The relationship between financial development and renewable energy consumption in South Asian countries

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Abstract
We analyse how financial development and renewable energy consumption are linked in the selected countries of South Asia using data covering from 1990 to 2018. On the indication of cross-sectional dependency among the variables of the models, we apply second-generation panel unit root tests and cointegration tests to check stationarity properties and long-run cointegrating relationships. We find that variables are stationary at the first difference, and long-run cointegration exists. By applying robust heterogeneous and cross-section augmented dynamic estimators, we find that growth in GDP increases renewable energy consumption by about 0.50–1.56%; however, it reduces by 0.01–0.03% after particular thresholds. Furthermore, on average, an increase in financial development reduces the propensity of renewable energy consumption by 0.07–0.15% in the long-run. On the other hand, panel causality results show unidirectional relationships from GDP to financial development and from financial development to renewable energy consumption but not vice versa. We suggest that the selected countries revisit and restructure the renewable energy policy and focus on institutional reforms to strengthen renewable energy development in the upcoming years.

Keywords Renewable energy · Financial development · Sustainability · Institutional reforms · South Asia

JEL Classification Q41 · Q42 · Q43 · Q48

Introduction
Energy has been playing a significant role when it comes to the world’s economic growth. Among others, Rehman et al. (2019); Amin et al. (2020a); and Amin and Rahman (2019) explicitly highlight that energy tends to play a major role in shaping the country’s many social aspects. Besides, given the importance of energy within the economies, Amin (2015) points out that historically, economies that achieved growth beyond subsistence level have at least ensured minimum level of energy for the consumers and producers. In the last couple of decades, energy demand has grown substantially, and it continues to grow with a significant rate. According to the British Petroleum’s recent statistics (BP, 2020), world energy demand has an increasing trend. Since 2010, the observed average growth is 1.6%. In 2018, the average growth rate of energy demand was 2.05%. Additionally, energy demand will increase by 1.3% annually till 2040 if the current consumption pattern prevails, and no policy changes are considered. The increasing demand for energy is attributed to population growth, changing lifestyles, improvements in production, household compliances, and economic development. Moreover, it is very important to indicate that the larger shares in the world energy mix are still occupied by three types of fossil energies, namely, oil, gas, and coal. According to the International Energy Agency’s latest statistics (IEA, 2020), the combined share of oil, gas, and coal in the world primary energy mix is 84.30%.

Recent statistics reveals that more than 80% of electricity generation depends on fossil energy (REN17, 2017; IEA, 2020). The environmental impact of using large amount of fossil energy for meeting our daily needs is detrimental.
Existing literature shows that high use of fossil energy pollutes air and water, hinders wildlife and habitat, damages public health, and increases global warming emissions. According to the Global Carbone Project (GCP) (2019), global CO₂ emissions from fossil energy were 37.15 gigatonnes (GtCO₂) in 2018, where China and India contributed around 35%. Moreover, the electricity sector alone was responsible for emitting 44% of the total CO₂ in 2018 (IEA, 2019). Since non-replenishable resources will not last forever and environmental sustainability for future is essential, energy diversification is very much needed, which has paved the way for renewable energy development.

Amin et al. (2018) and Khandker et al. (2018) argue that apart from ensuring global energy security, renewable energy helps to improve energy resilience and prevents environmental degradation due to its inexhaustibly and decentralised characteristics. However, induction of renewable energy within the economic system for various uses (such as electricity) tends to be very costly, especially in the case of developing countries. It requires high start-up costs, high research and development (R&D) spending, and a very sophisticated operational activities. A sound financial system is predicted to be an essential component in this context to ensure the efficient management and financing projects, market liquidity, and risk management (Kamp and Forn, 2016; Khan et al. 2014). Wurgler (2000) asserts that highly established financial structures accumulate investment in the rising industries. Therefore, in an atmosphere where renewable energy projects have been strongly promoted, financial growth would play a significant role.

Several empirical studies have been conducted to determine the linkage between economic growth, financial development, and energy consumption. Nevertheless, these studies have provided ambiguous results. There are very few studies exploring the role of financial development in renewable energy consumption. Among others, Sonntag-O’Brien and Usher (2004); Brunnschweiler (2010); Burakov and Freidin (2017); Shahbaz et al. (2013); Lin et al. (2016); Hassine (2017), Yazdi and Shakouri (2017); and Ali et al. (2018) find that a developed financial system is very much necessary for the development of the renewable industry. Rasoulinezhad and Saboori (2018) find short-run unidirectional relationship between financial transparency, economic growth, and renewable energy consumption. Eren et al. (2019) also reveal unidirectional causal links that extend from financial growth to renewable energy consumption and GDP growth in the long-run. Ali et al. (2018) indicate that Asian countries with low-, middle-, and high-income status have bidirectional relationships between financial development and different renewable energies. Yazdi and Shakouri (2017) also highlight bidirectional tie between financial growth and the use of renewable energy. However, the unidirectional causality of renewable energy utilisation to private sector loans, as proxies of financial growth, is noticed by Hassine (2017). On the other hand, Burakov and Freidin (2017) fail to confirm one-way causal effect on renewable energy usage from financial progress.

Given the background, this paper is unique and contributes to the existing literature in many respects. First, no attempts have been made to identify the dynamics between financial development and renewable energy consumption in South Asia utilising panel data covering data from 1990 to 2018. Due to current international events, South Asia is a small and well-known cohort from Asia’s list of rising and developing nations (Schwab, 2018). It should be worth highlighting that in the existing literature, revisiting issues at macro-level in different smaller sub-cohorts is common to capture profound insights and tailored time-variant policy implications (Ahmed et al. 2021a; Zhang and Liu, 2019; Topcu and Payne, 2018). Second, we utilise both symmetric and asymmetric recently developed robust econometric techniques to analyse the long-run association between the variables of interest, allowing for heterogeneity and cross-sectional dependency. Third, we also introduce non-linear effects into the model to understand the relationship among financial development, renewable energy consumption, and fossil energy consumption. Fourth, we validate our results with time series country-level results. Fifth, we aim to provide a few policies for sustainable growth in South Asia based on the findings.

To find out whether variables have any cross-sectional dependency, cross-sectional dependence tests are conducted. Second-generation panel unit root tests are conducted to make sure variables are stationary. In order to establish the significant long-run cointegrating relationship among the variables, second-generation cointegration tests are also being used. Next, panel dynamic ordinary least square (PDOLS), adjusted with common time pattern, pool mean group (PMG), panel autoregressive distributed lag (panel ARDL), panel non-linear ARDL, and continuously updated fully modified OLS (Cup-FMOLS) are being employed for estimating long-run coefficients of the variable interest. Besides, ARDL and NARDL models at country-level are also being employed to monitor and corroborate the results obtained from panel analysis. Finally, the Dumitrescu–Hurlin panel causality test is used to confirm long-run causalities among variables.

The remaining paper has the following structure. The second section presents a brief overview of the literature. The third section explains data, theoretical aspects, and empirical modelling approaches. The fourth section discusses results. The fifth section finally concludes the paper with a few policy recommendations.
Literature review

Consumption of renewable energy continues to grow, and its adaptation continues to have a significant economic impact across the countries. Relatively good number of empirical works have been done to relate financial development, economic growth, and the consumption of energy. The results are discussed and summarised in Table 1. However, there still exists minimal scrutiny on the role of financial development on renewable energy consumption.

The relationship between financial development and energy consumption has been investigated by Sadorsky (2011) for Central and Eastern Europe. It was found that an increase in financial growth leads to a rise in energy consumption. Similarly, Amin and Mahmood (2018) found that in Bangladesh, financial development has a positive influence on energy consumption. On the other hand, Furutaka (2015) found out by investigating Asian countries that a developed financial system does not lead to an increase in energy consumption; however, increase in energy consumption leads to a developed financial system. The increase in energy consumption is rather determined by economic factors like price, income level, and regulations.

Sonntag-O’Brien and Usher (2004) suggested that the degree of investment in the renewable energy projects can be critical. For example, renewable energy projects are comparatively expensive. These include high start-up costs, long-term loan repayments, and significant research and development expenditures. An established sector-specific financial system could channel funds effectively to the renewable energy industry. On the other hand, an underdeveloped financial system could lead to halt in the creation of new projects.

Brunnschweiler (2010) investigated the effect of financial intermediation on the generation of sustainable energy sources using panel data from 1980 to 2006 for the 119 non-OECD developed and emerging countries. International investment is found to be concentrated in the financial sector in these countries as stock and bond markets are not well developed, and risk capitalism is not anticipated. Their findings suggested that the energy firms of the emerging economies rely mainly upon international funding for new ventures.

Using data from 1980 to 2011, Lin et al. (2016) examined the factors of renewable electricity generation which affected China’s use of renewable energy in China. The Johansen methodology for cointegration and the vector error correction model (VECM) are used to examine the long-run and short-run relation between the variables. Different explanations depending on the empirical analysis were provided. First, real GDP per capita supports the renewable energy contribution to China’s total electricity use. Second, international investment and trade openness reduce the share of renewable energy in the electricity generation. Third, financial performance with the minimal effect would have a substantial and vital influence on the share of renewable energy in electricity generation. Fourth, the impact of renewable energy is enormous from traditional fossil energies from the environmental perspective. The causal links of renewable energy consumption, real GDP, trade, and financial growth were examined in the Gulf Countries of Cooperation (GCC) by Hassine (2017). The causalities from consumption of renewable energies to private sector loans (as proxy of financial development) are unidirectional. The study also revealed positive long-run impacts from the consumption of renewable energies to financial development.

Rasoulinezhad and Saboori (2018) studied the long-run and short-run causal relations between economic development, financial openness (proxy by Chinn–Ito index), renewable energy consumption, and fossil energy consumption in the 12 Commonwealth countries. Dumitrescu–Hurlin panel causality results indicated long-run bidirectional causality among all the variables. Using panel error correction model (ECM), they also found existence of short-run causalities from financial openness to renewable energy consumption as well as financial openness to fossil energy consumption. Similarly, Ali et al. (2018) studied the relationship between financial growth, commercial health, renewable energy, tourism, and overall reserves. The outcomes of panel Granger causalities from the VECM revealed bidirectional causal relationship between financial development and renewable energy-related variables for the low-, medium- and high-income countries in Asia.

Long-run management of sustainable energy consumption, financial sustainability, and economic growth in India from 1971 to 2015 was discussed by Eren et al. (2019). Unidirectional causal relations between financial growth, renewable energy consumption, and GDP were found from the VECM based Granger causality test. Similarly, Burakov and Freidins (2017), using VECM method, analysed the causal association between financial development, economic development, and renewable energy consumption for Russia. They asserted that the growth of financial sector would help renewable energy consumption. On the other hand, expanding renewable energy options would contribute to economic growth and financial security.

Shahbaz et al. (2013) analysed the case of Indonesia and concluded that GDP and domestic energy demand growth contribute to greater CO2 emissions, and they are being limited by financial progress and liberalisation. It was also observed that financial growth leads to the spread of sustainable energy consumption. Yazdi and Shakouri (2017) explored the causal links between renewable energy
| Study                          | Time period       | Country                        | Method                        | Result                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------|-------------------|--------------------------------|-------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Brunnschweiler (2010)         | 1980–2006         | 119 non-OECD countries         | GLS and difference GMM       | Energy firms of the less developed economies rely mainly upon international funding for new ventures                                                                                                                                                                                                                                         |
| Lin et al. (2016)             | 1980–2011         | China                          | VECM                          | International investment reduces the share of renewable energy. The effect on renewable energy is enormous from traditional fossil energies                                                                                                                                                                                                      |
| Hassine (2017)                | 1980–2012         | Gulf Countries of Cooperation  | VECM                          | The causalities from the use of renewable energies to private sector loans are unidirectional. The study also reveals positive long-run impacts from the consumption of renewables to finance                                                                                                                                                        |
| Rasoulinezhad and Saboori (2018) | 1992–2015       | 12 Commonwealth countries      | Dumitrescu–Hurlin panel causality | The key observational findings show that all the factors have bidirectional relationship                                                                                                                                                                                                                                                     |
| Ali et al. (2018)             | 1995–2015         | 19 Asia cooperation dialogue members | VECM                          | Bidirectional relationship between financial development and the renewable energy variables for the low-, medium- and high-income countries in Asia                                                                                                                                                                                                 |
| Eren et al. (2019)            | 1971–2015         | India                          | VECM based Granger causality  | Unidirectional causal relations between financial growth, renewable energy consumption, and GDP                                                                                                                                                                                                                                           |
| Burakov and Freidin (2017)    | 1997–2017         | Russia                         | VECM                          | Growth in the financial sector will help renewable energy consumption. Developing renewable energy options would contribute to economic growth and, therefore to financial security                                                                                                                                                                     |
| Shahbaz et al. (2013)         | 1975–2011         | Indonesia                      | VECM and ARDL                 | Financial growth leads to the spread of sustainable energy from renewable sources                                                                                                                                                                                                                                                         |
| Yazdi and Shakouri (2017)     | 1992–2014         | Iran                           | Granger causality             | The causalities between renewable energy use, economic development, and financial success are bidirectional                                                                                                                                                                                                                               |
| Furuoka (2015)                | 1980–2012         | Asian countries                | Dumitrescu and Hurlin panel causality | A developed financial system does not lead to an increase in energy consumption. An increase in energy consumption leads to a developed financial system                                                                                                                                                                                                 |
| Scholtens and Veldhuis (2015) | 1980–2008         | 198 countries                  | FE, RE, and dynamic panel models | Financial sector has a beneficial influence on investments in renewable energies                                                                                                                                                                                                                                                          |
| Sadorsky (2011)               | 1996–2006         | Central and Eastern European countries | System GMM                   | Financial growth leads to a rise in energy demand                                                                                                                                                                                                                                                                                     |
| Amin and Mahmood (2018)       | 1985–2013         | Bangladesh                     | Granger causality             | Financial development has a positive influence on energy consumption                                                                                                                                                                                                                                                                  |
| Zhao et al. (2021)            | Survey of 4 firms | China                          | DEMATEL                       | Firms from the energy sector should categorise critical success factors (CSFs) into cause and effect group                                                                                                                                                                                                                               |
| Ahmed et al. (2021b)          | 77 energy enterprises from 2011 to 2020 | Pakistan                      | RE                            | Significant effects of multinational subsidiary, profitability, and financial leverage on CSR disclosure                                                                                                                                                                                                                                 |
consumption, economic development, financial progress, and Iranian globalisation using annual data from 1992 to 2014. Granger causality test result revealed a two-way causality between the use of renewable energy, economic growth, and financial progress.

Using data of 198 countries, Scholten and Veldhuis (2015) performed panel regressions by applying fixed effect (FE), random effect (RE), and dynamic panel models to determine the effect on the renewables industry due to the development financial market. According to the results, the financial sector has a beneficial influence on investments in renewable energies, but the share of renewable resources is unfavourable. Results also revealed that financial support is much more likely to be spent on conventional resources. The impact of private loans on renewable capacity was found to be 11.3%. For non-renewable energy, the impact of private loans was 21.6%. This implies that financial intermediaries would channel less funds to renewable energy investors apart from the central bank, however, lower than non-renewable energy counterpart.

Corporate social responsibility (CSR) is now considered as one of the widely recognised approaches for sustainable energy sector development since it creates potential pathways for numerous types of investments. Zhao et al. (2021) investigated the influential success factors of CSR activities in China. They used Decision-Making Trial and Evaluation Laboratory (DEMATEL) for the quantitative analysis. According to the results, it was found that firms from the Chinese energy sector should categorise critical success factors (CSFs) into cause and effect groups for maximum benefit. They further proposed a unique decision-making framework for the managers to extend the CSR implementation roots within China. On the other hand, Ahmed et al. (2021b) analysed the relationship between CSR disclosures and its determinants within the energy enterprises in the case of Pakistan. For the empirical analysis, panel data of 77 energy enterprises were analysed (listed in the Pakistan Stock Market). A CSR disclosure index based on seven components was constructed with the obtained data. By applying the RE model, they revealed that multinational subsidiary, profitability, and financial leverage influence CSR disclosure in Pakistani energy enterprises.

### Data and methodology

The empirical analysis uses annual data for the period 1990–2018. Data on domestic credit to the private sector (financial development proxy), annual real GDP, renewable energy consumption, and fossil energy consumption are obtained from the World Development Indicators (World Bank, 2019).

The theoretical motivation of this paper comes from the theory of planned behaviour (TPB) (Ajzen, 1991) and the social exchange theory (SET) (Emerson, 1976). Yee et al. (2022) and Amin et al. (2022) highlight that from the last two decades, the TPB and the SET have been considered as two of the most popular theoretical frameworks for analysing human behaviours in different disciplines. Apart from renewable energy and its various aspects (Amin et al., 2022; Gamel et al. 2022; Claudy et al. 2013), both the TPB and the SET have been rigorously applied in the fields of agriculture (Fielding, et al. 2008; Wang et al. 2019), education (Underwood, 2012), finance (Raut et al. 2018; Wilson et al. 2018), and environmental quality (Amin et al. 2021b; Masud et al. 2016; Kumar, 2012).

The TPB postulates that ‘intention to act’ is the key driver fuelling the willingness to conduct any activity (i.e. production or consumption). Following the conceptualisation of Ajzen and Madden (1986), Ajzen (1991) defines intention as the motivational factor, which can measure pure willingness and efforts of the agent. Intention to do something on the other hand is highly characterised by individual attitude—an element based on prevailing subjective norms, and it tends to be significantly heterogeneous. Since individual attitude is based on subjective norms, perceived social pressure also determines individual behaviour (Yee et al. 2022). Finally, the SET captures the process through which the perceived social pressure influences individual attitudes. According the SET, attitude towards a particular activity depends on the potential benefits that are coming from the consequence of performing the activity. Once the benefits exceed the costs, agents within a group or society join the trade-off procedure.

From the perspective of energy consumption, when obtained benefits from the renewable energy consumption tend to be more significant than the other conventional energy sources, agents would focus on renewable energy development. As a result, one would expect more investment in renewable energy development. Furthermore, the investment intensity would increase as the financial sector becomes more developed. Therefore, the spectrum of renewable energy consumption would further expand. However, the situation may change if the benefits from using renewable energies become sub-optimal, which is especially true for many developing countries from the Asian region. The reason is well explained by Amin et al. (2021b, a). They point out that one of the primary reasons for sub-optimality in the benefits of renewable energy usage is the distinct difference between fossil energy and renewable energy. Fossil energies offer considerable advantages as these are readily available and comparatively easier to process depending on consumption. Therefore, a relatively significant skewness towards fossil energy generally prevails in primary energy and electricity generation. This situation lowers
the likelihood of renewable energy consumption spectrum expansion even if financial development is systematically facilitated.

Based on the discussion, following Ahmed et al. (2021a), Eren et al. (2019), and Burakov and Freidin (2017), we aim to analyse the model expressed by Eq. (1):

\[
REC_{it} = f(FD_{it}, GDP_{it}, GDP_{it}^2)
\]  
(1)

In this model, \(REC_{it}\) = renewable energy consumption, \(FD_{it}\) = financial development, and \(Y_{it}\) = GDP. Also, we extend our analysis by investigating the relationship between fossil energy and financial development following the same framework. The result of this paper would help distinguish between the impacts of financial development on renewable and fossil energies. Equation (2) shows the model considering fossil energy:

\[
FEC_{it} = f(FD_{it}, GDP_{it}, GDP_{it}^2)
\]  
(2)

We transform Eqs. (1) and (2) into a log-linear format for the estimation purpose. Equations (3) and (4) show the log-linear transformation of both the models. One of the advantages of using a log-linear equation is that the estimated coefficients can be expressed as elasticities (i.e. percent change), which is very effective in policy implications. Also, such transformation reduces the skewness that exists in the variables. \(\rho_i\) and \(\pi_i\) capture individual effects. \(\epsilon_{it}\) and \(\omega_{it}\) are the error terms:

\[
lnREC_{it} = \alpha + \beta lnFD_{it} + \gamma lnGDP_{it} + \delta lnGDP_{it}^2 + \rho_i + \epsilon_{it}
\]  
(3)

\[
lnFEC_{it} = \mu + \delta lnFD_{it} + \theta lnGDP_{it} + \phi lnGDP_{it}^2 + \pi_i + \omega_{it}
\]  
(4)

Cross-sectional dependency tests

Breusch–Pagan LM (Breusch and Pagan, 1980), Pesaran’s cross-sectional dependence (Pesaran, 2004), and Pesaran scaled LM (Pesaran, 2004) tests are applied to investigate the possible inter-dependence among the variables within the regions as it has been shown by many studies that often data of economic variables are inter-related across the region (Topcu and Payne, 2018; Amin et al. 2020b; Amin and Khan, 2021).

Panel unit root tests

CADF and CIPS have been employed as suggested by Pesaran (2007). Both measures have a cross-sectional presumption of dependency. The CADF and CIPS testing processes are identical, but the only difference is that CIPS has a cross-cutting sectional average of CADF testing. Let’s assume, \(x_{it}\) is the target variable, and \(\epsilon_{it}\) is the error, and we can write a normal ADF frame-dependent equation. This is the following equation:

\[
\Delta x_{it} = \alpha + \beta \tau_{i,t-1} + \rho_i T + \sum_{j=1}^{n} \theta_i \tau_{i,t-1} + \epsilon_{it}
\]  
(5)

The first differentiated operator \(\Delta\) is indicated in Eqs. (5). \(\alpha\) and \(T\) are both the intercept and the time trend. The null hypothesis of the tests assumes that variables are not stationary within the cross-section in the panel dataset.

Cointegration tests

We have used the Durbin–Hausman test (Westerlund, 2008). It is one of the most used second-generation panel cointegration tests in the current empirical literature. In this test, the cross-sectional dependency issue has been augmented. In addition, no previous knowledge about the integration order of the variable is needed for the Durbin–Hausman evaluation. Two tests are categorised for the Durbin–Hausman method. These are the Durbin–Hausman panel (DHP) and the Durbin–Hausman group (DHg). The following equations describe both the DHP and DHg tests:

\[
DH_p = \hat{S}_n(\hat{\theta} - \tilde{\theta})^2 \sum_{i=1}^{N} \sum_{t=2}^{T} \hat{\epsilon}_{i,t-1}
\]  
(6)

\[
DH_g = \sum_{i=1}^{N} \hat{S}_i(\hat{\theta}_i - \tilde{\theta}_i)^2 \sum_{t=2}^{T} \hat{\epsilon}_{i,t-1}
\]  
(7)

\(DH_p\) tests \(H_0 : \hat{\theta}_i = \theta = 1\) for all cross-sections against \(H_1 : \hat{\theta}_i = \theta < 1\) for all cross-sections in the panel dataset. In Eq. (6), \(\hat{\theta}\) and \(\tilde{\theta}\) are considered as pooled IV and pooled OLS estimators, respectively. Moreover, \(\hat{S}_n = \sum_{i=1}^{N} (\hat{\theta}_i - \tilde{\theta})^2\) with \(\hat{\sigma}_N^2 = \frac{1}{N} \sum_{i=1}^{N} \hat{\sigma}_i^2\) and \(\tilde{\sigma}_N^2 = \sum_{i=1}^{N} \hat{\sigma}_i^2\). In contrast, \(DH_g\) tests \(H_0 : \hat{\theta}_i = \theta = 1\) for all cross-sections against \(H_1 : \hat{\theta}_i < 1\) for the panel data collection for at least one cross-section. Similar to Eq. (6), in Eq. (7) \(\hat{\theta}_i\) and \(\tilde{\theta}_i\) are considered as pooled IV and pooled OLS estimators, respectively. Next, let us define that the variance of estimator for \(\hat{S}_i = \frac{\hat{\sigma}_i^2}{\tilde{\sigma}_i^2}\) and \(\hat{\sigma}_i^2\) is consistent over a long period of time.

The LM bootstrap panel cointegration test has also been used to check the cointegration relationship. Westerlund and Edgerton (2007) have suggested a new version of LM test of McCoskey and Kao (1998) with
the bootstrap application. The following setup can obtain the LM static.

\[
LM = \frac{1}{NT^2} \sum_{t=1}^{N} \sum_{i=1}^{N} \hat{\omega}_i^2 S_{it}^2
\]  

(8)

In Eq. (8), the long-run variance is \(\hat{\omega}_i^2\), and \(S_{it}\) is the process of a partial sum of \(\hat{\epsilon}_{it}\).

**Estimation of the cointegrating factors**

The continuously updated fully modified estimator (Cup-FM) introduced by Bai et al. (2009) is one of the recent advancements in the field of heterogeneous panel estimation. Suppose we have a multifactor model, stationary dependent variables, and a set of \(m\) stationary global components:

\[
E_{it} = \gamma Y_{it}^2 + \beta Y_{it} + \epsilon_{it} \rightarrow x'_{it} + \epsilon_{it}
\]  

(9)

where

\[
\epsilon_{it} = \lambda_i^t F_i + u_{it}
\]  

(10)

\[
x_{it}' = x_{it-1}' + \epsilon_{it}
\]  

(11)

\[
F_i = F_{i-1} + \eta_i
\]  

(12)

Cup-FMOLS modifies the traditional panel bias over iterations. By resolving the following equation iteratively, the Cup-FMOLS can be achieved. Pesaran et al. (1999) proposed the pool mean group (PMG) panel ARDL model. One of the main benefits of the PMG ARDL panel evaluation is that the integration order can be used. In the following equation, the model \((p, q)\) can be defined, wherein \(T\) is set to be large enough to match the model for each category:

\[
Y_{it} = \sum_{j=1}^{p} \lambda_{ij} Y_{i,t-j} + \sum_{j=0}^{q} \theta_{ij} X_{i,t-j} + \tau_i + \epsilon_{it}
\]  

(13)

The design provides the following representation for the correction of errors:

\[
Y_{it} = \varphi_1 (Y_{i,t-1}' - X_{it}') + \sum_{j=1}^{p-1} \lambda_{ij} Y_{i,t-j} + \sum_{j=0}^{q-1} \theta_{ij} X_{i,t-j} + \tau_i + \epsilon_{it}
\]  

(14)

where disequilibrium parameter is characterised by \(\varphi_1\), which captures the long-term speed of equilibrium (or adjustment). In this paper, we have only examined the effects of a long-term estimate. We have tested potential asymmetry with the panel NARDL. This technique has the capacity to capture (if any) influence of positive and negative shocks to explanatory variable on the dependent variable of the model. ARDL model’s asymmetrical variant can be described as follows:

### Table 2 Cross-sectional dependency tests

| Tests          | Test statistics model 1 | Test statistics model 2 |
|---------------|-------------------------|-------------------------|
| Breusch–Pagan LM | 283.14***               | 168.79***               |
| Pesaran scaled LM | 48.96***               | 35.51***               |
| Pesaran CD     | −1.52                  | 1.92***                 |

The confidence rates of 99% and 95% are marked with *** and **, respectively.

### Table 3 Panel unit root test

| Variable | Level | First difference |
|----------|-------|------------------|
|          | Intercept | Intercept and trend | Intercept | Intercept and trend |
| lnFD     | −2.08  | −1.71            | −4.42*** | −4.34***          |
| lnREC    | −1.92  | −2.52            | −5.22*** | −5.15***          |
| lnGDP    | −1.86  | −2.12            | −4.60*** | −5.10***          |
| lnFEC    | −2.45  | −2.78*           | −5.96*** | −6.01***          |
| CADF     |        |                  |          |                   |
|          | Intercept | Intercept and trend | Intercept | Intercept and trend |
| lnFD     | −0.70  | 1.68             | −2.87*** | −1.35*            |
| lnREC    | 0.14   | −0.75            | −1.88**  | 0.05              |
| lnGDP    | −1.7   | −2.23            | −2.48**  | −3.18***          |
| lnFEC    | 0−0.90 | −1.20            | −2.33*   | −3.12**           |

99%, 95%, and 90% confidence rates are marked with ***, **, and *, respectively. Critical values are not stated but may be delivered on request for reasons of brevity.
The modified correction speed is in Eq. (17) which is \( \tau, \mu \) is the basic group effect, further explanatory variables are described by the value \( \omega_i, \) and \( \varphi^+ \) and \( \varphi^- \) are the positive and negative shocks to every variable. \( \varphi^+ \) and \( \varphi^- \) are defined as follows:

\[
\varphi^+_i = \sum_{k=1}^{t} \Delta \varphi_{i,k}^+ = \sum_{k=1}^{t} \max(\Delta \varphi_{i,k}, 0) \\
\varphi^-_i = \sum_{k=1}^{t} \Delta \varphi_{i,k}^- = \sum_{k=1}^{t} \min(\Delta \varphi_{i,k}, 0)
\]

(16) (17)

The dynamic OLS (DOLS) was expanded to Kao and Chiang (2001) for panel analysis. The outcome of the estimate is the following equation:

\[
Y_{it} = \beta_0 X_{it} + \sum_{j=-q}^{q} \theta_j \Delta X_{i,t+j} \Delta Y_{ij} + \varphi_{it} + \varepsilon_{it}
\]

(18)

Here, \( q \) indicates the lag or lead order that is usually selected by info criteria. The benefit of the DOLS is the monitoring of endogeneity in the model by introducing the correct lead and lagged differences of the variables. To augment cross-section dependence, a homogenous trend of time has been used as suggested by Mark and Sul (2003).

**Dumitrescu–Hurlin panel causality test**

Following confirmation of the cointegrating relationships and estimation of long-run coefficients, the Dumitrescu–Hurlin panel causality is used to validate the causality of the variables involved. In the case of cross-dependence, this test enables parameter coefficients to shift throughout the cross-sections in a reasonable small data panel collection (Dumitrescu and Hurlin, 2012). The test is applied to an uneven and heterogeneous model and to situations in which \( T > N \) or \( T < N \) are applied.

The null hypothesis is defined as \( H_0 : \beta_i = 0 \) implying that no homogeneous Granger causality for the cross-sectional units.

Otherwise, \( H_1 : \left\{ \begin{array}{l} \beta_i = 0 \quad \text{for} \quad i = 1, 2, \ldots, N \\ \beta_i \neq 0 \quad \text{for} \quad i = N + 1, N + 2, \ldots, N \end{array} \right. \) assumes no less than a causal link in the information. It also limits strongly the number of the panel units identifying the conclusion that such a null hypothesis is being rejected.

**Results and discussions**

**Cross-sectional dependency test results**

Table 2 shows that the selected variables have cross-sectional dependency across the countries for model 2. For model 1, except Pesaran CD, other two tests confirm cross-sectional dependency.

**Panel unit root test results**

Results of CADF and CIPS unit root tests are highlighted in Table 3. Both tests show that variables are stationary at the first difference but non-stationary at levels. It implies that variables follow I (1) process:

**Cointegration test results**

From Table 4, we find that variables from both the models are cointegrated in the long-run. The results allow us to investigate the long-run panel causality as well as estimation of long-run coefficients of the concerned variables.

**Estimation of the cointegrating factors**

To find out the effects of GDP and developed financial system on renewable energy and fossil energy consumptions in the long-run, we now focus on the PDOLS, PMG ARDL, and Cup-FMOLS estimation results. Looking at the results reported in Table 5, we reveal that there is a non-linear effect of GDP on renewable energy consumption (inverted ‘U’). We find that a 1% increase in GDP will lead to an increase in renewable energy consumption; however, the square term...
The coefficients of the squared GDP as per the PDOLS, PMG ARDL, and FMOLS estimations are $-0.07$, $-0.03$, and $-0.03$, respectively. Besides, financial development is positively associated with fossil energy consumption in the long-run. A 1% increase in financial development will boost fossil energy consumption by 0.28%, 0.25%, and 0.22%, respectively, as per the PDOLS, PMG ARDL, and Cup-FMOLS estimation results. This result is different from Abokyi et al. (2019) and Gokmenoglu and Sadeghieh (2019) who highlight no relationship among the variables in long-run.

Shukla et al. (2017) and Amin et al. (2021b) have shown that South Asian countries are highly dependent on fossil energy for electricity generation and other sectoral activities. We argue that these South Asia countries depend heavily on traditional energies for most of the economic and household activities. An advanced financial structure would eventually lead them to further invest in the traditional energies to ensure completion of different activities rather than renewable energy. Hence, as per the postulates of the TBT and the SET, we argue that growth in financial progress will have a detrimental effect on the utilisation of renewable energy unless there are systematic changes in the energy policy and institutional orientations.

Following Rafiq and Bloch (2016), we also use the NARDL to verify whether financial development has any asymmetric impact on the level of energy consumption. To simplify, estimators like PDOLS, PMG ARDL, and Cup-FMOLS only show how changes in the financial development would influence the consumptions of renewable energy and fossil energy symmetrically; however, due to the asymmetric effect evolving from the unobserved components, the results of positive and negative shocks may not be the same. Table 7 illustrates the impact on the level of long-run renewable energy and fossil energy consumptions from both positive and negative shocks of financial development. It is evident that a positive shock of financial development

### Table 5: Estimation of cointegrating factors of model 1

| Variables | PDOLS | PMG ARDL | Cup-FMOLS |
|-----------|-------|----------|-----------|
| lnGDP     | 0.50 (0.16)*** | 1.56 (0.66)*** | 0.85 (0.13)*** |
| lnGDP$^2$ | $-0.01$ (0.001)*** | $-0.03$ (0.01)*** | $-0.02$ (0.002)*** |
| lnFD     | $-0.15$ (0.02)*** | $-0.12$ (0.02)*** | $-0.07$ (0.001)*** |
| Inflexion point for GDP $[\exp(\beta_1/\beta_2)]$ | 19.87 | 23.78 | 19.96 |
| Turning point | 0.42 | 21.25 | 0.47 |

The confidence rates of 99%, 95%, and 90% are marked with ***,**, and *, respectively. Standard errors are in parenthesis. The error correction term (ECT) for PMG ARDL is $-0.36**$. Turning point values are in constant billion (2010 USD).

### Table 6: Estimation of cointegrating factors of model 2

| Variables | PDOLS | PMG ARDL | Cup-FMOLS |
|-----------|-------|----------|-----------|
| lnGDP     | 4.02 (2.17)$^*$ | 2.17 (1.17)$^*$ | 1.75 (0.25)*** |
| lnGDP$^2$ | $-0.07$ (0.04)$^*$ | $-0.03$ (0.02)$^*$ | $-0.03$ (0.004)*** |
| lnFD     | 0.28 (0.07)$^*$ | 0.25 (0.06)$^*$ | 0.22 (0.02)*** |
| Inflexion point for GDP $[\exp(\beta_1/\beta_2)]$ | 25.47 | 27.94 | 28.11 |
| Turning point | 115.28 | 1368.63 | 1624.74 |

The confidence rates of 99%, 95%, and 90% are marked with ***,**, and *, respectively. Standard errors are in parenthesis. The error correction term (ECT) for PMG ARDL is $-0.23**$. Turning point values are in constant billion (2010 USD).
will decrease renewable energy consumption by 0.10%, and a negative impact of financial development will increase renewable consumption by 0.13%. However, the asymmetrical impact on the consumption of renewable energy due to financial development is not valid because the Wald tests of equality supports the null hypothesis of symmetric effect. On the other hand, we can reject the null hypothesis of symmetric effect with a 10% significance level for fossil energy consumption. According to the estimation, a positive shock of financial development will increase fossil energy consumption by 0.22%, whereas a negative shock will reduce the consumption of fossil energies by 0.09% in the long-run.

By analysing panel data, we have identified the long-run linkage between the variables of interest. However, every country in our sample may not have identical cointegrated relationships because of the effect of unobserved components (Westerlund et al., 2015). Therefore, we aim to review the cointegrated linkages between our variables of interest at the country-level for further robustness check of our results by following the discussion of Salim et al. (2019). From Table 8, we can see the country-level NARDL and ARDL long-run estimation results. We find that in all the countries, cointegration exists at varying levels of statistical significance. In addition, results indicate negative and statistically significant error correction conditions (or adjustments of speeds) at different levels of statistical significance. From the renewable energy’s perspective (model 1), all the countries show symmetric relationship among the variables of interest, suggesting similarity with the conclusion of panel NARDL results reported in Table 7. According to the estimated results, a 1% increase in financial development will decrease renewable energy consumption by 0.43%, 0.36%, 0.21%, 0.14%, and 0.11% for Bangladesh, India, Pakistan, Nepal, and Sri Lanka, respectively, and vice versa.

On the other hand, none of the countries have asymmetric effect except Bangladesh for financial development and fossil energy consumption (model 2). This outcome gives the evidence of a weak level of asymmetric effect found in panel NARDL (model 2) from Table 7. For the case of Bangladesh, Wald test indicates the presence of asymmetric effect at 1% significance level. A positive shock of financial development will increase fossil energy consumption by 0.34%, and a negative will reduce fossil energy consumption by 0.24%. We argue that a relatively smaller effect of the negative shock of financial development is due to consumer reluctance resulting from their preference and high skewness of fossil energy in the primary energy mix. On the other hand, a 1% increase in financial development will symmetrically increase fossil energy consumption by 0.04%, 0.11%, 1.16%, and 0.17% for India, Pakistan, Nepal, and Sri Lanka. However, it is worth mentioning that for India, the coefficient is not significant.3

Dumitrescu–Hurlin panel causality test results

After analysing the marginal effects of the explanatory variables, we now aim to examine the long-run causal relationship among the variables. From Table 9, it is evident that there is a unidirectional causal relationship from GDP to financial development but not vice versa. Then, we find a unidirectional causal relationship from financial development to renewable energy and fossil energy consumption. Furthermore, we observe that the causal relationship from GDP growth to renewable energy consumption is unidirectional, indicating the conservation hypothesis. However, we find evidence of growth hypothesis in the case of fossil energy and GDP. The long-run causality results also justify our proposed models are robust as there is no indication of reverse causality among the dependent and independent variables.

Conclusion

There is no doubt regarding the fact that energy is a critical component of global economic growth. However, the way energy is being consumed (i.e. the skewness towards fossil energy) harms the environment, and day by day, it is becoming costly for the society. As a result, it is essential to gradually shift our consumption from traditional sources to renewable sources of energy. Since better financial structure increases the potentiality of new business and development of different commodity industries, this paper aims to discover the fundamental link between financial development and renewable energy consumption for the South Asian countries with the help of annual data covering from 1990 to 2018.

Given the stationary properties and cross-dependencies, empirical evidences have suggested that financial development, energy consumption (both renewable and fossil), and GDP are cointegrated in the long-run. We have identified unidirectional relationships from GDP to financial development and financial development to renewable and fossil energy consumptions in the long-run. From the robust long-run estimation results, it has been revealed that financial

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1 Even if one or some cross-sections do not show a cointegration relationship, it has been shown that inference from the panel estimations tends to be valid.

2 We consider autoregressive distributed lag (ARDL) bound test procedure.

3 We suspect one of the possible reasons behind such an outcome is the relatively smaller country-level data coverage (1990–2018), which is only 28 years.
### Table 8: Country-level NARDL and ARDL estimations

| Variable  | Model 1: NARDL | Model 1: ARDL | Model 2: NARDL | Model 2: ARDL |
|-----------|----------------|---------------|----------------|--------------|
| Bangladesh|                |               |                |              |
| lnGDP     | 0.47 (0.69)*** | 0.61 (0.06)**** | 8.28 (3.34)** | 0.36 (0.05)*** |
| lnGDP$^2$ | −0.01 (0.002)*** | −0.01 (0.003)*** | −1.14 (0.06)** | −0.01 (0.002)*** |
| lnFD      |                | −0.43 (0.09)*** |                | 0.49 (0.06)*** |
| lnFD$^+$  | −0.51 (0.08)*** |                | 0.34 (0.08)*** |              |
| lnFD$^-$  | −0.53 (0.26)   |                | 0.24 (0.13)    |              |
| $W_{LR}$  | 0.01           | 17.25***       |                |              |
| ECT       | −0.82***       | −0.67***       | −0.83***       | −0.43***     |
| Cointegration | 3.93*** | 4.78**        | 4.10           | 16.82***     |

| India     |                |               |                |              |
| lnGDP     | −2.38 (7.13)   | −8.63 (4.44)‘ | 0.49 (0.20)** | 4.52 (1.55)*** |
| lnGDP$^2$ | 0.05 (0.12)    | 0.15 (0.07)   | −0.01 (0.01)  | −0.07 (0.27)*** |
| lnFD      |                | −0.36 (0.16)*** |                | 0.04 (0.06)   |
| nFD$^+$   | −0.66 (0.48)   |                | 0.33 (0.18)‘   |              |
| lnFD$^-$  | 0.99 (1.55)    | −1.06 (0.73)  |                |              |
| $W_{LR}$  | 0.69           | 1.21          |                |              |
| ECT       | −0.24‘         | −0.34**       | −0.16          | −0.33**      |
| Cointegration | 4.22‘ | 5.45**        | 3.19           | 5.04**       |

| Pakistan  |                |               |                |              |
| lnGDP     | 0.44 (0.09)*** | 0.58 (0.04)*** | 4.99 (1.81)** | 0.20 (0.02)*** |
| lnGDP$^2$ | −0.11 (0.004)*** | −0.02 (0.001)*** | −0.09 (0.03)*** | −0.001 (0.009)*** |
| lnFD      |                | −0.21 (0.03)*** |                | 0.11 (0.03)*** |
| lnFD$^+$  | −0.34 (0.11)*** |                | 0.02 (0.29)    |              |
| lnFD$^-$  | −0.20 (0.04)*** |                | 0.10 (0.02)*** |              |
| $W_{LR}$  | 1.26           | 1.07          |                |              |
| ECT       | −0.91***       | −0.78***      | −1.34***       | −0.57***     |
| Cointegration | 5.86*** | 6.46***       | 7.38***         | 3.84‘        |

| Nepal     |                |               |                |              |
| lnGDP     | 0.24 (0.10)‘   | 0.30 (0.07)*** | 1.53 (0.89)‘   | 1.14 (0.83)‘ |
| lnGDP$^2$ | −0.001 (0.005) | −0.002 (0.003) | −0.06 (0.04)‘  | −0.05 (0.03) |
| lnFD      |                | −0.14 (0.05)‘  |                | 1.16 (0.59)‘ |
| lnFD$^+$  | −0.13 (0.05)‘  |                | 1.17 (0.43)‘   |              |
| lnFD$^-$  | 0.11 (0.04)‘   |                | 0.96 (0.28)‘   |              |
| $W_{LR}$  | 0.15           | 0.15          |                |              |
| ECT       | −0.89***       | −0.55***      | 0.86‘          | −0.30‘       |
| Cointegration | 4.18‘ | 3.87‘         | 4.47‘           | 3.68‘        |

| Sri Lanka |                |               |                |              |
| lnGDP     | 0.50 (0.06)*** | 0.48 (0.02)*** | 0.28 (0.16)‘   | 17.23 (5.85)*** |
| lnGDP$^2$ | −0.13 (0.003)*** | −0.12 (0.001)*** | −0.01 (0.008)  | −0.35 (0.11)*** |
| lnFD      |                | −0.11 (0.03)*** |                | 0.17 (0.06)*** |
| lnFD$^+$  | −0.08 (0.03)‘  |                | 0.15 (0.08)‘   |              |
| lnFD$^-$  | 0.17 (0.16)    |                | −0.16 (0.39)   |              |
| $W_{LR}$  | 0.36           | 0.58          |                |              |
| ECT       | −0.94***       | 0.74***       | −0.47***       | −0.68***     |
| Cointegration | 4.90‘ | 4.52‘         | 5.93***          | 4.25‘        |

The confidence rates of 99%, 95%, and 90% are marked with ***, **, and *, respectively. Standard errors are in parenthesis. ECT (model 2) of Pakistan is more than 1%, indicating instability of the economic system. Following Salim et al. (2019), we argue that the reason behind such a result is the lack of observation.
null hypothesis  & W-statistic  \\hline
$\ln \text{GDP} \rightarrow \ln \text{FD}$ & 6.98$^{**}$  \\hline
$\ln \text{FD} \rightarrow \ln \text{GDP}$ & 4.16  \\hline
$\ln \text{REC} \rightarrow \ln \text{FD}$ & 4.09  \\hline
$\ln \text{FD} \rightarrow \ln \text{REC}$ & 8.32$^{***}$  \\hline
$\ln \text{REC} \rightarrow \ln \text{GDP}$ & 2.72  \\hline
$\ln \text{GDP} \rightarrow \ln \text{REC}$ & 5.78$^{*}$  \\hline
$\ln \text{FD} \rightarrow \ln \text{FEC}$ & 3.23  \\hline
$\ln \text{FEC} \rightarrow \ln \text{FD}$ & 8.02$^{***}$  \\hline
$\ln \text{FEC} \rightarrow \ln \text{GDP}$ & 4.45$^{*}$  \\hline
$\ln \text{GDP} \rightarrow \ln \text{FEC}$ & 3.44  \\hline

The confidence rates of 99%, 95%, and 90% are marked with $^{***}$, $^{**}$, and $^{*}$, respectively.

development is negatively associated with renewable energy consumption but positively linked with fossil energy consumption. A 1% improvement in financial development will increase fossil energy consumption by 0.25% on average; however, it will reduce renewable energy consumption by 0.11% in the long-run. Country-level time series analysis was also done to fortify the panel results.

The negative relationship between financial development and renewable energy consumption indicates a gap in the renewable energy development policies. Apart from the domestic renewable energy development agendas, following Rafiq et al. (2016) and Pan et al. (2019), we argue that strategies such as liberal trade regimes (bilateral or multilateral) and tailored financial incentives for renewable technology and renewable energy infrastructure development should be highly considered. Furthermore, we propose that a regional integrated renewable energy act could be established to strengthen technical assistance among the countries, use of standard rules to maximise inter-country renewable energy investment, exchange of information within the firms, and cooperative mechanism with the countries from neighbouring regions. It would be also useful to create social awareness since acceptance of renewable energy as a leading energy source is somewhat neglected by both consumers and political agendas.

Nevertheless, achieving a greater success while executing the discussed policies, as highlighted by Imam et al. (2019) and Amin et al. (2022), we also emphasis on the institutional robustness, which should be ensured given the common trait of the South Asian countries. Among others, Cai and Aoyama (2018); Vijay et al. (2015); and Ghafoor et al. (2016) show that an absence of a decentralised system’s administrative authority (i.e. fragmentation) with a centralised setup prevents and slows the formulation of the appropriate renewable energy regulatory regime and execution framework. Furthermore, potential investments, especially in renewable energy and demand side management, also fall out due to the lack of improper administrative mechanisms (Mittal et al. 2018; Amin et al. 2021b, a). As the renewable energy augmentation process accelerates, detailed administrative mechanisms and different financial schemes should be formulated so that financing of the renewable energy projects becomes less stringent. The results and the policy implications discussed in favour of the selected South Asian countries could be precisely generalised (considering the minimal effect of unobserved common and individual components) by the similar developing and emerging countries from the neighbouring regions to ensure their future renewable energy development. However, we strongly recommend conducting empirical exercises before implementing any policies.

This paper has only considered 5 South Asian countries (Bangladesh, India, Pakistan, Nepal, and Sri Lanka) but excludes Maldives, Bhutan, and Afghanistan for preparing a balanced panel dataset. Another limitation of the paper is the absence of different control variables. The use of control variables such as institutional reforms, energy mix dynamics, the direction of trade, and geopolitical variables would have made the analysis even more dynamic.

An analysis of financial development and renewable energy consumption at the disaggregated level could be a promising continuation of this paper. Such analysis might provide meaningful insights on how financial development in the selected South Asian countries influences the consumption pattern of different types of renewable energies at sectoral level. Based on the results, different financial models could be prepared to boost the renewable energy industry development process. On the other hand, region-wise comparison of the relationship could be another avenue of extension for revealing the differences in the energy policy regimes adopted by the different governments.

**Author contribution** SA generated the idea of the paper, formulated theoretical framework, conducted empirical part, and supervised the paper. FK conducted the empirical part, reviewed literature, and prepared parts of the paper. MdR conducted the empirical part, reviewed literature, and prepared parts of the paper. All authors read and approved the final manuscript.

**Data availability** The dataset of different variables generated and/or analysed during analysis are available in the World Development Indicators (WDI) repository. Please follow the link: https://databank.worldbank.org/source/world-development-indicators.

**Declarations**

**Ethics approval** Ethical approval is not applicable for this paper since the analysis does not involve any test on animals or human subjects.
Consent to participate  Consent to participate is not applicable for this paper due to the nature of the analysis. This is a purely empirical paper using secondary macroeconomic data.

Consent for publication  Consent for publication is not applicable for this paper since the paper does not use any data or other instruments prepared by other individuals.

Competing interests  The authors declare no competing interests.

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