Impact of Renewable Energy Transition, Modernization and Regulations on Agricultural and Industrial Productivity: Is South Asia Sacrifice Productivity for Environmental Sustainability

Nouman Ghani[1], Assad Ullah Khan[2], Azra[3] and Abdul Wahab Khan[4]

https://doi.org/10.62345/jads.2025.14.1.20

Abstract

For sustainability, South Asian economies are transitioning to renewable energy (RE) sources and modern technology and applying strict regulations. But whether they compromise on productivity for environmental sustainability was unclear. To answer this question, this study aimed to empirically analyze the influence of RE transition, modernization, and regulations on the agriculture and industrial productivity of South Asian nations between 2000 and 2023. Before estimating coefficients, necessary pre-estimation diagnostic tests were conducted by the study to check econometric problems in data. Thus, the study conducted the correlation matrix for multicollinearity, Pesaran cross-sectional dependency(CD) test for CD, Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), Fisher-ADF, and Fisher-PP tests for unit root, and Durbin-Watson test for autocorrelation. The study checked cointegration among variables through the Pedroni and Kao cointegration tests. Based on the results of these pre-estimation tests, the Fully Modified Ordinary Least Square (FMOLS) method was employed by the study to estimate the variables' coefficients. The empirical outcomes revealed that both the increase in RE transition and modernization significantly improve both agricultural and industrial productivity. While regulations reduce the productivity of both agriculture and industrial sectors. In the last, the study conducted the Dumitrescue-Hurlin test to check the direction of causality among the variables. The result indicates that agriculture and industrial productivity have a bidirectional causal relation with the RE transition, modernization, and regulations. However, the study finds a unidirectional relation between FDI and industrial productivity. The findings suggest that South Asian economies should invest and encourage the transition to RE transition and modernization and remove strict regulations from agriculture and industrial sectors.

Keywords: RE Transition, Agriculture and Industrial Productivity, Modernization, FMOLS.

Introduction

Energy plays a vital role across political, cultural, economic, social, and fields driving the car of civilization by meeting all societal requirements. Energy serves diverse purposes, including electricity production, heating, and cooling applications (Faninger, 2011; Park, 2017). As energy fulfills the requirements of households, businesses, industries, and traded goods, therefore, its demand is gradually increasing. Moreover, the rising demand for energy sources (7.4 % annually) is mainly because of the high population and positive economic growth (EG).

[1]*MPhil Scholar at Department of Economics, University of Science & Technology, Bannu. Email: nouman.econo@gmail.com*
[2]*Assistant Professor, Department of Economics, University of Science & Technology, Bannu. Email: asadwazir82@yahoo.com*
[3]*Lecturer, Department of Economics, Kohat University of Science & Technology. Corresponding Author Email: azra@kust.edu.pk*
[4]*MPhil Economics, University of Science & Technology, Bannu. Email: ab.wahabeco@gmail.com*

Compliance with ethical standards: There are no conflicts of interest (financial or non-financial). This study did not receive any funding.

Consequently, the increasing dependency on energy sources is overtaking the limited availability thereby resulting in the energy crisis. The sustained supply of energy is key for a nation's EG as it caters to various demands. The South Asian countries still generate the majority of their energy from traditional non-renewable energy (NRE) sources which are not only expensive but also damaging environment (Adams et al., 2018). For instance,(Chaudhury et al., 2023) reports that South Asian nations consumed 62.2% fossil fuel energy while only 37.8% RE. South Asian countries are prominently featured among the rapidly growing economies globally. South Asian nations collectively hold a 4.21% stake in world GDP, amounting to USD 3.31 trillion (Abbas et al., 2018; Kumaran et al., 2020). Energy promotes EG by facilitating each sector of the economy, that is, services, industry, transportation, and agricultural activities (Shafie et al., 2011; X. Zhao et al., 2020).

All sectors have contributions, but the industrial sector significantly contributes to a nation's EG by generating income, creating jobs, and fostering innovation. It often catalyzes other sectors, such as agriculture and services, driving a multiplier effect on the overall economy. Industrial goods contribute significantly to a country's exports, enhancing its global competitiveness. A strong industrial base allows a nation to participate actively in international trade, improving its balance of payments and foreign exchange reserves. The industrial sector plays a significant role in South Asian economies, contributing approximately 2.6% to Afghanistan, Maldives, and Nepal, and 3.5% to Bangladesh, Bhutan, and Sri Lanka, while 3.2% to India and Pakistan GDP. Also, employment in the industrial sector is substantial with about 19%, 10%, and 16% in Afghanistan, Bhutan, and Nepal respectively, while 27%, 25%, 24%, and 22% of the workforce in Maldives, Pakistan, India, and Bangladesh (World Bank, 2023). The industrial sector, accounting for approximately 37% of global delivered energy, surpasses all other end-use sectors in energy consumption. Projections suggest that worldwide industrial usage will rise to 71,961 ZW by 2030, which was 51,275 ZW in 2006, reflecting an average yearly growth rate of 1.4% in the next 25 years (UNIDO, 2024). Energy has a crucial role in production and stands as the cornerstone of the industrial sector (Stern, 2011). In South Asia, the industrial sector stands out as the most energy-intensive segment, accounting for 45% of the total energy consumption. Following closely is domestic use at 25.1%, transportation at 13.5%, public and commercial services at 3.7%, agriculture/forestry at 2.5%, other non-specified at 1.3%, and non-energy use at 9.2%(World Bank, 2023).

In line with the industrial sector, agriculture also plays a remarkable part in boosting South Asian economies' economic development. After the global food crisis and surge in food prices observed during 2008–2009, agriculture has once again become a hot topic in international politics and the priorities of policymakers (Shrestha et al., 2023). Agriculture serves as the cornerstone of South Asian countries not only sustaining the growing population by providing food and employment but also playing a pivotal role in overall EG. Agricultural sector has a significant part in the economies of Pakistan, India, Bangladesh, and Bhutan, contributing approximately 20% to their total GDP (Finance Division Pakistan, 2023; Ministry of Finance Bangladesh, 2023; Ministry of Finance India, 2023; National Statistics Bureau Bhutan, 2023), while in Nepal, it contributes 33.1% to GDP (Ministry of Agriculture and Livestock Development Nepal, 2023). Also, employment in the agriculture sector is substantial, with around 50% of the total workforce in Pakistan, India, and Bangladesh, 31% in Sri Lanka, and the highest at 65.6% in Nepal (ILO, 2023). Approximately 55% of South Asian nations' rural labor force is engaged in this sector, and primary source of foreign reserves and fulfills the region's food requirements. Given its central role in the South Asian economies, the agricultural sector significantly influences the overall economic landscape. However, as of 2023, agricultural productivity (value-added per-worker) in South Asia, remained below 1,200 USD. The dull productivity of the agriculture sector led to increased levels of poverty, malnourishment, underemployment, and food shortages in the region. Addressing these challenges necessitates a complete understanding of the factors affecting agricultural growth and productivity. The theory has recognized various elements influencing the productivity and growth of agriculture, including GDP, capital deployment, skilled workforce, agriculture chemicals, industrialization, agriculture terms of trade, environment, and trade openness. Notably, energy stands out as a crucial factor in this situation (Zakaria et al., 2019). Energy plays a central part in agriculture, contributing significantly to both crop production and value addition. The use of human, animal, and mechanical energy is prevalent across different agricultural tasks. Agricultural sector energy needs divided into two main types: direct and indirect energy. Direct is directly applied on farms and fields, fulfilling tasks including irrigation, land preparation, cultivation, harvesting, and threshing. While indirect energy is utilized in the production, packing, and transformation of seeds, pesticides, fertilizers, and farm machinery.

Though energy is necessary for the industrial and agriculture sectors, most of the energy consumed in these sectors is derived from NRE sources. And, NRE sources proved to be environmentally unsustainable, leading to increased CO_2 emissions and exacerbating global warming in South Asia (Neupane et al., 2022). While RE sources can fulfill all energy needs at low and one-time costs without degrading the environment. Therefore, globally all nations, including South Asia, are actively undertaking various initiatives for transition to RE sources (Mehmood, 2021)to achieve environmental sustainability. Hence, nowadays RE transition is a trending topic among researchers and policymakers. Although South Asian countries are transiting to RE sources, whether the transition to RE sources compromises the productivity of agriculture and industrial sectors or not is unclear. Hence, to answer the question, the study reviewed a large number of studies but did not find a single study that empirically answered the question. Most studies analyzed the nexus between EG, environmental quality, industrialization, and RE and NRE consumption in South Asian countries in panel and individually. However, the scope of RE transition in each sector of the economy has been ignored. Also, most of the studies ignored checking for econometric problems in data. Thus, to fill the research gaps and make novel contribution, this study investigated the influence of the RE transition, modernization, and regulations on agriculture and industrial productivity in South Asian countries between 2000 and 2023.

Remaining study is organized as the following section is a review of the literature. Section 3 describes data source, models, and methodology. Empirical outcomes obtained from the methods mentioned earlier are presented and discussed in section 4. Lastly, Section 5 recaps the study.

Literature Review

This study is about the role of RE transition, modernization, and regulations on both agricultural and industrial productivity of South Asia; therefore, a literature review exploring the nexus among REC, modernization, regulations, agriculture productivity, and industrial productivity. The existing literature predominantly analyzed the nexus among RE consumption, NRE consumption, environmental degradation, and EG. However, empirical studies are scarce on the specific relationship between RE, modernization, regulations agriculture productivity, and industrial productivity.

Zhou et al. (2024) analyzed agricultural productivity in APEC countries from 2000 to 2023, focusing on the impacts of energy transition, environmental degradation, deforestation, natural resource consumption, global trade integration, and natural resource consumption. Using CS-ARDL, AMG, and CCEMG methods, their findings revealed that global trade integration energy transition was found to improve agricultural productivity. Conversely, abundant consumption of natural resources, deforestation, and environmental degradation negatively affect agricultural productivity.

Soni and RL (2024) investigated how RE consumption impacts agricultural productivity in BRICS countries from 2000 to 2020 by using ARDL method, the study found that revealed that RE consumption positively affects agricultural productivity.

Paul et al. (2023) explored the energy intensity, inequality, urbanization, and ICT asymmetric impacts on agricultural productivity between 1990 and 2020 across twenty Asia-Pacific economies. Employing panel NARDL, the study found that, in long term, both negative and positive fluctuations in urbanization, energy intensity, and ICT are asymmetric, while symmetric in the short-term.

Emami et al. (2023) examined the nexus between energy consumption and total factor productivity (TFP) in Iran's industrial sector employing a threshold-type nonlinear model. The study is based on a sample encompassing data from 110 industrial branches between 2002 and 2019. Results revealed that the state or regime of energy consumption determines how energy consumption affects TFP in the industry sector. Coefficients of the energy consumption variable exhibit a consistently negative and significant influence on TFP across all identified regimes.

Sumaira and Siddique (2023) explore energy consumption and industrialization's impact on pollution in South Asia from 1984 to 2016 by AMG and CCEMG. Results of AMG and CCEMG revealed industrialization and energy consumption as key contributors to environmental pollution. Long-run cointegration among the variables was confirmed by using Westerlund cointegration test. Furthermore, the Dumitrescu-Hurlin causality test validates a two-way causality between pollution and industrialization.

The influence of energy consumption, urbanization, and industrialization on CO_2 emissions across five South Asian countries analyzed (Voumik et al., 2023) from 1972 to 2021. The study employed the widely recognized Stochastic Regression model STIRPAT. For robustness, CS-ARDL, AMG, MG, and CCEMG models were also applied. Outcomes revealed that EG, urbanization, and industrial development contribute to an increase in CO_2 emissions.

Amin and Song (2023) comparatively investigated the nexus of REC, EG, urbanization, trade, and CO_2 emission between South and East Asian countries. Employing the CS-ARDL approach, the study finds that in South Asia CO_2 emissions rise with increased REC and EG in the long-term, but in the short-term CO_2 emissions decline with the increase in trade and REC. Meanwhile, in East Asia CO_2 emissions both in the short and long-term rise with the increase in EG, NRE consumption, trade, and urbanization, while declining with the increase in REC.

Noor et al. (2023) studied the influence of both RE and NRE sources on South Asia's sustainable development employing data from 1995 to 2019. The study utilized the Panel ARDL to evaluate both short-term and long-term effects. Findings from the panel ARDL analysis indicated that both REC and NRE consumption exerted significant and positive long-term effects on the South Asian region's sustainable development.

Ahmad and Majeed (2022) examined the influence of REC and NRE consumption on the EG of South Asian nations in the long term. Upon confirming cointegration among variables by (Kao, 1999) and (Pedroni, 1999, 2004) tests, the study used panel FMOLS estimation method. Results revealed that REC and NRE consumption increase EG in long term, and one-way causality from EG to REC was revealed.

The influence of agricultural value-added (AVA), EG, NRE consumption, RE consumption, and tourism on CO_2 emissions between 1995 and 2017 in South Asian countries investigated Usman et al. (2022) results showed that AVA, EG, and NRE consumption negative effect on environmental degradation. However, REC recovers this region's environmental quality.

Mentel et al. 2022) investigates the nexus among CO_2 emissions, industrial value added, and REC within a sample of forty-four Sub-Saharan African countries from 2000 to 2015. Additionally, the study explores whether the EKC exists while considering the industrial sector's contributions to GDP. Employing a two-step system GMM estimator, the findings revealed that a rise in the industry's share in GDP raises CO_2 emissions, while a rise in renewable electricity output mitigates CO_2 emissions. Additionally, the study indicates that RE sources act as a mediator, mitigating the influence of industrial value added on the environment. The study also confirmed the EKC between GDP per capita and CO_2 emissions.

Effect of REC and industrialization on GHG emissions in European Central Asia analyzed by (Mentel et al., 2022). Two-step system GMM estimator applied to forty-eight countries sample from 2000 to 2018. Findings show that industrialization has a positive impact on CO_2 emissions, while REC alleviates CO_2 emissions.

Growth of agricultural TFP across fifteen Southeast and South Asian economies between 2002 and 2016 was investigated by (Liu et al., 2020). Findings revealed that overall agricultural productivity decreased during the taken period. However, results also revealed that developmental investment, urbanization, and human capital have a positive while agriculture imports have a negative correlation with agricultural TFP.

Adelegan and Out (2020) examined and estimated energy impact on industrial productivity in Nigeria between 1980 and 2018 by employing the ARDL and OLS estimation techniques. Results demonstrate a significant and positive relation between gross capital formation, electricity consumption, gas consumption, and petroleum products consumption with industrial productivity in the long run. In the short term, all independent variables exhibited a direct and noteworthy relationship with industrial productivity, except electricity consumption, which showed a negative and statistically insignificant impact. Consequently, the study recommended strategic investments in alternative energy sources and emphasized the potential of incorporating abundant natural gas into Nigeria's energy portfolio.

Zakaria et al. (2019) analyzed the influence of various factors on South Asian economies' agricultural productivity from 1973 to 2015. Outcomes revealed that agricultural productivity increased with the rise in trade openness, income level, industrialization, financial development, and physical and human capital. While CO_2 emission, rural labor force, and term of trade decrease agricultural productivity in the region.

Data, Model and Methodology

Data

This study used panel data from all South Asian nations from 2000 to 2023. Data on agriculture value added and fertilizers consumption is obtained from the Food and Agriculture Organization STAT (FAOSTAT), industrial value added from the United Nations Industrial Development Organization (UNIDO), and REC from the International Energy Agency (IEA). Data on regulatory quality, number of mobile cellular subscriptions, and FDI is taken from World Development Indicators (WDI).

Empirical Models

Given the dependent and independent variables, the empirical models of this study are formulated as follows in equations (1) & (2):

$$lnAGRI.P_{it} = \alpha_0 + \alpha_1 lnREN.T_{it} + \alpha_2 lnREG_{it} + \alpha_3 lnMOD_{it} + \alpha_4 lnFERTI_{it} + \mu_{it} \quad (1)$$

$$lnIND.P_{it} = \beta_0 + \beta_1 lnREN.T_{it} + \beta_2 lnREG_{it} + \beta_3 lnMOD_{it} + \beta_4 lnFDI_{it} + \mu_{it} \quad (2)$$

Where α_0 and β_0, i, t, and μ_{it} in the models represent the constant terms, individual cross-sections, specific time dimensions, and error terms, respectively. Moreover, *AGRI.P* represents agriculture productivity, *IND.P* represents industrial productivity, *REN.T* represents renewable energy consumption, *REG* represents regulations, *MOD* represents modernization, *FERTI* represents fertilizers consumption, and FDI represents foreign direct investment. The α_1, α_2, α_3, and α_4 locate the coefficients of the concerned variables of the model shown by equation (1), while β_1, β_2, β_3, and β_4 locate the coefficients of concerned variables of the model shown by equation (2).

Variables Description

Agricultural value-added per worker is used to proxy agriculture productivity and is measured in percentage of GDP following (Huynh, 2024).

Industrial value-added per worker is used for industrial productivity as a proxy and is measured in percentage of GDP similar to (Adelegan & Otu, 2020).

Renewable energy consumption in % of total energy consumption is used for RE transition as a proxy. As (Murshed et al., 2021) did the same.

Regulatory quality: Following (Jalilian et al., 2007), for regulations, this study used the estimated value of regulatory quality as a proxy.

Internet users: For modernization, the number of internet users in the percentage of the total population is used as a proxy in this study as (Hu et al., 2025; Wang et al., 2025) also used.

Fertilizer consumption is measured in kilograms per hectare of arable land.

Foreign direct investment s measured in percentage of GDP.

Normalization and transformation: Data normalization is crucial to standardize values to a uniform unit of measurement. For instance, REC is reported in percentage of total energy consumption, the regulatory quality estimate is reported as an index, the internet user is reported in percentage of total population, whereas FDI, agriculture, and industrial value added are reported in percentage of GDP. Therefore, transforming the data using natural logarithms helps alleviate potential distortions in the series' dynamic properties. Logarithmic transformation is preferred as each coefficient shows elasticity.

Econometric Methodology

To analyze the impact of RE transition, modernization, and regulations, the study has to estimate the variables' coefficients. However, which method of estimation is appropriate is ambiguous because each method has its own purpose of use. Hence, to select a suitable estimation method, this study initially conducted various diagnostic tests. First of all, descriptive statistics is done to search for abnormalities and outliers in the data. Secondly, to check multicollinearity, correlation was employed by the study. Third,(Pesaran, 2004) CD test was conducted to check the CD. As the presence or absence of CD guides in the selection of first- or second-generation tests and estimation methods. If CD exists, second-generation diagnostic tests are used, while in the case of no CD, the first generation is applied (Pesaran, 2004) results revealed no CD, thereby compelling the application of first-generation tests and estimation methods. Thus, in the fourth step, to check stationary problems, the study conducted first-generation unit-root tests, i.e., LLC of (Levin et al., 2002), IPS of (Im et al., 2003), and Fisher-ADF and Fisher-PP of (Maddala & Wu, 1999). For estimating long-run estimates, it is necessary to check whether a cointegration relation exists among the variables. Hence, in the fifth step, first-generation cointegration tests of (Pedroni, 1999, 2004) and (Kao, 1999) conducted to check the presence of long-run nexus among variables. Finally, keeping in view the outcomes of these pre-estimation diagnostic tests, this analysis estimated the coefficients by the FMOLS. Since FMOLS do not tell anything about the direction of causation between variables, therefore to check causality direction, the causality test of (Dumitrescu & Hurlin, 2012)was applied in the last.

The causes, consequences, and tests of each of the previously stated problems are discussed below.

Multicollinearity

Model misspecification and high correlation among regressors are the main causes of multicollinearity. Ignoring it leads to inflated standard error, high R^2 but few significant t-ratio, and makes it difficult to track the influence of each regressor. Hence, this study used a correlation matrix, to find whether multicollinearity exists or not.

Correlation Matrix

Two variables in a correlation matrix are correlated when the value of correlation between them surpasses the threshold level, which is 0.70 (Rohendi et al., 2024).

Cross-sectional Dependency

Main causes of CD are economic, cultural, and geographic ties of economies. (Hadri, 2000; Levin et al., 2002) assumed that panel unit-root tests operate under the assumption of independence among cross-sections. However, (O'Connell, 1998) acknowledged that this assumption has certain limitations. In cases where cross-sections exhibit correlation; the outcomes of panel checks can be notably inaccurate. Disregarding CD issues can cause in inconsistent, biased, and misleading estimates. Consequently, the assessment of cross-section correlation becomes a crucial component of panel testing. CD involves eliminating averages when calculating bivariate correlations among series (Usman & Hammar, 2021). Therefore, before testing stationarity, (Pesaran, 2004) CD test was employed to check CDs.

Pesaran CD Test

Pesaran, (2004) stated the null hypothesis regarding cross-section dependence by focusing on the correlations among the disturbances across various cross-sectional units as shown in equation (3):

$$H_0:\ \rho_{ij} = corr(\mu_{it}, \mu_{jt}) = 0 \quad where i \neq j \tag{3}$$

(Pesaran, 2004) developed his test statistic as expressed by equation (4), which relies on computing the average of pairwise correlation coefficients ρ_{ij}.

$$CD_P = \sqrt{\frac{2T}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} T_{ij}\rho_{ij}^2} \tag{4}$$

Where, ρ_{ij}, are correlation coefficients, and derived from the residuals of models shown by equations (1)&(2).

Stationarity (Panel Unit-Root)

It is important to check the stationarity in the variables under consideration to evade spuriousness in regression. Panel estimation remains consistent when the variables are integrated at order "0" or "1," but its efficiency compromised with variables integrated at order 2. (Sharif Hossain, 2011) recommended conduction of multiple unit root tests, emphasizing the superiority of each test based on their distinct statistical properties. Each panel unit root test is chosen based on its statistical properties, considering issues related to size and power. Thus, the stationarity of variables is determined by employing four unit-root tests; LLC developed by (Levin et al., 2002), IPS developed by (Im et al., 2003), Fisher-ADF, and Fisher-PP tests developed by (Choi, 2001; Maddala & Wu, 1999).

Levin-Lin-Chu Test

The (Levin et al., 2002), often utilized as a left unilateral test, follows the ADF test method. (Levin et al., 2002) enhanced inspection formula, derived from the ADF inspection, is given below in equation (5).

$$\Delta y_{it} = \rho y_{i,t-1} + \sum_{j=1}^{k_i} \gamma_{ij}\, \Delta y_{i,t-j} + Z'_{it}\emptyset + \varepsilon_{it} \tag{5}$$

The test null and alternative hypotheses are given below:

$H_0:\ \rho = 0 \quad (unit - root)$

$H_1:\ \rho < 0 \quad (nounit - root)$

Im-Pesaran-Shin Test

It was assumed by (Levin et al., 2002) that ρ_i is the same across cross-sections due to a common unit-root process. However, the models proposed by (Im et al., 2003), as well as the Fisher-ADF and PP tests, accommodate the possibility of individual unit root processes, allowing ρ_i to change for different cross-sectional units.

Hence, for each cross-section (Im et al., 2003) stipulated individual ADF regressions as follows in equation (6).

$$\Delta y_{it} = \rho_i y_{i,t-1} + \sum_{j=1}^{k_i} \gamma_{ij}\, \Delta y_{i,t-j} + Z'_{it} + \emptyset + \varepsilon_{it} \qquad (6)$$

Null and alternative hypotheses for the test are given below:

H_o: $\rho_i = 0$ for all i

$$H_1: \begin{cases} \rho_i = 0 \text{ for } i = 1, 2, \ldots.. N_1 \\ \rho_i < 0 \quad \text{for } i = N+1, N+2, \ldots.. N \end{cases}$$

Fisher-ADF and Fisher-PP Test

Choi (2001) and Maddala and Wu (1999) introduced an alternate method, using Fisher's (1932) findings they formulate tests that aggregate ρ-value from each unit root test. If the ρ-value designated as ρ_i derived from each unit root test as ρ-value for cross-section *i,*and assume a null hypothesis of unit root for all N cross-sections, the asymptotic outcome becomes as given below in equation (7).

$$Fisher - ADF = -2 \sum_{i=1}^{N} \log(\rho_i) \qquad (7)$$

Furthermore, Choi illustrates that:

$$Z = \frac{1}{\sqrt{N}} \sum_{i=1}^{N} \phi^{-1} (\rho_i) \qquad (8)$$

Where ϕ represents the reverse of the standard normal cumulative distribution function.

Panel Cointegration

Cointegration is the existence of a long-run relation between the independent and dependent variables. Cointegration is checked as a pre-requisite before estimating long-run estimates when the variables are non-stationary at the level. Hence, before estimation, this study applied the cointegration test of (Pedroni, 1999, 2004) and (Kao, 1999) discussed as follows. Both tests rely on the residuals derived from the models shown by equation (1) & (2).

Pedroni Cointegration Test

To assess the presence of a long-term relation among variables, this study employed panel cointegration techniques of (Kao, 1999) and (Pedroni, 1999, 2004). Pedroni (1999, 2004) developed multiple statistical tests to examine the null hypothesis of no cointegration.

It is assumed that both independent and dependent variables are first-difference stationary, I(1). In the examination of long-run relations, the estimated residuals' structure is crucial. Under the null hypothesis of no cointegration, residuals of equations (1) & (2) are expected to be stationary at first difference.

For testing null hypothesis of no cointegration, denoted as shown in equation (9) follows, (Pedroni, 1999, 2004) tests seven statistics: three between-dimension and four within-dimension.

H_0: $\rho_i = 1$ for all i

where ρ_i represents the estimated residuals' coefficients.

Two distinct alternative hypotheses are posited for the two sets of tests. The first alternative, expressed as H_1: $\rho_i = \rho < 1$ for all i, is referred to by Pedroni as the within-dimension. The second alternative posits H_1: $\rho_i < 1$ for all i, termed by Pedroni as the between-dimension. All seven tests exhibit asymptotic normal distribution and the null hypothesis is rejected when the test statistics surpass critical values, thereby showing the presence of a cointegration.

Kao Cointegration Test

To validate findings, Kao residual-based test introduced by (Kao, 1999). (Kao, 1999) residual-based cointegration test we also applied. like to (Pedroni, 1999, 2004) test evaluates the long-term relationship within panel data. Kao test specifies homogeneous coefficients and cross-section-specific intercepts on the first-stage regressors but otherwise takes the same general methodology as Pedroni's tests.

To test null hypothesis of no cointegration, Kao derived the statistic given in equation (9) below.

$$ADF = \frac{t_{\hat{\rho}} + \sqrt{6N\hat{\sigma}_v}/\widehat{2\sigma}_{0v}}{\sqrt{\frac{\hat{\sigma}_{0v}^2}{2\hat{\sigma}_{0v}^2} + 3\hat{\sigma}_{0v}^2/(10\hat{\sigma}_{0v}^2)}} \quad (9)$$

Under the null of no cointegration, Kao shows that following the statistics,

Serial Correlation

Serial Correlation is the existence of a correlation between the current and lag value of a residual or variable. Its main causes are omitting necessary variables, time dependency, and inherent patterns. Not taking into account serial correlation consequently causes unreliable inference, inefficient estimates, and biased standard error(Wooldridge, 2010).Hence, to check serial autocorrelation, this study conducted the Durbin-Watson (DW) test.

Durbin-Watson Test

The Durbin-Watson test utilized the d-statistic as given below:

$$\mathrm{d} \approx 2\left(1 - \frac{\sum_{t-1}^{T} \hat{u}_t\, \hat{u}_{t-1}}{\hat{u}_{it}^2}\right) \quad (10)$$

$$\text{Since, } \hat{\rho} = \frac{\sum_{t-1}^{T} \hat{u}_t \hat{u}_{t-1}}{\hat{u}_{it}^2} \quad (11)$$

Hence, equation (10) can be expressed as given in equation (12):

$$\mathrm{d} \approx 2\,(1 - \hat{\rho}) \quad (12)$$

Since, $-1 \leq \rho \leq 1$, equation (12) implies that:

$0 \leq d \leq 4$

Since the above d-statistic has a range of 0 to 4, according to the rule of thumb: a test value equal to two indicates no serial correlation, a test value less than two shows the existence of positive serial correlation, and a test value greater than two indicates negative serial correlation.

Panel Long-Run Estimation Technique

Finally, after conducting pre-estimation diagnostic tests, the study applied FMOLS estimation technique. FMOLS is preferred over other estimation techniques because it corrects the problems of serial autocorrelation and endogeneity and enhances the accuracy of the analysis.

Fully Modified Ordinary Least Square

For panels that show cointegration (Hamit-Haggar, 2012) proposed a most suitable method of estimation, which is FMOLS. In line with (Adom & Kwakwa, 2014),for model shown by equation(1)this study expressed the FMOLS estimator as follows in equation (13).

$$\widehat{\alpha}_i = \left(\sum_{t=1}^{T} Z_t Z_t'\right)^{-1} \left(\sum_{t=1}^{T} Z_t Y_t^{+} - T\hat{J}^{+}\right) \quad (13)$$

Also, for the model shown by equation (2), the FMOLS estimator is expressed as follows in equation (14).

$$\widehat{\beta}_i = \left(\sum_{t=1}^{T} Z_t Z_t'\right)^{-1} \left(\sum_{t=1}^{T} Z_t Y_t^{+} - T\hat{J}^{+}\right) \quad (14)$$

Where, for endogeneity$Y_t^{+} = y_t - \hat{\lambda}_{0x}\hat{\lambda}_{xx}^{-1}\Delta x_t$ isa correction term, and $\hat{\lambda}_{0x}$ and $\hat{\lambda}_{xx}$ are long-run covariances' kernel estimates, and for serial correlation$\hat{J} = \hat{\Delta}_{0X} - \ddot{\lambda}_{0X}\hat{\lambda}^{-1}xx\hat{\Delta}_{XX}$ is correction term and $\hat{\Delta}_{0X}$ and $\hat{\Delta}_{XX}$are one-sided long-run covariances' kernel estimates.

Panel Causality Test

If long-run cointegration is present in a dataset, determining the direction of causality becomes essential. In cases where there is no CD, the Dumitrescu and Hurlin (2012) Granger causality test can be employed.

Dumitrescu-Hurlin Causality Test

Dumitrescu and Hurlin (2012) relies on Wald statistics to assess non-causality among individual cross-sectional entities. Mathematically, this is expressed in equation (15) as the mean of diagonal elements indicating non-causality.

$$y_{it} = \alpha_i + \sum_{j=1}^{J} \rho_i^j X_{i(t-j)} + \sum_{j=1}^{J} \beta_i^j x_{i(t-j)} + \mu_{it} \quad (15)$$

where x and y denote distinct observations, ρ_i^j denotes autoregressive parameters, and β_i^jsignifying the coefficient estimates of regression. Both ρ_i^j and β_i^j are assumed to vary across individual cross-sections. The null and alternative hypotheses are to be tested using the Wald statistic mean in equation (16) as follows:

$$W_{NT}^{HNC} = N^{-1} \sum_{i=1}^{N} W_{i,T} \quad (16)$$

where W represents the Wald test statistic calculated for each cross-section individually.

Results and Discussion

This section presents and deliberates on the outcomes obtained through the designated methodologies.

Results

First of all, descriptive statistics calculated and displayed its results in table 1. presents a summary of descriptive statistics. In descriptive statistics, means values are average values, minimum values are the lowest values, and maximum values are the highest values of the respective variables. Moreover, skewness quantifies the degree of symmetry or asymmetry in data distribution, while kurtosis quantifies the concentration of data points around the mean within a probability distribution.

Table 1: Descriptive Statistic Results

	AGRI.P	IND.P	REN.T	REG	MOD	FERTI	FDI
Mean	7.443	8.574	3.448	0.473	1.891	3.967	0.161
Median	7.215	8.348	3.840	0.389	2.197	4.693	0.083
Minimum	6.095	7.259	0.039	-3.360	-5.390	-0.430	-4.837
Maximum	9.666	10.368	4.538	4.172	4.517	5.998	7.601
Std. Dev.	0.883	0.785	1.253	0.908	1.861	1.571	1.44
Skewness	1.074	0.408	-1.748	-0.034	-1.313	-0.789	0.933
Kurtosis	3.583	2.468	4.861	6.951	5.490	2.359	7.532

In table 1, industrial productivity has the highest mean value (8.574), while foreign direct investment has the lowest mean value (0.083). Additionally, industrial productivity has the highest minimum value (7.259), indicating that industrial productivity in South Asia has never faced a downturn, while modernization holds the lowest minimum value (-5.390), indicating it has once experienced the most adverse conditions. Moreover, the lowest volatility was observed in industrial productivity, while the highest volatility was in modernization.

Next, the study conducted a correlation matrix for checking multicollinearity and presented their results in table 2.

Table 2: Correlation Matrix Results

	AGRI.P	IND.P	REN.T	REG	MOD	FERTI	FDI
AGRI.P	1	0.528	0.817	-0.162	0.450	0.153	0.449
IND.P	0.528	1	0.232	-0.202	0.020	0.020	0.335
REN.T	0.817	0.23	1	0.040	0.004	0.004	0.411
REG	-0.162	-0.202	0.040	1	0.215	0.215	0.107
MOD	0.450	0.373	0.287	0.273	1	0.306	0.011
FERTI	0.153	0.020	0.004	0.215	0.306	1	0.046
FDI	0.449	0.335	0.411	0.107	0.011	0.046	1

In table 2, every variable coefficient's value is less than the threshold value of 0.60 followed by (Rohendi et al., 2024) evident no multicollinearity between variables of the models shown by equation (1) and (2).

Next, Pesaran's (2004) CD test was employed to check CD in models shown by equations(1) and (2) and presented its results in **Table 3**. Results in **Table 3** indicate that the null hypothesis of no cross-section interdependence was accepted for both models. Consequently, it is deemed appropriate to proceed with first-generation panel unit root tests.

Table 3: Cross-sectional dependence test results

	Model 1		Model 2	
	Statistic	**Prob.**	**Statistic**	**Prob.**
Pesaran CD	0.209	0.834	0.611	0.541
Note: ***, **, and * indicate significant levels of 1%, 5%, and 10% respectively.				

Next, the stationarity of variables was checked by employing four first-generation unit-root tests, namely LLC, IPS, Fisher-ADF, and Fisher-PP tests, and their outcomes are presented in table 4.

Table 4: Panel unit-root test results

		At Level		At First Difference	
Tests	**Variables**	**Intercept**	**Trend & Intercept**	**Intercept**	**Trend & Intercept**
Levin-Lin-Chu	lnAGRI.P	-0.895	0.403	-10.422***	-9.561***
	lnIND.P	0.050	-0.102	-7.747***	-7.114***
	lnREN.T	-1.556	2.378	-10.245***	-10.133***
	lnREG	-0.927	-0.747	-11.917***	-10.854***
	lnMOD	-3.787	1.923	-27.510***	-25.266***
	lnFERTI	-1.940	-2.681***	-12.406***	-10.646***
Im-Pesaran-Shin	lnAGRI.P	1.530	1.206	-9.246***	-8.030***
	lnIND.P	1.450	0.623	-6.588***	-6.110***
	LnREN.T	0.528	2.189	-9.400***	-8.940***
	lnREG	-1.792	-0.687	-12.719***	-11.796***
	lnMOD	-1.313	-1.730	-16.742***	-16.255***
	lnFERTI	-0.385	-1.773**	-11.143***	-9.443***
Fisher-ADF	lnAGRI.P	11.230	12.393	99.844***	79.400***
	lnIND.P	11.564	1.282	69.675***	54.302***
	lnREN.T	11.729	12.817	109.772***	97.987***
	lnREG	33.399	22.752	140.726***	116.296***
	lnMOD	22.165	33.784	334.727***	325.880***
	lnFERTI	17.069	24.419*	121.063***	92.962***
Fisher-PP	lnAGRI.P	11.484	12.956	101.081***	87.804***
	lnIND.P	11.620	6.610	69.343***	74.131***
	lnREN.T	10.887	13.715	116.109***	312.168***
	lnREG	33.317	23.274	194.752***	416.435***
	lnMOD	42.010	97.956	337.191***	339.302***
	lnFERTI	19.753	24.280*	160.303***	170.761***

Note: ***, **, and * indicate significant levels of 1%, 5%, and 10% respectively.

Findings reveal that all variables are stationary at level with both intercept and trend & intercept, suggesting they are integrated of order one, except fertilizers consumption which is stationary at level with trend and intercept.
After establishing that all variables are first-difference stationary, this study checked the presence of long-term relationships among variables examined by panel cointegration tests of (Pedroni, 1999, 2004) its outcomes in table 5.

Table 5: Pedroni's residual cointegration test results

Model 1				
Statistic Type	t-Statistic	Probability	Weighted Statistic	Probability
Within-Dimension				
Panel υ	-2.834	0.998	-2.712	0.997
Panel ρ	-2.319**	0.010	-2.224**	0.013
Panel PP	-7.490***	0.000	-7.169***	0.000
Panel ADF	-10.118***	0.000	-9.217***	0.000
Between Dimension				
Group ρ	1.637	0.949		
Group PP	-0.881	0.189		
Group ADF	-2.359***	0.009		
Model 2				
Within Dimension				
Panel υ	-2.663	0.996	-2.776	0.997

Panel ρ	-2.677***	0.004	0.383	0.649
Panel PP	-6.215***	0.000	-1.291*	0.098
Panel ADF	-6.113***	0.000	-0.984	0.162
Between Dimension				
Group ρ	1.226	0.890		
Group PP	-1.853**	0.031		
Group ADF	-1.860**	0.031		

Note: ***, **, and * indicate significant levels of 1%, 5%, and 10% respectively.

Out of eleven, seven statistics significantly reject the null hypothesis of no cointegration. As the majority of statistics of the test reject the null hypothesis of no cointegration, consequently the study rejected the null hypothesis of no cointegration. The results from the Pedroni panel cointegration tests affirm a long-term relationship among all variables.

Furthermore, the Kao residual cointegration test (Kao 1999) is conducted as an alternative to validate the identified cointegration from the Pedroni test. Kao test results are presented in table 6.

Table 6: Kao's residual cointegration test results

	Model 1		Model 2	
Statistic Type	t-Statistic	Probability	t-Statistic	Probability
ADF	-1.703**	0.044	-2.696***	0.003

Note: *** and ** indicate significant levels of 10% and 5% respectively.

Kao residual cointegration test results reveal that the null hypothesis of no cointegration is rejected at a 1% significance level. This aligns with the Pedroni panelcointegration test findings, supporting the presence of a long-term relationship among the variables.

After cointegration, the study checked the serial autocorrelation by the Durbin-Watson test and displayed its results in table 7.

Table7: Durbin-Watson autocorrelation test results

	Model 1	Model 2
***d*-statistic**	0.092	0.189

Outcomes in table 7 show that the *d*-statistic for both models is less than two. Thus, according to the rule of thumb, a *d*-value less than 2 indicates positive autocorrelation, and there is positive serial autocorrelation in both models, as shown by equations (1) & (2).

Finally, after doing all pre-estimation tests, we can estimate long-run coefficients. Since, both models have positive serial autocorrelation, while no CD. Hence, for long-run estimation, this study employed FMOLS introduced by (Pedroni, 2001). FMOLS is preferred over other estimation techniques because it controls the problems of serial autocorrelation and endogeneity. However, FMOLS has a limitation that it does not account for CD. The outcomes of the panel FMOLS estimators are displayed in table 8.

Table 8: Results of the long-run elasticity estimates (FMOLS)

Model 1					Model 2				
Variables	Coefficient	S.E	t-statistic	Prob.	Variables	Coefficient	S.E	t-statistic	Prob.
lnREN.T	1.174	0.073	15.959	0.000	lnREN.T	1.760***	0.054	32.202	0.000
lnREG	-0.201	0.101	-1.979	0.049	lnREG.Q	-0.371**	0.166	-2.232	0.027
lnMOD	0.404	0.063	6.436	0.000	lnMOD	0.913***	0.091	9.926	0.000
lnFERTI	0.311	0.075	4.163	0.000	lnFDI	1.266***	0.113	11.167	0.000

Note: *** and ** indicate significant level of 1% and 5% respectively.

Outcomes of long-run estimates derived from the panel FMOLS estimators, as presented in table 8, exhibit consistent signs, magnitudes, and statistical significance across all coefficients, indicating robust and reliable findings suitable for statistical inference. Panel FMOLS results, in Table 6, consistently demonstrate that RE transition, fertilizers consumption, and modernization has a positive impact while regulations have a negative impact on both agriculture and industrial productivity in South Asian nations. Moreover, the elasticity of agriculture productivity with respect to REC, regulations, modernization, and fertilizers consumption is 1.174, -0.201, 0.404, and 0.311 respectively. More precisely, a 1% increase in REC, modernization, and fertilizers consumption increase agriculture productivity by 1.174%, 0.404%, and 0.311% respectively, while 1% increase in regulations decreases agriculture productivity by 0.201%. Similarly, the findings, in Table 6, demonstrate that the elasticity of industrial productivity with respect to REC, regulations, modernization, and FDI is 1.760, -0.371, 0.913, and 1.266 respectively. Precisely, a 1% increase in REC, modernization, and FDI increases industrial productivity by 1.760%, 0.913%, and 1.266% respectively, while a 1% increase in regulations declines industrial productivity by 0.371%.

Since panel FMOLS cannot detect causality between variables, the recently introduced (Dumitrescu & Hurlin, 2012) panel causality test was thus applied by the study to find causality direction and presented its results in table 9.

Table 9: Dumitrescue-Hurlin Causality test results

Causality	W-bar statistic	Z-bar statistic	Prob.
REN.T doesn't cause AGRI.P	2.677	2.547	0.011
AGRI.P does not cause REN.T	3.480	3.859	0.000
REG doesn’t cause AGRI.P	13.269	2.194	0.028
AGRI.P doesn’t cause REG	18.384	3.984	0.000
MOD doesn’t cause AGRI.P	4.503	5.530	0.000
AGRI.P doesn’t cause MOD	3.354	3.652	0.000
FERTI doesn’t cause AGRI.P	2.389	2.077	0.038
AGRI.P doesn’t cause FERTI	2.733	2.639	0.008
REG doesn’t cause REN.T	1.995	1.434	0.151
REN.T doesn’t cause REG	3.115	3.263	0.001
MOD doesn’t cause REN.T	7.225	9.976	0.000
REN.T doesn’t cause MOD	2.723	2.623	0.009
FERTI doesn’t cause REN.T	3.787	0.189	0.850
REN.T doesn’t cause FERTI	5.231	1.320	0.187
MOD doesn’t cause REG	3.426	3.771	0.000
REG doesn’t cause MOD	2.395	2.087	0.037
FERTI doesn’t cause REG	2.328	-0.953	0.340
REG doesn’t cause FERTI	3.959	0.324	0.746
FERTI doesn’t cause MOD	12.455	18.520	0.000
MOD doesn’t cause FERTI	3.123	3.277	0.001
REN.T doesn’t cause IND.P	6.977	9.571	0.000
IND.P doesn’t cause REN.T	2.386	2.071	0.038
REG doesn’t cause IND.P	2.298	2.929	0.053
IND.P doesn’t cause REG	3.731	4.270	0.000
MOD doesn’t cause IND.P	5.479	3.422	0.001
IND.P doesn’t cause MOD	5.126	3.044	0.002
FDI doesn’t cause IND.P	2.416	2.120	0.034
IND.P doesn’t cause FDI	1.121	0.005	0.996
FDI doesn’t cause REN.T	2.241	1.835	0.066
REN.T doesn’t cause FDI	2.136	1.663	0.096
FDI doesn’t cause REG	2.520	2.520	0.011
REG doesn’t cause FDI	1.701	1.701	0.089
FDI doesn’t cause MOD	6.001	1.923	0.054
MOD doesn’t cause FDI	5.982	1.909	0.056

Outcomes indicate that agricultural productivity has a bidirectional causal relationship with the RE transition, regulations, modernization, and fertilizer consumption.RE transition has also a bidirectional causal relationship with modernization change but with regulations, it has a unidirectional causal relationship, and with fertilizers consumption, it has no causal relationship. Moreover, regulations have a bidirectional causal relationship with modernization, while no causal relationship with fertilizer consumption. Additionally, modernization has a bidirectional causal relationship with fertilizer consumption. Furthermore, industrial productivity has a two-way causal relationship with the RE transition, regulations, and modernization, but only with FDI, it has a unidirectional causal relationship. Finally, FDI has a two-way causal relation with all RE transitions, regulations, and modernization.

Discussion

This study's findings are consistent with related studies (Abbasi et al., 2022; Abdullahi et al., 2015; Chopra et al., 2022; Rosano-Peña & Daher, 2015; Shita et al., 2019). Similar to the outcomes of this study, (Chopra et al., 2022) finds that using RE sources in the agriculture sector increases its productivity within ASEAN nations, while (Abbasi et al., 2022) finds that the industrial sector growth of Pakistan increased due to positive shocks in REC. However, we can note that the elasticity of agriculture and industrial productivity with respect to RE transition is high in this study. The possible reason for this is the increasing return to scale of RE sources in these sectors of South Asian nations due to heavy reliance on NRE sources. The advantage of RE transition is that it not only increases productivity but also reduces environmental contamination.

The analysis finds consistent results with (Barbera & McConnell, 1990) showing that regulations reduce industrial and agricultural productivity because regulations serve as a constraint and put limits on production. Although environmental regulation limits output, however, it improves industrial and agricultural products' quality. This analysis is limited by the availability of data to measure the regulations 'effect on the quality of industrial and agricultural products.

This study finds that the rise in modernization raises agriculture and industrial productivity. Similarly, (Shita et al., 2019)find that the adoption of technology has a significantly positive influence on the agricultural productivity of Ethiopia both in short- and long-term, while (Dolage et al., 2010)find that a rise in flexible manufacturing technology (FMT) has a positive impact on Malaysia's manufacturing industry's total factor productivity growth.

Furthermore, (Zhao & Zhang, 2010) finds that FDI has a positive and spillover effect on China's growth and industrial productivity level. Also, (Iddrisu et al., 2015) found significant and long-run positive effects of FDI on the industrial sector productivity in Ghana. Similarly, in this study, we find that FDI has an increasing impact on the industrial productivity of South Asian nations. The coefficient of FDI may be due to appreciative policies adopted by South Asian nations. According to (Sahoo et al., 2006) policies regarding FDI have shifted positively, focusing on bilateral trade agreements and offering investment incentives to foreign investors across South Asian nations.

Conclusion

For sustainability, South Asian economies are transiting to renewable energy (RE) sources and modern technology, and applying strict regulations. However, the question that motivated the study was whether the South Asian nations compromise on productivity for sustainability was unclear. Hence, to answer the question, this study investigated the impact of the RE transition, regulations, and modernization on agriculture and industrial productivity by analyzing panel data from eight South Asian nations for 23 years (2000-2022) using the FMOLS estimation method. Other studies (Adams et al., 2018; Ahmad & Majeed, 2022; Bhat, 2018; Noor et al.,

2023; Tuna & Tuna, 2019; Vural, 2020; Zhang et al., 2023) analyzed the nexus among RE consumption, NRE consumption, environmental quality, and EG, however, this is the sole study that analyzed the impact of the RE transition, regulations, and modernization on agriculture and industrial productivity individually in the case of South Asian nations.
Before going to the estimation of variables' coefficients, we conducted several pre-estimation diagnostic tests. First, we conducted (Pesaran, 2004) CD test, and found that there is no CD among the variables. Consequently, first-generation unit root and cointegration tests employed that assume no CD. Thus, to check the order of integration this study used the LLC test of (Levin et al., 2002), Im-Pesaran-Shin test of (Im et al., 2003), and Fisher-ADF and Fisher-PP of (Choi, 2001; Maddala & Wu, 1999), and find that all variables are first-difference stationary, except fertilizer consumption which is stationary at level with intercept and trend. Then, we tested autocorrelation by the Durbin-Watson test and found that our models contain serial autocorrelation. Next, we tested the cointegration relation among variables by (Pedroni, 1999, 2004) and (Kao, 1999) tests of cointegration, and its empirical results verified that long-run relation exists among the given variables. Finally, after confirming long-run cointegration, we estimated the coefficients of the variables with FMOLS because it corrects for serial autocorrelation. Long-run estimates of FMOLS demonstrate that the RE transition and modernization increase, while regulations reduce the agriculture and industrial productivity of South Asian nations in the long run. Moreover, panel FMOLS can't detect causality between variables, hence, this study applied a newly introduced (Dumitrescu & Hurlin, 2012) panel causality test. Results revealed a two-way relationship of both agriculture and industrial productivity with the RE transition, regulations, and technology.

Policy Recommendations

Based on the results this study proposed some effective policy suggestions. First, results show that the RE transition has a positive effect on the productivity of both agriculture and industrial sectors. Hence, South Asian countries' governments should encourage, incentivize, and adopt policies that facilitate the adoption of RE sources in those sectors. This would reduce the cost of fuel, and reliance on fossil fuels, mitigate environmental impacts, and enhance energy security. Second, results show that modernization and FDI positively impact the productivity of agriculture and the industrial sector. Hence, South Asian economies should facilitate foreign and local investors for investing in modern technology. This should include government grants, tax incentives, and public-private partnerships to support the development and adoption of advanced technologies. Last but not least, outcomes show that regulations have a significantly negative effect on the productivity of agriculture and industrial sectors of South Asian nations. Though regulations are necessary for sustainability, but regulatory authorities in South Asian nations should focus on the balance between environmental protection and productivity. Avoid implementing strict regulations and review existing regulations to ensure they are effective and efficient, and do not put unnecessary burdens on businesses.

References

- Abbas, S. Z., Kousar, A., Razzaq, S., Saeed, A., Alam, M., & Mahmood, A. (2018). Energy management in South Asia. *Energy Strategy Reviews*, *21*, 25–34. https://doi.org/https://doi.org/10.1016/j.esr.2018.04.004
- Abbasi, K. R., Hussain, K., Radulescu, M., & Ozturk, I. (2022). Asymmetric impact of renewable and non-renewable energy on the industrial sector in Pakistan: Fresh evidence from Bayesian and non-linear ARDL. *Renewable Energy*, *187*, 944–957. https://doi.org/https://doi.org/10.1016/j.renene.2022.02.012
- Abdullahi, H. S., Mahieddine, F., & Sheriff, R. E. (2015). Technology impact on agricultural productivity: A review of precision agriculture using unmanned aerial vehicles. *Lecture Notes of the*

Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST, *154*, 388–400. https://doi.org/10.1007/978-3-319-25479-1_29

- Adams, S., Klobodu, E. K. M., & Apio, A. (2018). Renewable and non-renewable energy, regime type and economic growth. *Renewable Energy*, *125*, 755–767. https://doi.org/https://doi.org/10.1016/j.renene.2018.02.135
- Adelegan, A. E., & Otu, E. (2020). *Energy and Industrial Productivity in Nigeria: An Insight from ARDL Approach*. https://doi.org/10.36349/EASJEBM.2020.v03i05.056
- Adom, P. K., & Kwakwa, P. A. (2014). Effects of changing trade structure and technical characteristics of the manufacturing sector on energy intensity in Ghana. *Renewable and Sustainable Energy Reviews*, *35*, 475–483. https://doi.org/https://doi.org/10.1016/j.rser.2014.04.014
- Ahmad, W., & Majeed, M. T. (2022). Does renewable energy promote economic growth? Fresh evidence from South Asian economies. *Journal of Public Affairs*, *22*(4). https://doi.org/10.1002/pa.2690
- Amin, N., & Song, H. (2023). The role of renewable, non-renewable energy consumption, trade, economic growth, and urbanization in achieving carbon neutrality: A comparative study for South and East Asian countries. *Environmental Science and Pollution Research*, *30*(5), 12798–12812. https://doi.org/10.1007/s11356-022-22973-2
- Barbera, A. J., & McConnell, V. D. (1990). The impact of environmental regulations on industry productivity: Direct and indirect effects. *Journal of Environmental Economics and Management*, *18*(1), 50–65. https://doi.org/https://doi.org/10.1016/0095-0696(90)90051-Y
- Bhat, J. A. (2018). Renewable and non-renewable energy consumption—impact on economic growth and CO2 emissions in five emerging market economies. *Environmental Science and Pollution Research*, *25*(35), 35515–35530. https://doi.org/10.1007/s11356-018-3523-8
- Chaudhury, S., Bose, R., Samanta, D., & Anbumozhi, V. (2023). *Written notice to and permission from ERIA*.
- Choi, I. (2001). Unit root tests for panel data. *Journal of International Money and Finance*, *20*(2), 249–272. https://doi.org/10.1016/S0261-5606(00)00048-6
- Chopra, R., Magazzino, C., Shah, M. I., Sharma, G. D., Rao, A., & Shahzad, U. (2022). The role of renewable energy and natural resources for sustainable agriculture in ASEAN countries: Do carbon emissions and deforestation affect agriculture productivity? *Resources Policy*, *76*, 102578. https://doi.org/https://doi.org/10.1016/j.resourpol.2022.102578
- Dolage, D. A. R., Sade, A. B., & Ahmed, E. M. (2010). The influence of Flexible Manufacturing Technology adoption on productivity of Malaysian manufacturing industry. *Economic Modelling*, *27*(1), 395–403. https://doi.org/10.1016/j.econmod.2009.10.005
- 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
- Emami, S. A., Abtahi, S. Y., Tabatabaienasab, Z., & Dehghan Tafti, M. A. (2023). *Energy Consumption and Total Factor Productivity Dynamics in the Industrial Sector*. https://doi.org/10.22054/jiee.2023.71769.1973
- Faninger, G. (2011). *Economic Perspectives of Renewable Energy Systems*.
- Finance Division Pakistan. (2023). *Agricultural sector contribution to GDP in Pakistan*.
- Granger, C. W. J. (1969). Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econometrica*, *37*(3), 424–438. https://doi.org/10.2307/1912791
- Hadri, K. (2000). Testing for stationarity in heterogeneous panel data. *The Econometrics Journal*, *3*(2), 148–161. https://doi.org/https://doi.org/10.1111/1368-423X.00043
- Hamit-Haggar, M. (2012). Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. *Energy Economics*, *34*(1), 358–364. https://doi.org/10.1016/J.ENECO.2011.06.005
- Hu, A., Zhou, S., & Xie, Y. (2025). *Understanding Xi Jinping's Governance Study on the National Conditions of Modernization with Chinese Characteristics*.

- Huynh, C. M. (2024). Climate change and agricultural productivity in Asian and Pacific countries: how does research and development matter? *Journal of Economic Studies*, *51*(3), 712–729. https://doi.org/10.1108/JES-04-2023-0192
- Iddrisu, A.-A., Adam, B., & Halidu, B. O. (2015). The Influence of Foreign Direct Investment (FDI) on the Productivity of the Industrial Sector in Ghana. *International Journal of Academic Research in Accounting*, *5*(3), 1–13. https://doi.org/10.6007/IJARAFMS/v5-3/50
- ILO. (2023). *World Employment and Social Outlook Trend*. https://doi.org/10.54394/SNCP1637
- Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*(1), 53–74. https://doi.org/10.1016/S0304-4076(03)00092-7
- Jalilian, H., Kirkpatrick, C., & Parker, D. (2007). The Impact of Regulation on Economic Growth in Developing Countries: A Cross-Country Analysis. *World Development*, *35*(1), 87–103. https://doi.org/10.1016/j.worlddev.2006.09.005
- Jebli, B., Youssef, B., Ben Jebli, M., & Ben Youssef, S. (2015). *The role of renewable energy and agriculture in reducing CO2 emissions: evidence for North Africa countries The role of renewable energy and agriculture in reducing CO 2 emissions: evidence for North Africa countries*.
- Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, *90*(1), 1–44. https://doi.org/10.1016/S0304-4076(98)00023-2
- Karkacier, O., Gokalp Goktolga, Z., & Cicek, A. (2006). A regression analysis of the effect of energy use in agriculture. *Energy Policy*, *34*(18), 3796–3800. https://doi.org/10.1016/j.enpol.2005.09.001
- Kumaran, V. V., Ridzuan, A. R., Khan, F. U., Abdullah, H., & Mohamad, Z. Z. (2020). An empirical analysis of factors affecting renewable energy consumption in association of Southeast Asian nations-4 countries. *International Journal of Energy Economics and Policy*, *10*(2), 48–56. https://doi.org/10.32479/ijeep.8142
- Levin, A., Lin, C. F., & Chu, C. S. J. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of Econometrics*, *108*(1), 1–24. https://doi.org/10.1016/S0304-4076(01)00098-7
- Liu, J., Wang, M., Yang, L., Rahman, S., & Sriboonchitta, S. (2020). Agricultural productivity growth and its determinants in south and southeast Asian countries. *Sustainability (Switzerland)*, *12*(12). https://doi.org/10.3390/su12124981
- Maddala, G. S., & Wu, S. (1999). A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test. *Oxford Bulletin of Economics and Statistics*, *61*(S1), 631–652. https://doi.org/https://doi.org/10.1111/1468-0084.0610s1631
- Mehmood, U. (2021). Renewable-nonrenewable energy: institutional quality and environment nexus in South Asian countries. *Environmental Science and Pollution Research*, *28*(21), 26529–26536. https://doi.org/10.1007/s11356-021-12554-0
- Mentel, G., Tarczyński, W., Dylewski, M., & Salahodjaev, R. (2022). Does Renewable Energy Sector Affect Industrialization-CO2 Emissions Nexus in Europe and Central Asia? *Energies*, *15*(16). https://doi.org/10.3390/en15165877
- Mentel, U., Wolanin, E., Eshov, M., & Salahodjaev, R. (2022). Industrialization and CO2 Emissions in Sub-Saharan Africa: The Mitigating Role of Renewable Electricity. *Energies*, *15*(3). https://doi.org/10.3390/en15030946
- Ministry of Agriculture and Livestock Development Nepal. (2023). *Agricultural sector contribution to GDP in Nepal*.
- Ministry of Finance Bangladesh. (2023). *Agricultural sector contribution to GDP in Bangladesh*.
- Ministry of Finance India. (2023). *Agricultural sector contribution to GDP in India*.
- Murshed, M., Ahmed, R., Kumpamool, C., Bassim, M., & Elheddad, M. (2021). The effects of regional trade integration and renewable energy transition on environmental quality: Evidence from South Asian neighbors. *Business Strategy and the Environment*, *30*(8), 4154–4170. https://doi.org/10.1002/bse.2862
- National Statistics Bureau Bhutan. (2023). *Agricultural sector contribution to GDP in Bhutan*.
- Neupane, N., Chaudhary, P., Rijal, Y., Ghimire, B., & Bhandari, R. (2022). *The role of renewable energy in achieving water, energy, and food security under climate change constraints in South Asia*. https://data.worldbank.org/.

- Noor, M., Khan, D., Khan, A., & Rasheed, N. (2023). The impact of renewable and non-renewable energy on sustainable development in South Asia. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-023-03210-3
- Paul, A., Sahoo, D., & Jena, A. (2023). Asymmetric impacts of ICT and energy intensity on agricultural productivity: Evidence from Asia-Pacific region. *Review of Development Economics*, *27*(3), 1537–1561. https://doi.org/https://doi.org/10.1111/rode.12993
- Pedroni, P. (1999). *Critical Vaues for Cointegration Tests in Heterogenous Panels with Multiple Regressors*. https://doi.org/10.1111/1468-0084.0610s1653
- Pedroni, P. (2001). Fully modified OLS for heterogeneous cointegrated panels. In B. H. Baltagi, T. B. Fomby, & R. Carter Hill (Eds.), *Nonstationary Panels, Panel Cointegration, and Dynamic Panels* (Vol. 15, pp. 93–130). Emerald Group Publishing Limited. https://doi.org/10.1016/S0731-9053(00)15004-2
- Pedroni, P. (2004). Panel Cointegration: Asymptotic and Finite Sample Properties of Pooled Time Series Tests with an Application to PPP Hypothesis. *Econometric Theory*, *20*(03), 597–625. https://doi.org/10.1017/S0266466604203073
- Pesaran, M. H. (2004). *General Diagnostic Tests for Cross Section Dependence in Panels* (Vol. 78, Issue 4). http://ssrn.com/abstract=572504
- Rahman, M. M., & Velayutham, E. (2020). Renewable and non-renewable energy consumption-economic growth nexus: New evidence from South Asia. *Renewable Energy*, *147*, 399–408. https://doi.org/10.1016/j.renene.2019.09.007
- Rohendi, H., Ghozali, I., & Ratmono, D. (2024). Environmental, social, and governance (ESG) disclosure and firm value: the role of competitive advantage as a mediator. *Cogent Business & Management*, *11*(1), 2297446. https://doi.org/10.1080/23311975.2023.2297446
- Rosano-Peña, C., & Daher, C. E. (2015). The Impact of Environmental Regulation and Some Strategies for Improving the Eco-Efficiency of Brazilian Agriculture. In P. Guarnieri (Ed.), *Decision Models in Engineering and Management* (pp. 295–322). Springer International Publishing. https://doi.org/10.1007/978-3-319-11949-6_16
- Sahoo, P., Mccawley, P., Brooks, D., Menon, J., Kanamori, T., Lee, J. K., & Sinsiri, N. (2006). *Foreign Direct Investment in South Asia: Policy, Trends, Impact and Determinants*.
- Sebri, M., & Abid, M. (2012). Energy use for economic growth: A trivariate analysis from Tunisian agriculture sector. *Energy Policy*, *48*, 711–716. https://doi.org/10.1016/j.enpol.2012.06.006
- Shafie, S. M., Mahlia, T. M. I., Masjuki, H. H., & Andriyana, A. (2011). Current energy usage and sustainable energy in Malaysia: A review. *Renewable and Sustainable Energy Reviews*, *15*(9), 4370–4377. https://doi.org/10.1016/J.RSER.2011.07.113
- Sharif Hossain, M. (2011). Panel estimation for CO2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy Policy*, *39*(11), 6991–6999. https://doi.org/10.1016/J.ENPOL.2011.07.042
- Shita, A., Kumar, N., & Singh, S. (2019). The impact of technology adoption on agricultural productivity in Ethiopia: ARDL approach. In *Indian Journal of Economics & Business* (Vol. 19, Issue 1). https://www.researchgate.net/publication/332268701
- Shrestha, R. B., Bokhtiar, S. M., Khetarpal, R., & Thapa, Y. B. (2023). *Asia-Pacific Association of Agricultural Research Institutions (APAARI), Bangkok SAARC Agriculture Center (SAC), Dhaka South Asian Association for Regional Cooperation Agricultural Policy and Program Framework Priority Areas for Research & Development in South Asia*. www.sac.org.bd
- Soni, S., & RL, M. (2024). The dynamic nexus between agricultural productivity and renewable energy consumption in BRICS: the role of financial inclusion and foreign direct investment. *International Journal of Energy Sector Management*, *ahead-of-print*(ahead-of-print). https://doi.org/10.1108/IJESM-08-2023-0028
- Stern, D. I. (2011). The role of energy in economic growth. *Annals of the New York Academy of Sciences*, *1219*(1), 26–51. https://doi.org/10.1111/j.1749-6632.2010.05921.x
- Sumaira, & Siddique, H. M. A. (2023). Industrialization, energy consumption, and environmental pollution: evidence from South Asia. *Environmental Science and Pollution Research*, *30*(2), 4094–4102. https://doi.org/10.1007/s11356-022-22317-0

- Toichoa Buaha, G., Apland, J., & Hicks, D. (1995). *Staff paper series a regression analysis of the effects of planting date and variety on corn yields in Minnesota*.
- Tuna, G., & Tuna, V. E. (2019). The asymmetric causal relationship between renewable and non-renewable energy consumption and economic growth in the ASEAN-5 countries. *Resources Policy*, *62*, 114–124. https://doi.org/10.1016/J.RESOURPOL.2019.03.010
- UNIDO. (2024). *The Future of Industrialization: Building Future-Ready Industries to Turn Challenges into Sustainable Solutions*.
- Usman, M., Anwar, S., Yaseen, M. R., Makhdum, M. S. A., Kousar, R., & Jahanger, A. (2022). Unveiling the dynamic relationship between agriculture value addition, energy utilization, tourism and environmental degradation in South Asia. *Journal of Public Affairs*, *22*(4). https://doi.org/10.1002/pa.2712
- Usman, M., & Hammar, N. (2021). Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries. *Environmental Science and Pollution Research*, *28*(12), 15519–15536. https://doi.org/10.1007/s11356-020-11640-z
- Voumik, L. C., Mimi, M. B., & Raihan, A. (2023). Nexus Between Urbanization, Industrialization, Natural Resources Rent, and Anthropogenic Carbon Emissions in South Asia: CS-ARDL Approach. *Anthropocene Science*, *2*(1), 48–61. https://doi.org/10.1007/s44177-023-00047-3
- Wooldridge, J. M. (2010). *Econometric Analysis of Cross Section and Panel Data*.
- World Bank. (2023). *Tracking Sustainable Development Goal 7: Annual Progress Report*.
- Zakaria, M., Jun, W., & Khan, M. F. (2019). Impact of financial development on agricultural productivity in South Asia. *Agricultural Economics (Czech Republic)*, *65*(5), 232–239. https://doi.org/10.17221/199/2018-AGRICECON
- Zhang, T., Yin, J., Li, Z., Jin, Y., Ali, A., & Jiang, B. (2023). A dynamic relationship between renewable energy consumption, non-renewable energy consumption, economic growth and CO2 emissions: Evidence from Asian emerging economies. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.1092196
- Zhao, X., Gu, B., Gao, F., & Chen, S. (2020). Matching Model of Energy Supply and Demand of the Integrated Energy System in Coastal Areas. *Journal of Coastal Research*, *103*(SI), 983–989. https://doi.org/10.2112/SI103-205.1
- Zhao, Z., & Zhang, K. H. (2010). FDI and industrial productivity in China: Evidence from panel data in 2001-06. *Review of Development Economics*, *14*(3), 656–665. https://doi.org/10.1111/j.1467-9361.2010.00580.x
- Zhou, Z., Sharif, A., Inglesi-Lotz, R., & Bashir, M. F. (2024). Analysing the interplay between energy transition, resource consumption, deforestation, and environmental factors on agricultural productivity: Insights from APEC countries. *Journal of Cleaner Production*, *446*, 141408. https://doi.org/https://doi.org/10.1016/j.jclepro.2024.141408
- Zoundi, Z. (2017). CO2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. *Renewable and Sustainable Energy Reviews*, *72*, 1067–1075. https://doi.org/10.1016/J.RSER.2016.10.018