the alternative hypothesis ($H1: \beta i < 0$ *for some i*) highlights the case of no stationarity. This is determined by the CADF technique, Thus to assess stationarity, this study draws on the Pesaran (2007) cross-sectional augmented CIPS stationarity technique, developed on the average of separate CADF analysis for the entire group (see Eq. (16)).

$$CIPS = N^{-1} \sum_{i=1}^{N} CADFi \tag{16}$$

It is noteworthy that CADFi is the CADF assessment measure for the cross-sectional unit of the *ith* item.

3.4.4 Test of bootstrap cointegration

There is always the need to assess the long-term associations between variables. Relative to this need, the Westerlund and Edgerton (2007) panel technique for long-term technique is employed in this study to handle CS issues. To account for the CD, the Westerlund and Edgerton (2007) long-term technique is used to estimate the probable amount of the method with

the bootstrapping technique. In line with the assertion of no long-term (null) association, a minimum of one CS unit or a long-term relationship of a full panel, alternative principles of cointegration, two group-mean estimates, and two-panel approaches are required. Thus this study, under the cointegration test, performs four estimations in line with Westerlund and Edgerton (2007). This is expressed as follows:

$$\Delta Y_{i,t} = \delta' d_t + \alpha_i (y_{i,t-1} - \beta_i' X_{1,t-1}) + \sum_{j=1}^{pi} \alpha_{ij} \Delta y_{i,t-j} + \sum_{-qi}^{pi} \gamma_{ij} \Delta X_{i,t-j} + e_{i,t} \tag{17}$$

The deterministic component is indicated by d_t. The varying lead orders across CDs and the lag lengths, are determined by qi and pi respectively. With this specification, two group-means calculated are G_t and G_a, and two-panel statistics to be determined are denoted Pt and Pa. The following are modelled in line with Westerlund and Edgerton (2007) procedure as:

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{\hat{a}}{SE(\hat{a})} \tag{18}$$

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{T\hat{a}}{\hat{a}_i(1)} \tag{19}$$

$$P_t = \frac{\hat{a}_i}{SE(\hat{a}_i)} \tag{20}$$

$$P_\alpha = T\hat{\alpha} \tag{21}$$

This tests significance is to offer test statistics that help to nullify the null presumption of a long-run relationship between the model's factors.

3.4.5 Augmented mean group (AMG) analysis

In addition, this study utilizes three robust estimation techniques presumed to offer more reliable analysis. Precisely, the Augmented Mean Group (AMG) heterogenous panel technique by Eberhardt and Bond (2009) as well as Eberhardt and Teal's (2010). estimation techniques are employed These estimation procedures are expressed in Eq. (22):

$$\Delta Y_{it} = \alpha_i + \beta_i \Delta X_{it} + \sum_{t=1}^{T} \pi_t D_t + \varphi_i UCF_t + \mu_{it} \tag{22}$$

An Ordinary Least Squares technique of variance is used to the AMG method. The Y_{it} and X_{it} the mean values together with the unnoticed common impacts while D is a time-variant dummy coefficients in Eq. (22). The OLS test of the differenced Eq. (22) is applied to obtain the AMG technique as shown in Eq. (23) whereas φ_i symbolises the projected slope parameters of X_{it} coefficient in Eq. (22).

$$AMG = \frac{1}{N} \sum_{i=1}^{N} \varphi_i \tag{23}$$

3.4.6 Method of moments quantile regression (MM-QR) technique

This analysis implements the panel quantile regression approach to assess sectoral and heterogeneous impact throughout quantiles. This analysis procedure draws on prescriptions determined in Koenker and Bassett (1978). This specification estimates the median value relative to quantile regressions to assess the approach of the respondents. This Quantile regression model has proven to be reliable compared with the simple regression models (Sarkodie & Strezov, 2019). This analysis procedure is crucial to the reliability of econometric analysis estimations (Binder & Coad, 2011). Thus, this analysis relies on the Method of Moment Quantile Regression (MMQR) paired with static impact analysis as indicated in Machado and Silva (2019). The quantile regression model establishes adequate resilience and is less sensitive to unseen heterogeneity (Canay, 2011; Koenker, 2004). MMQR approach increases the ability to detect partial heterogeneous covariance effects in a parsimonious fashion. It is also efficient for instances that possess multiple consequences of human actions and endogenous response variables. It also possesses much simplicity for use due to its ability to limit non-crossing predictions of the regression quantiles. The model is estimation for the contingent quantiles $Q_Y(\tau/X)$, is estimated as:

$$Y_{it} = \alpha_i + X'_{it}\beta + \left(\delta_i + Z'_{it}\gamma\right) U_{it} \qquad (24)$$

whereas the probability, $P\{\delta_i + Z_{it}'\gamma > 0\} = 1$. $(\alpha, \beta', \delta, \gamma')'$ are factors for the analysis. (α_i, δ_i), $i = 1\ldots\ldots, n$, shows the individuals I fixed impact and Z is the k-vector of recognised factor of X which are differentiable alterations with component l given by:

$$Z_l = Z_l(X), \; l = 1\ldots k \qquad (25)$$

where, Xit id the proxy of any fixed i and is independent across time (t). Uit is a proxy of distributed across individuals (i) and across time (t) which are normalized to satisfy the moment situation in Machado and Silva (2019) which does not imply limit as show in Eq. (15) show as:

$$Q_Y(\tau/X_{it}) = (\alpha_i + \delta_i q(\tau)) + X'_{it}\beta + Z'_{it}\gamma q(\tau) \qquad (26)$$

From Eq. (17), X_{it} represents vector of explanatory factors which are per capital income (GDP), access to technological innovation (ATI), access to clean energy (CE) and urbanization (URB). $Q_Y(\tau/x_{it})$ represents the dependent variables in this analysis which is, human development index (HDI).

3.4.7 Panel causality test

To determine the direction of causal relationship among the variables, we perform Dumitrescu and Hurlin (2012) modified Granger (1969) non-causality test which accommodates heterogeneity and CD in panel data. We report the Dumitrescu and Hurlin (2012) Granger causality test for empirical analysis as following:

$$Y_{it} = \delta_i + \sum_{k=1}^{p} \beta_{1ik} Y_{i,t-k} + \sum_{k=1}^{p} \beta_{2ik} X_{i,t-k} + \varepsilon_{it} \qquad (27)$$

From Eq. (27), β_{2ik} and β_{1ik} denote the independent coefficients and the autoregressive coefficients for separate panel variables i at time t individually. Subsequently, to the scheme of a equilibrium panel of estimation for the variables Y_{it} and X_{it}, the null concept

Table 2 Descriptive statistics and Correlation matrix analysis

	LnHDI	LnGDP	LnCE	LnATI	LnURB
Mean	0.6270	6.8175	4.0596	1.0187	3.1453
Median	0.6481	6.7164	4.0174	1.4904	3.2495
Maximum	0.7700	8.2569	4.5453	4.8938	3.5957
Minimum	0.4519	5.9056	3.5480	-8.3708	2.2170
Std. dev	0.1907	0.5751	0.2757	3.2423	0.3452
Skewness	0.5373	0.6217	0.2355	-0.6772	-0.5954
Kurtosis	2.7205	2.7802	2.1566	2.6126	2.5162
Jarque–Bera	6.9360	8.9697	4.0596	1.0187	9.2947
LnHDI	1				
p value	–				
LnGDP	0.8646	1			
p value	0.0000*	–			
LnCE	0.2058	0.4090	1		
p value	0.0166**	0.0000*	–		
LnATI	0.5541	0.5089	0.3443	1	
p value	0.0000*	0.0000*	0.0000*	–	
LnURB	-0.0149	0.1960	0.8895	0.1780	1
p value	0.8635	0.0227**	0.0000*	0.0388**	–

$^{*}<0.01$, $^{**}<0.05$, $^{***}<0.10$

of absence of causality regarding the variables was examine associated to the alternative concept of heterogenous causality in the panel opinion.

4 Results

This section presents the empirical results, commencing with a preliminary analysis of basic summary statistics and subsequent correlation analysis before delving into the baseline regression in the following section. Table 2 illustrates the descriptive statistics of the coefficients in the model. Economic growth exhibits the highest mean of $6.8175 million yearly, a median of $6.7164 million yearly, a minimum of $0.9056 million yearly, and a maximum of $8.2569 million yearly. Similarly, the human development index shows a mean of 0.6270% persons yearly, a median of 0.6481% persons yearly, a minimum of 0.4519% persons yearly, and a maximum of 0.7700% persons yearly. The investigation yields both positively and negatively skewed distributions. Per capita income, access to clean energy, and access to technological innovation reveal a positively significant correlation with the human development index, while urbanization exhibits a negatively insignificant correlation with the human development index. The variance inflation factor (VIF) or tolerance factor, the converse of VIF, echoes the findings of Pearson correlation techniques (see the Appendix for VIF/I/VIF results).

Table 3 presents estimations of the Cross-sectional Dependency assessment. The test provides a basis for the presence of cross-sectional dependence in the panel analysis, thereby offering sufficient evidence to reject the null hypothesis that supports an independent cross-section for the variables in this study. The slope Homogeneity tests of Pesaran

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

Model	Pesaran (2007) CD Test	Pesaran (2015) LM Test	Breusch and Pagan (1980) LM Test	Assessing for SH ($\widetilde{\Delta}$ test)	Assessing for SH ($\widetilde{\Delta}$ adj test)
LnHDI = f(LnGDP, LnCE, LnATI, LnURB)	− 23.785	− 1.133	4537.89	6.765	7.159
p value	0.0026*	0.004*	0.000*	0.002*	0.00*

*<0.01

Table 4 Panel CIPS and CADF unit root test

COEFFICIENTS	CIPS		CADF		Decision
	I(1)		I(1)		
	C	C&T	C	C&T	
LnHDI	− 4.9060*	− 5.0550*	− 5.1697*	− 5.1293*	I(1)
LnGDP	− 4.1260*	− 4.2970*	− 5.0384*	− 5.0243*	I(1)
LnCE	− 3.7130*	− 3.9300*	− 4.4160*	− 4.3310*	I(1)
LnATI	− 4.0720*	− 4.1920*	− 4.9289*	− 4.9637*	I(1)
LnURB	− 5.1590*	− 5.1690*	− 5.3028*	− 5.2256*	I(1)

*<0.01

Table 5 Westerlund (2007) cointegration test

Statistics	Value	p value
Gτ	− 0.303	0.000*
Gα	− 1.551	0.000*
Pτ	− 0.512	0.000*
Pα	− 0.791	0.003*

*<0.01

and Yamagata (2008) were also significant at 1%, suggesting that the South Asian countries under study convey economic shocks among them. These test results also strongly support the absence of multicollinearity and serial autocorrelation in the datasets.

Results for the CADF and CIPS stationarity techniques, following Pesaran (2007), are outlined in Table 4 to confirm this assumption for the coefficients in the analysis. The subsequent Table 5 denotes the panel cointegration analysis. The unit root outcomes relative to the CIPS in Table 4 confirm stationarity for the variables at order one (1(I)).

The Westerlund (2007) Cointegration assessment shown in Table 5 establishes a long-run association between the highlighted variables in the panel analysis. This conclusion is evidenced in the test statistic rejecting the null hypothesis based on the significance of the obtained group statistics and the panel statistics.

The analysis techniques utilized in this study include AMG and MM-QR. The estimations exhibit closely aligned outcomes, with minimal variations within the scales of

the assessed variables and their relative statistical significance. The analysis reveals that per capita income and access to technological innovation (ATI) have a positively significant connection with the human development index in both estimations. This result indicates that both coefficients contribute to sustainable development. Moreover, this finding aligns with the observations of Asongu (2018), Steve et al. (2021), and Alola et al. (2021), supporting the comprehensive SDG-8 campaign by the UN.

Furthermore, the impact of GDP growth on HDI extends to the influence of the information and communications technology (ICT) sector. Exposure to ICT is shown to promote ecological sustainability. The likely rationale for the ICT-induced perspective on environmental sustainability is that increased efficiency in economic activity enhances both economic and environmental performance, facilitating the achievement of sustainable environments. To support this claim, Lee et al. (2017) examined 102 nations between 2000 and 2013 and found that the proliferation of ICTs is crucial for universal human growth. The study also noted that each country's financial status and type of technological investments mediate the effect of ICT on human development. This perspective is further reinforced by the spillover effect of regional ICT advancements, considering nations lacking ICT infrastructures (Asongu & Roux, 2017).

In terms of access to clean energy, the long-term impact on human development demonstrates a positive and significant effect, aligning with global economic goals. The use of clean energy mitigates ecological hazards that can adversely affect human growth and economic activity. As noted by Alola et al. (2021), Gyamfi et al. (2021a), and Gyamfi (2022), clean energy usage contributes to household well-being by fostering the adoption of new energy generation methods, sustainable resource usage, and economic and political consensus. Nations actively involved in clean energy production, particularly using hydro and biofuels, may initially pose environmental challenges compared to green energy alternatives like wind or solar. However, in the long run, with a concerted effort to maximize the proportion of clean technologies through energy funding via public–private partnerships, there is a significant increase in environmental sustainability (Energy Information Administration, 2018).

On the other hand, urbanization reveals a negative and significant effect on human development in the long run for South Asian countries. This finding is consistent with the observations of Wang et al. (2018) and Onifade et al. (2021). The relationship between urbanization and HDI is not linear and depends on how urbanization is managed. While urbanization brings various benefits, it can also lead to issues such as poverty, inequality, and isolation. For instance, despite Sub-Saharan Africa experiencing a higher level of urbanization than South Asia, its human development achievement is comparatively lower. In general, the association suggests that a growing level of urbanization correlates with a higher human development index (HDI) (Malik, 2014) (Table 6).

For robustness analysis, this study utilizes both GMM and System GMM techniques, capable of addressing cross-sectional dependency issues, as presented in Table 7. The outcomes of the robustness techniques affirm the findings of the main techniques (AMG and MM-QR), indicating that income exhibits a positive relationship with the human development index. The GMM and System GMM techniques show significant levels of 0.2096% and 0.2053%, respectively.

Furthermore, a percentage change in clean energy increases the human development index of South Asian countries by 0.0568% for GMM and 0.0674% for System GMM. Similarly, as technological innovation increases, the human development index in South Asia also increases by 0.0519% with GMM and 0.0161% with System GMM. Lastly, a

Table 6 AMG and MM-QR

Variables	AMG	MM-qtile_25	MM-qtile_50	MM-qtile_75
LnGDP	0.2728	0.2398	0.2498	0.2311
	[0.0164]	[0.0214]	[0.0191]	[0.0135]
p value	0.000*	0.000*	0.000*	0.000*
LnCE	0.0236	0.0661	0.0344	0.1693
	[0.0702]	[0.0919]	[0.0820]	[0.0578]
p value	0.036**	0.073***	0.005*	0.004*
LnATI	0.0105	0.1089	0.0112	0.0146
	[0.0027]	[0.0676]	[0.0031]	[0.0022]
p value	0.000*	0.010**	0.001*	0.000*
LnURB	− 0.0981	− 0.1089	− 0.1693	− 0.2924
	[0.0516]	[0.0676]	[0.0603]	[0.0425]
p value	0.058***	0.011**	0.006*	0.000*
Constant	− 2.2849	− 1.7221	− 1.6577	− 0.5575
	[0.4921]	[0.6439]	[0.57447]	[0.4051]
p value	0.000*	0.008*	0.005*	0.071***
Number of ID	5	5	5	5

* < 0.01, ** < 0.05, *** < 0.10

[], standard error

Table 7 GMM and system GMM

Variables	GMM	System GMM
LnGDP	0.2096	0.2053
	[0.0506]	[0.0320]
p value	0.0001*	0.0000*
LnCE	0.0568	0.0674
	[0.1149]	[0.0517]
p value	0.0217**	0.0079*
LnATI	0.0519	0.0161
	[0.0196]	[0.0096]
p value	0.0091*	0.0004*
LnURB	− 0.2999	− 0.2790
	[0.0831]	[0.0538]
p value	0.0005*	0.0000*
R^2	0.8543	0.9981
ADJ R^2	0.8447	0.9956

* < 0.01, ** < 0.05, *** < 0.10

[], standard error

percentage change increase in urbanization decreases the human development index by 0.2999% and 0.2790%, respectively, for GMM and System GMM (Fig. 1).

Form the Dumitrescu and Hurlin (2012) Granger causality test shown in Table 8, it is observed that there is a feedback causal relationship between per capita income and human development index. This implies that, the economy of the south Asia countries has impact
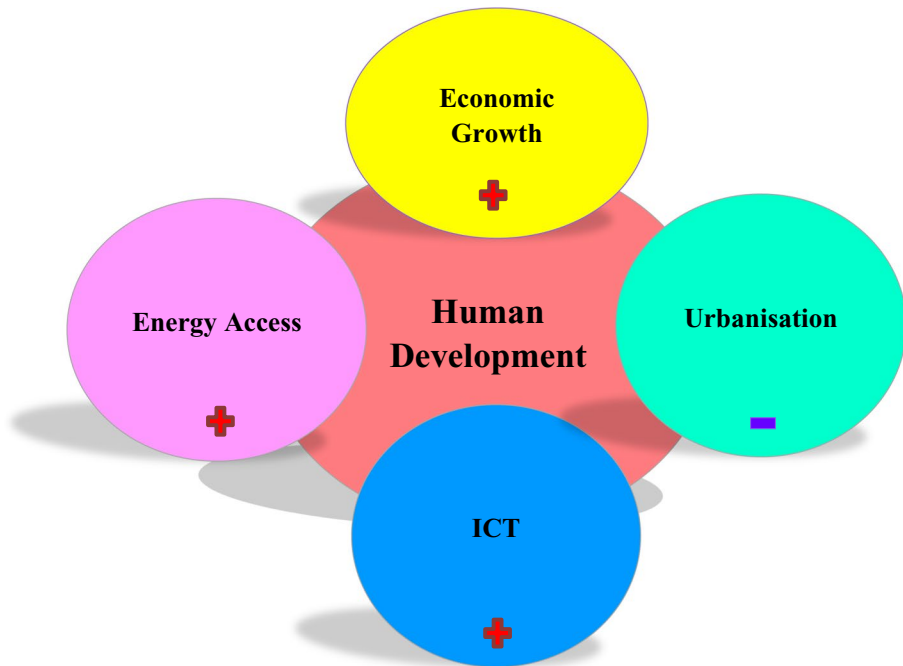
Fig. 1 Empirical Findings from GMM, AMG and MMQR

Null hypothesis	W-bar statistic	Z-bar stat statistic	p value
LnGDP→LnHDI	6.4324	3.7891	0.0002*
LnHDI→LnGDP	5.9029	3.3126	0.0009*
LnCE→LnHDI	5.5502	2.9952	0.0027*
LnHDI→LnCE	4.5368	2.0831	0.0372**
LnATI→LHDI	2.7965	0.5168	0.6052
LnHDI→LnATI	5.3880	2.8492	0.0044*
LnURB→LnHDI	12.4676	9.2208	0.0000*
LnHDI→LnUBR	8.52632	5.6736	1.E-08*

Table 8 Dumitrescu and Hurlin (2012) Granger non-causality analysis

* <0.01, ** <0.05, *** <0.10

→ ,"does not Granger-cause"

on the advancement of their human development index. Moreover, access to clean energy have a feedback causal direction on human development index. Similarly, urbanization and human development index have bi-directional causal relationship. Lastly, access to technological innovation showed a one-way connection with human development index. Which shows that, technological innovation affects the human development of the south Asia countries. These causality results have far-reaching policy implications for the investigated blocs highlighted that all the outlined variables are pertinent for better performance of the South Asian economies.

5 Discussion

In the context of South Asian economies, a significant number of countries find themselves listed among the globe's 46 least developed countries (LDCs), indicating a prevalent status of lower-income economies. The region grapples with a technological gap of approximately 20 years compared to developed economies, leading to disparities in energy usage and accessibility. Despite the surge in urban developmental processes, South Asian nations face a persistent barrier in the form of limited access to clean energy. This challenge, explored in the study, delves into the specific role of clean energy accessibility and technological development catalyzed by the burgeoning urban population.

The empirical evidence highlights the impact of energy vulnerability on household income and austerity, emphasizing the urgent need for a sustainable solution. For example, Teschner et al. (2020) advocate for clean energy access as a driver of economic growth and human development, but this quality remains a global challenge faced by many countries.

South Asian countries, including Sri Lanka, Bangladesh, India, Nepal, and Pakistan, grapple with energy shortages, heavily relying on fossil energy imports. Human development emerges as the cornerstone of sustainable economic development, and energy consumption plays a vital role in every aspect of life. While some studies emphasize the positive impact of green energy on human development, there are also different results that complicate the explanation.

This research highlights the complexity between per capita income (GDP), access to technological innovation (ATI), access to clean energy (CE), and urbanization (URB) in South Asia. Notably, GDP, CE, and ATI exhibit a positive impact on the HDI, while URB yields a negative effect. Employing a balanced panel econometric model, the findings underline the positive correlation between economic progress, as measured by GDP, and sustainable development in South Asia. The statistical evidence supporting the association between sustainable development and information technology access highlights the revolutionary power of technological innovation. This aligns with the Solow growth model, emphasizing the pivotal role of technological productivity in fostering economic efficiency at both aggregate and micro levels.

However, the study reveals a paradox regarding urbanization, typically considered a marker of progress. If urbanization is not managed effectively, urbanization can permanently lead to problems such as poverty, inequality and isolation. The findings highlight whether the link between urbanization and the HDI is compatible with non-linear parts, the development of which is a consideration of technology developments.

6 Conclusion and recommendations

6.1 Conclusion

The growth of a nation's economy and its energy usage are interconnected. However, the increasing global demand for energy has not been adequately met by supply, resulting in significant deficits at both the household and aggregate levels. This energy shortfall is termed energy poverty in the literature, particularly at the micro-level where households' energy needs remain unmet. Despite these challenges, there are few empirical findings for South Asian blocs in existing studies. Therefore, this research explores crucial catalysts of sustainable development through human development from new perspectives. The selected variables align with the UN-SDGs to justify the assertions made in this research. The Westerlund

cointegration test confirms the presence of a long-run interrelationship among the coefficients of the study, signifying their potential contribution to sustainable progression.

According to our regression analysis, economic progress in South Asia contributes to sustainable development. It indicates that increased economic activity in the region leads to better and more acceptable HDI indices. Given the positive impact on HDI performance, officials in the area should enhance macroeconomic variables to boost economic efficiency within the region. Moreover, there is statistical evidence for a favourable association between sustainable development and information technology access in South Asia. The credible and straightforward explanation for the interrelationship between sustainable development and IT access is linked to technological benefit, as highlighted in the Solow growth model (SGM). This model suggests the relevant role of technological productivity in stimulating the efficiency of commercial operations in the region at both the aggregate and micro (SME) levels, as well as its spill-over effects to other economic areas.

In South Asia, the universal access to green and sustainable energy does not necessarily translate into sustainable growth, reflecting the current state of the region. Most nations in the area face an energy deficit, resulting in insufficient energy for household and cooking operations, as well as inadequate energy for powering home devices. This shortage has a detrimental impact on HDI indices such as literacy, life expectancy, and income level. Energy access is deemed fundamental to a country's development, as stated by the US Energy Information Administration.

Our research affirms that having access to energy contributes to the region's economic development. However, due to the early stages of efforts to enhance economies through renewable energy access in most nations, growth remains limited. Furthermore, urbanization in this region hinders sustainable development, indicating that the urban growth rate does not necessarily promote sustainable development. The following are some concluding observations and policy implications drawn from the findings of this research.

6.2 Recommendations

The statistically significant positive relationship between economic progress, measured by GDP, and HDI suggests a crucial policy implication for policymakers in the South Asia region. This implies that fostering a robust economic framework will likely lead to higher literacy rates, increased income levels, and improved longevity. Consequently, there is a need to explore creating a conducive environment for sustainable development in the region. The increased access to Information and Communication Technology (ICT) resulting from technological innovation also showcases the region's potential to promote sustainable development. Policymakers should prioritize developing technical infrastructure through partnerships with private organizations and fostering a favorable environment for Foreign Direct Investment (FDI) in the ICT sector.

The research further supports the energy-induced sustainable development (SD) growth theory in the South Asia zone. This highlights that energy, facilitated by the availability of clean energy, is a major factor in sustainable development. However, the region faces significant challenges, including a substantial electricity deficit or load shedding, which has profound implications for various economic sectors, including production, services, and Small and Medium Enterprises (SMEs). This, in turn, hampers economic activity and slows down sustainable development in the area. While progress is being made in overcoming the challenges of energy poverty, further advancements are essential to stimulate continued prosperity.

Furthermore, Al Gore's documentary, "An Inconvenient Sequel," sheds light on the future of South Asia's energy landscape, featuring interviews with Indian officials discussing the shift away from coal to reduce global carbon emissions. Despite the simplicity of such statements, the reality is more complex. Even after 150 years of seemingly unstoppable economic progress in the West, challenges persist. Given the growing importance of environmental sustainability, developing nations like India have become focal points. To avert an energy crisis, strategic planning is essential in South Asia, considering limited incentives for private sector investment in renewable energy, high initial project costs, lack of government support, and sustained economic development.

Authorities must enact policies that promote clean and affordable energy access (SDG-7), including offering energy subsidies to incentivize increased production by energy firms and ensuring the availability of energy technology at a reasonable cost. To attract energy finance and encourage Foreign Direct Investment (FDI), the government should foster public–private partnerships. Improving their international reputation by addressing corruption and financial irresponsibility will position South Asian countries to obtain project finance from international institutions such as the United Nations and World Bank-associated agencies.

To address the deficit in green energy expansion in South Asia, policymakers can consider various policy suggestions and measures. First, introducing financial incentives, tax breaks, and subsidies for private companies investing in green energy projects can be effective. Additionally, establishing comprehensive frameworks to encourage investments in green energy projects and enhancing existing practices should be prioritized.

Secondly, there should be financial support and guarantees for green energy projects to mitigate investment risks. Establishing a government-backed fund dedicated to supporting renewable energy initiatives in the region would be instrumental. Allocating funds for research and development in the field of renewable energy technologies is crucial for promoting innovation and efficiency. Partnerships with research institutions and universities can expedite technological advancements in clean energy.

Investing in training programs and educational initiatives to cultivate a skilled workforce for the renewable energy sector is another imperative. Collaboration with national and international educational institutions to develop specialized courses and degrees in renewable energy technologies would contribute to building a skilled workforce.

Finally, to ensure the effectiveness of these regulations, bureaucratic obstacles should be minimized, and a set of clear and standardized rules should be established to attract more investors.

7 Appendix

See Tables 9 and 10.

Table 9 VIF estimations

Variables	VIF	1/VIF
LnGDP	2.82	0.078012
LnCE	5.61	0.116186
LnATI	5.34	0.119922
LnURB	1.17	0.854045
Mean VIF	3.735	

Table 10 Summary of studies reviewed

Author	Region	Method	Dependent Variable	Findings
Alola et al. (2021)	African states	Panel ARDL DOLS	Human development index	Economic expansion, access to energy and technological innovation in the sampled countries spur higher HDI indices
Ansari et al. (2020)	37 Asian states	GMM	Ecological and material footprint	EKC in ecological footprint exist in case of whole panel with Central-and East Asian sub-panel
Altintas and Kassouri (2020)	Europe	CCEMG	CO2 emissions	Renewable energy is an environmentally friendly source while fossil fuels contribute to environmental degradation
Alam and Murad (2020)	OECD	Panel ARDL DOLS	CO2 emissions	GDP, Tech. Innovation drives renewable energy utilization
Sarkodie and Ozturk (2020)	Pakistan	NARDL	Environmental quality	An increase in GDP per capita and household consumption expenditure increases energy consumption
Ulucak and Khan (2020)	BRICS	DOLS, FMOLS	Ecological footprint	Natural resource rent, renewable energy, and urbanization was found to reduce ecological footprint
Dogan et al. (2020)	BRICST	AMG	Ecological	EKC hypothesis is not valid, and energy intensity and energy
Khan et al. (2020)	China, India, Pakistan	FMOLS, DOLS	CO2 emissions	The application of green energy resources and green practices can mitigate negative effects on social and environmental sustainability
Destek and Sinha (2020)	OECD	DOLS, FMOLS	Ecological footprint	Results show that the inverted U-shaped Environmental Kuznets Curve hypothesis does not hold in OECD countries
Zhang et al. (2019)	Thailand	Panel ARDL DOLS	Toursim growth	This research concludes with the importance of the logistics and transport sector that deem it is necessary to increase international tourists' arrivals and enhance the quality of inbound tourism

Table 10 (continued)

Author	Region	Method	Dependent Variable	Findings
Khan et al. (2019)	South Asia	Panel models	Logistics performance	The application of green energy resources and green practices can mitigate negative effects on social and environmental sustainability in terms of higher GDP per capita, trade openness and greater export opportunities
Churchill et al. (2019)	G7	Non-parametric panel estimation	CO_2 emissions	Common trend functions gradually increased for the first 110 years (1870–1980), but then flattened out and showed a slight decrease for the next three decades
Sarkodie et al. (2019)	Australia	DADL Simulation	Environmental sustainability	Food and energy consumption underpin socio-economic development and vice versa
Nguyen and Kakinaka (2019)	107 states	Panel cointegration		CO_2 increases renewable energy use & GDP reduces renewable energy use for low income states. While CO_2 reduces, GDP increases renewable energy use
Lin and Raza (2019)	Pakistan	LMDI, Scenario analysis	CO_2 emissions	Energy supply, technology improvement, and clean energy resources are more efficient in reducing CO_2 emissions
Chang et al. (2019)	121 countries	LMDI	CO_2 emissions	significant heterogeneities in the time and spatial dynamics of the contribution of different drivers
Acheampong (2018)	116	GMM	CO_2 emissions	Energy consumption uni-directionally causes economic growth. A bi-directionally causality exists between carbon emissions and economic growth
Liu and Hao (2018)	69 countries	VECM, FMOLS, DOLS	CO_2 emissions	The Environmental Kuznets curve in China was testified

Table 10 (continued)

Author	Region	Method	Dependent Variable	Findings
Sarkodie (2018)	17 countries	Random & Fixed effect models	Environmental degradation	Energy consumption, food production, economic growth, permanent crop, agricultural land, birth rate, and fertility rate play a major role in environmental degradation and pollution in Africa
Mahalik et al. (2018)	BRICS	ARDL	Environmental quality	The long-run results based on ARDL bounds testing revealed that income inequality leads to increase in CO2 emissions for Brazil, India and China, while the same factor leads to reduction in CO2 emissions for South Africa
Zhou et al. (2018)	China	ARDL	Environmental quality	China's urban carbon emissions do not follow the inverted U-shaped hypothesis of the traditional EKC curve theory and presents an inverted N-type
Asongu and Le Roux (2017)	sub-Saharan Africa	Panel ARDL DOLS	Human development	There is a long-run relationship between EC, CE, and GDP. Second, a long-term effect from CE to GDP and EC is apparent, with reciprocal paths
Akar (2016)	Balkan states	System-GMM	Environmental degradation	Per capita GDP reduces renewable energy use, and Trade, natural gas rent increase renewable energy use

Declarations

Conflict of interest I wish to disclose here that there are no potential conflicts of interest at any level of this study.

Ethical approval Authors mentioned in the manuscript have agreed for authorship read and approved the manuscript and given consent for submission and subsequent publication of the manuscript.

Consent to participate Note Applicable.

Consent to publish Applicable.

References

Acheampong, A. O. (2018). Economic growth, CO2 emissions and energy consumption: What causes what and where? *Energy Economics, 74*, 677–692.

Adebayo, T. S., & Kirikkaleli, D. (2021). Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: Application of wavelet tools. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-021-01322-2

Agboola, P. O., Hossain, M., Gyamfi, B. A., & Bekun, F. V. (2022). Environmental consequences of foreign direct investment influx and conventional energy consumption: evidence from dynamic ARDL simulation for Turkey. *Environmental Science and Pollution Research, 29*(35), 1–14.

Akar, B. G. (2016). The determinants of renewable energy consumption: An empirical analysis for the Balkans. *European Scientific Journal, 12*(11), 594–607.

Akinsola, G. D., Adebayo, T. S., Kirikkaleli, D., Bekun, F. V., Umarbeyli, S., & Osemeahon, O. S. (2021). Economic performance of Indonesia amidst CO2 emissions and agriculture: A time series analysis. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-13992-6

Alam, M., & Murad, M. (2020). The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic cooperation and development countries. *Renewable Energy, 145*(1), 382–390.

Alola, A. A., Ozturk, I., & Bekun, F. V. (2021). Is clean energy prosperity and technological innovation rapidly mitigating sustainable energy-development deficit in selected sub-Saharan Africa? A Myth or Reality. *Energy Policy, 158*, 112520. https://doi.org/10.1016/j.enpol.2021.112520

Altıntas, H., & Kassouri, Y. (2020). Is the environmental Kuznets curve in Europe related to the per-capita ecological footprint or CO2 emissions? *Ecological Indicators, 113*, 106187.

Ansari, M. A., Haider, S., & Khan, N. A. (2020). Environmental Kuznets curve revisited: An analysis using ecological and material footprint. *Ecological Indicators, 115*, 106416.

Arisman, A. (2018). Determinant of human development index in ASEAN countries. *Signifikan, 7*(1), 113–122.

Asia and the Pacific Renewable Energy Status Report (2019) – REN21 https://www.ren21.net/asia-report-2019,https:/news.un.org/en/news/region/europe,August,28,2020june10

Asongu, S. A. (2018). Comparative sustainable development in sub-Saharan Africa. *Sustainable Development, 26*(6), 638–651.

Asongu, S. A., & Le Roux, S. (2017). Enhancing ICT for inclusive human development in Sub-Saharan Africa. *Technological Forecasting and Social Change, 118*, 44–54. https://doi.org/10.1016/j.techfore.2017.01.026

Asongu, S. A., Le Roux, S., & Biekpe, N. (2018). Enhancing ICT for environmental sustainability in sub-Saharan Africa. *Technological Forecasting and Social Change, 127*, 209–216.

Asongu, S. A., & Odhiambo, N. M. (2019). How enhancing information and communication technology has affected inequality in Africa for sustainable development: An empirical investigation. *Sustainable Development, 27*(4), 647–656.

Bamati, N., & Raoofi, A. (2020). Development level and the impact of technological factor on renewable energy production. *Renewable Energy, 151*, 946–955. https://doi.org/10.1016/j.renene.2019.11.098

Bamidele, R., Ozturk, I., Gyamfi, B. A., & Bekun, F. V. (2022). Tourism-induced pollution emission amidst energy mix: Evidence from Nigeria. *Environmental Science and Pollution Research, 29*(13), 19752–19761.

Bekun, F. V., Alola, A. A., Gyamfi, B. A., & Ampomah, A. B. (2021a). The environmental aspects of conventional and clean energy policy in sub-Saharan Africa: Is N-shaped hypothesis valid? *Environmental Science and Pollution Research, 28*(47), 66695–66708.

Bekun, F. V., Alola, A. A., Gyamfi, B. A., & Yaw, S. S. (2021b). The relevance of EKC hypothesis in energy intensity real-output trade-off for sustainable environment in EU-27. *Environmental Science and Pollution Research, 28*(37), 51137–51148.

Binder, M., & Georgiadis, G. (2010). Determinants of Human Development: Insights from State-Dependent Panel Models (SSRN Scholarly Paper ID 2351556). Social Science Research Network. https://papers.ssrn.com/abstract=2351556

Binder, M., & Coad, A. (2011). From average Joe's happiness to miserable Jane and cheerful John: Using quantile regressions to analyze the full subjective well-being distribution. *Journal of Economic Behavior & Organization, 79*(3), 275–290.

Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. *Review of Economic Studies, 47*(1), 239–253. https://doi.org/10.2307/2297111

Bugaje, I. M. (2006). Renewable energy for sustainable development in Africa: A review. *Renewable and Sustainable Energy Reviews, 10*(6), 603–612. https://doi.org/10.1016/j.rser.2004.11.002

Canay, I. A. (2011). A simple approach to quantile regression for panel data. *The Econometrics Journal, 14*(3), 368–386.

Chang, C. P., Dong, M., Sui, B., & Chu, Y. (2019). Driving forces of global carbon emissions: from time-and spatial-dynamic perspectives. *Economic Modelling, 77*, 70–80.

Churchill, S. A., Inekwe, J., Smyth, R., & Zhang, X. (2019). R&D intensity and carbon emissions in the G7: 1870e2014. *Energy Economics, 80*, 30–37.

Danish, Zhang, B., Wang, B., & Wang, Z. (2017). Role of renewable energy and non-renewable energy consumption on EKC: Evidence from Pakistan. *Journal of Cleaner Production, 156*, 855–864.

Davies, A., & Quinlivan, G. (2006). A panel data analysis of the impact of trade on human development. *The Journal of Socio-Economics, 35*(5), 868–876.

Destek, M. A., & Sinha, A. (2020). Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organization for economic Co-operation and development countries. *Journal of Cleaner Production, 242*, 118537.

Dogan, E., Ulucak, R., Kocak, E., & Isik, C. (2020). The use of ecological footprint in estimating the Environmental Kuznets Curve hypothesis for BRICST by considering cross-section dependence and heterogeneity. Sci. Total Environ. 138063

Dumitrescu, E.-I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling, 29*(4), 1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Eberhardt, M. and Bond, S. (2009). Cross-section dependence in nonstationary panel models: a novel estimator. Munich Personal RePEc Archive. http://mpra.ub.uni-muenchen.de/17692/

Eberhardt, M. and Teal, F. (2010). Productivity analysis in global manufacturing production.Discussion Paper 515, Department of Economics, University of Oxford. http://www.economics.ox.ac.uk/research/WP/pdf/paper515.pdf

Energy Information Administration, 2018. Available at: https://www.eia.gov/conference/2018/. (Accessed 1st September, 2021).

Ganger, R. N. (1969). U.S. Patent No. 3,485,027. Washington, DC: U.S. Patent and Trademark Office.

Gyamfi, B. A. (2022). Consumption-based carbon emission and foreign direct investment in oil-producing Sub-Sahara African countries: The role of natural resources and urbanization. *Environmental Science and Pollution Research, 29*(9), 13154–13166.

Gyamfi, B. A., Adedoyin, F. F., Bein, M. A., Bekun, F. V., & Agozie, D. Q. (2021a). The anthropogenic consequences of energy consumption in E7 economies: Juxtaposing roles of renewable, coal, nuclear, oil and gas energy: Evidence from panel quantile method. *Journal of Cleaner Production, 295*, 126373.

Gyamfi, B. A., Bekun, F. V., Balsalobre-Lorente, D., Onifade, S. T., & Ampomah, A. B. (2022a). Beyond the environmental Kuznets curve: Do combined impacts of air transport and rail transport matter for environmental sustainability amidst energy use in E7 economies? *Environment, Development and Sustainability, 29*(9), 13154–13166.

Gyamfi, B. A., Onifade, S. T., Nwani, C., & Bekun, F. V. (2022b). Accounting for the combined impacts of natural resources rent, income level, and energy consumption onenvironmental quality of G7 economies: A panel quantile regression approach. *Environmental Science and Pollution Research, 29*(2), 2806–2818.

Gyamfi, B. A., Ozturk, I., Bein, M. A., & Bekun, F. V. (2021b). An investigation into the anthropogenic effect of biomass energy utilization and economic sustainability on environmental degradation in E7 economies. *Biofuels, Bioproducts and Biorefining, 15*(3), 840–851.

Kazar, G., & Kazar, A. (2014). The renewable energy production-economic development nexus. *International Journal of Energy Economics and Policy, 4*(2), 312–319.

Khan, A., Chenggang, Y., Xue Yi, W., Hussain, J., Sicen, L., & Bano, S. (2020). Examining the pollution haven, and environmental kuznets hypothesis for ecological footprints: An econometric analysis of China, India, and Pakistan. *Journal of the Asia Pacific Economic.* https://doi.org/10.1080/13547860.2020.1761739

Khan, S. A. R., Jian, C., Zhang, Y., Golpîra, H., Kumar, A., & Sharif, A. (2019). Environmental, social and economic growth indicators spur logistics performance: from the perspective of South Asian Association for Regional Cooperation countries. *Journal of Cleaner Production, 214*, 1011–1023.

Koenker, R., Bassett Jr, G. (1978). Regression quantiles. Econometrica Journal of the Econometric Society, 33–50.

Koenker, R. (2004). Quantile regression for longitudinal data. *Journal of Multivariate Analysis, 91*(1), 74–89.

Lee, S. O., Hong, A., & Hwang, J. (2017). ICT diffusion as a determinant of human progress. *Information Technology for Development, 23*(4), 687–705.

Lin, B., & Raza, M. Y. (2019). Analysis of energy related CO2 emissions in Pakistan. *Journal of Cleaner Production, 219*, 981–993.

Liu, Y., & Hao, Y. (2018). The dynamic links between CO2 emissions, energy consumption and economic development in the countries along "the Belt and Road." *Science of the Total Environment, 645*, 674–683.

Maccari, N. (2014). Environmental sustainability and human development: A greening of human development index. Available at SSRN 2426073.

Machado, J. A., & Silva, J. S. (2019). Quantiles via moments. *Journal of Econometrics, 213*(1), 145–173.

Mahalik, M. K., Mallick, H., Padhan, H., & Sahoo, B. (2018). Is skewed income distribution good for environmental quality? A comparative analysis among selected BRICS countries. *Environmental Science and Pollution Research., 25*(23), 23170–23194.

Malik, U. A. (2014). Urbanization and human development: A new look, briefing paper Mahbub ul Haq human development centre, Lahore. We address https://mhrc.lums.edu.pk/sites/default/files/user376/urbanization_and_human_development_0.pdf, (Accessed)

Mohamed, M., Murray, A., & Mohamed, M. (2010). The role of information and communication technology (ICT) in mobilization of sustainable development knowledge: A quantitative evaluation. *Journal of Knowledge Management, 14*(5), 744–758.

Narayan, S. (2020). Energy cooperation in South Asia: Utilizing natural resources for peace and sustainable development—In Mirza Sadaqat Huda, Taylor and Francis, https://www.isas.nus.edu.sg/books/fueling-south-asias-energy-goals/

Nguyen, K. H., & Kakinaka, M. (2019). Renewable energy consumption, carbon emissions, and development stages: some evidence from panel cointegration analysis. *Renewable Energy, 132*, 1049–1057.

Nickell, S. (1981). Biases in dynamic models with fixed effects. *Econometrica: Journal of the Econometric Society, 49*, 1417–1426.

Odugbesan, J. A., Adebayo, T. S., Akinsola, G. D., & Olanrewaju, V. O. (2021). Determinants of environmental degradation in Thailand: Empirical evidence from ARDL and wavelet coherence approaches. *Pollution, 7*(1), 181–196. https://doi.org/10.22059/poll.2020.309083.885

Oladapo, I. A., & Ab Rahman, A. (2016). Re-counting the determinant factors of human development: a review of the literature. *Humanomics, 32*(2), 205–226.

Onifade, S. T., Gyamfi, B. A., Haouas, I., & Bekun, F. V. (2021). Re-examining the roles of economic globalization and natural resources consequences on environmental degradation in E7 economies: Are human capital and urbanization essential components? *Resources Policy, 74*, 102435.

Oyedepo, S. O. (2014). Towards achieving energy for sustainable development in Nigeria. *Renewable and Sustainable Energy Reviews, 34*, 255–272. https://doi.org/10.1016/j.rser.2014.03.019

Pesaran, H. M. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics, 22*, 265–312. https://doi.org/10.1002/jae.951

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews, 34*(6–10), 1089–1117. https://doi.org/10.1080/07474938.2014.956623

Pesaran, M. H., & Smith, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of Econometrics, 68*(1), 79–113. https://doi.org/10.1016/0304-4076(94)01644-F

Pesaran, M. H., Ullah, A., & Yamagata, T. (2008). A bias-adjusted LM test of error cross-section independence. *Econometrics Journal, 11*(1), 105–127. https://doi.org/10.1111/j.1368-423X.2007.00227.x

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics, 142*(1), 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010

Pîrlogea, C. (2012). The human development relies on energy. *Panel Data Evidence Procedia Finance, 3*, 496–501. https://doi.org/10.1016/S2212-5671(12)00186-4

Sadath, A. C., & Acharya, R. H. (2017). Assessing the extent and intensity of energy poverty using multidimensional energy poverty index: Empirical evidence from households in India. *Energy Pol., 102*, 540–550.

Sarkodie, S. A. (2018). The invisible hand and EKC hypothesis: What are the drivers of environmental degradation and pollution in Africa? *Environmental Science and Pollution Research, 25*(22), 21993–22022.

Sarkodie, S. A., & Ozturk, I. (2020). Investigating the environmental kuznets curve hypothesis in Kenya: A multivariate analysis. *Renewable and Sustainable Energy Reviews, 117*, 109481.

Sarkodie, S. A., & Strezov, V. (2019). Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. *Science of the Total Environment, 646*, 862–871.

Sarkodie, S. A., Strezov, V., Weldekidan, H., Asamoah, E. F., Owusu, P. A., & Doyi, I. N. Y. (2019). Environmental sustainability assessment using dynamic autoregressive distributed lag simulations nexus between greenhouse gas emissions, biomass energy, food, and economic growth. *Science of the Total Environment, 668*, 318–332.

Sharma, R., Sinha, A., & Kautish, P. (2020). Examining the impacts of economic and demographic aspects on the ecological footprint in South and Southeast Asian countries. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-020-09659-3

Soylu, Ö. B., Adebayo, T. S., & Kirikkaleli, D. (2021). The Imperativeness of environmental quality in China amidst renewable energy consumption and trade openness. *Sustainability, 13*(9), 5054. https://doi.org/10.3390/su13095054

Soukiazis, E., Muchová, E., & Leško, P. (2017). Are the transition economies balance-of-payments constrained? An aggregate and multisector approach applied to Central and Eastern Europe. *Eastern European Economics, 55*(5), 453–476.

Steve, Y. S., Murad, A. B., Gyamfi, B. A., Bekun, F. V., & Uzuner, G. (2021). Renewable energy consumption a panacea for sustainable economic growth: Panel causality analysis for African blocs. *International Journal of Green Energy*. https://doi.org/10.1080/15435075.2021.1966793

Swamy, P. A. (1970). Efficient inference in a random coefficient regression model. *Econometrica: Journal of the Econometric Society*. https://doi.org/10.2307/1913012

Teschner, N., Sinea, A., Vornicu, A., Abu-Hamed, T., & Negev, M. (2020). Extreme energy poverty in the urban peripheries of Romania and Israel: Policy, planning and infrastructure. *Energy Research & Social Science, 66*, 101502.

Ulucak, R., & Khan, S. U. D. (2020). Determinants of the ecological footprint: Role of renewable Energy, natural resources, and urbanization. *Sustainable Cities and Society, 54*, 101996.

United Nations Development Programme UNDP (2018.) Human Development Indices and

United Nations. (2020). United Nations LDCs at a Glance.

Wang, Z., Bui, D., Zhang, B., Lasantha, C., Nawarathna, K., & Mombeuil, C. (2021). The nexus between renewable energy consumption and human development in BRICS countries: The moderating role of public debt. *Renewable Energy, 165*(1), 381–390.

Wang, Z., Bui, Q., & Zhang, B. (2020). The relationship between biomass energy consumption and human development: Empirical evidence from BRICS countries. *Energy, 194*, 116906.

Wang, Z., Zhang, B., & Wang, B. (2018). Renewable energy consumption, economic growth and human development index in Pakistan: Evidence form simultaneous equation model. *Journal of Cleaner Production, 184*, 1081–1090.

Welsch, H., & Biermann, P. (2017). Energy affordability and subjective well-being: Evidence for European countries. *Energy J., 38*(3), 159–176.

Westerlund, J., & Edgerton, D. L. (2007). New improved tests for cointegration with structural breaks. *Journal of Time Series Analysis, 28*(2), 188–224. https://doi.org/10.1016/j.econlet.2007.03.003

World Bank Development Indicator (WDI) (2020). Available at World Bank Open Data | Data. Accessed 25 April 2020.

Zhang, L., Li, Z., Kirikkaleli, D., Adebayo, T. S., Adeshola, I., & Akinsola, G. D. (2021). Modeling CO2 emissions in Malaysia: An application of Maki cointegration and wavelet coherence tests. *Environmental Science and Pollution Research, 28*(20), 26030–26044. https://doi.org/10.1007/s11356-021-12430-x

Zhang, Y., Khan, S. A. R., Kumar, A., Golpîra, H., & Sharif, A. (2019). Is tourism really affected by logistical operations and environmental degradation? An empirical study from the perspective of Thailand. *Journal of Cleaner Production, 227*, 158–166.

Zhou, Y., Fu, J., Kong, Y., & Wu, R. (2018). How foreign direct investment influences carbon emissions, based on the empirical analysis of Chinese urban data. *Sustainability, 10*(7), 2163.

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