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Does Biomass Energy Consumption Improve Human Development? Evidence from South Asian Countries

Shamal C. Karmaker*, #, ^, Shahadat Hosan*, # and Bidyut B. Saha*, #, 1

Abstract – *The effect of biomass energy consumption on the economy, environment, and human development is still a debatable issue, and researchers have not yet been reached any consensus about this issue. Several studies have examined the impact of biomass energy usage concerning economic, environmental, and human wellbeing perspectives and found mixed results. As a large number of people in South Asia are relying on these biomass energy usages, it is obvious to investigate whether the use of biomass energy is contributing positively to human development or not. Thus, this paper enhances the existing literature by exploring the influence of biomass energy usage on human development in South Asian nations in 1990-2016. Panel cointegration approaches, along with a Dumitrescu-Hurlin panel causality test, have been performed to assess the long-run causality between biomass energy use and human development. Our findings suggest that biomass energy usage has an adverse effect on human development in South Asian countries and a bidirectional causal relationship between these two variables. Policymakers might suggest reducing the use of traditional biomass, such as firewood and cow dung cake, to achieve SDG-7 and improve the quality of life.*

Keywords – *Biomass, economic growth, human development, panel cointegration, South Asian countries.*

1. INTRODUCTION

Energy is an integral component of economic and societal development, and biomass energy is an essential form of energy source, particularly in developing nations. Energy utilization contributes to job creation, agricultural development, industrialization, transportation, and trade development, leading to poverty alleviation and sustainable human development. Over the last century, growing energy consumption has become the main factor in the industrialization and economic development process [1]. Energy plays a significant role in improving a nation's economy, and hence it impacts human welfare. For instance, modern health, education, and communication facilities are directly related to the supply of available energy. The scarcity of energy resources causes poor health services, fewer opportunities for education and growth, and a high likelihood of poverty in the population [2]. Energy consumption is a crucial tool that represents the societal advancement level. It is necessary to generate a sufficient amount of energy for the modernization process to facilitate sustainable development [3].

Industrialization with rapid economic and population growth has led to a growing demand for energy globally. Globally, energy consumption raised around 44% between 1971 and 2014 [4], and approximately 80% of it comes from fossil energy [5]. Dependence on fossil fuels has raised questions about insufficient availability, environmental degradation, and energy safety [6]. Environmental issues are at the center of those concerns. The use of fossil fuels is often seen as a significant element in growing greenhouse gas emissions responsible for climate change and global warming [7]. Renewable energy use can protect the environment for achieving sustainable development goals, for which fossil fuels are replacing it. Besides environmental benefits, renewable energy allows economies to minimize their dependence on foreign resources and increase job opportunities [8]. Renewable energy has the highest growth rate, resulting in rising three times quicker than fossil fuels between 2013 and 2018 [5]. According to IRENA projections, this percentage could rise to 60% by 2050 [9]. Such type of energy production, for example, can prompt economic development and allow those countries to achieve higher rates of human development [10].

Biomass is the form of energy that accounts for the most significant share of renewable energy. Bioenergy contributed 12% of overall total energy consumption in 2018 [5]. The percentage of modern bioenergy in renewable energy used in 2018 (excluding conventional biomass usage) is 50%. As demand increases, researchers are also increasingly paying attention to the impacts of biomass. Although one research group concentrated on the correlation between biomass and economic growth [6], [11], [14], another group looked at the ecological impacts of biomass [15]–[18]. The findings of this research have not reached a consensus.

*International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University, 744 Motooka, Nishi-ku, Fukuoka-shi, Fukuoka 819-0395, Japan.

#Mechanical Engineering Department, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka-shi, Fukuoka 819,0395, Japan.

^Department of Statistics, University of Dhaka, Dhaka-1000, Bangladesh.

[1]Corresponding author;
E-mail: saha.baran.bidyut.213@m.kyushu-u.ac.jp

Some studies point out that the use of renewable energy stimulates economic development and is environmentally sustainable, and other studies suggest the reverse. Therefore, it remains a controversial question of whether biomass should be used more or less.

This research would like to add to the current literature by examining the effects of biomass energy use on human wellbeing. United Nations Development Program (UNDP) defines human development as the expansion of human opportunities and choices. For a long period, the per capita Gross Domestic Product (GDP) is often used to measure the HDI; however, economic indicators like GDP do not capture the overall human wellbeing [19]. The HDI has gradually replaced GDP as the primary indicator for assessing human development since UNDP first introduced it in 1990. Considering three aspects like long and healthy life, knowledge, and decent living standards, HDI can reflect the entire quality of human lives. Growing this HDI now becomes a target for almost every country. Policymakers require to consider all three dimensions of sustainable development: cultural, environmental, and social. Nevertheless, earlier research concentrated on the ecological and economic growth impact of biomass energy use and failed to examine human development effects. Investigating the link between biomass energy usage and human development would provide policymakers with a comprehensive analysis of the impacts of biomass energy use on human development.

The traditional use of biomass in developed and developing economies supplies energy for cooking and heating through simple and typically unreliable fires or stoves. In recent years, the quantity of biomass used in traditional applications has marginally declined from an estimated 27.2 EJ in 2010 to 26 EJ in 2018 [5]. The drop is mainly due to attempts to reduce traditional biomass and advance access to clean energy, given the adverse effects of biomass burning on local air quality and the related health impacts. Biomass energy production and consumption may impact the environment causing deforestation, biodiversity loss, resource depletion, and food insecurity. For instance, traditional forms of biomass usage, such as wood and waste, can generate indoor air pollution that may harm health and the environment [20], [21]. Also, collecting traditional forms of biomass for domestic cooking can also engage the women refraining them from being involved in child care and education [22]. This may be the reason how biomass energy consumption can impede human development. However, biomass energy also may affect society directly by ensuring easy access and secure energy supply to rural people, generating employment, alleviating energy poverty, and helping in economic growth in a country [11]. By providing a neutral balance of carbon emission, biomass energy helps combat climate change accelerated through fossil fuels. Therefore, it can be said that biomass energy may have both positive and negative impacts on human development [23].

This research adds in many ways to the current scope of literature. The most considerable energy use across the globe is linked to human activities. This particular research field has yet to be explored. But quantifying the relationship between energy consumption and HDI may be necessary. Examining the connection between HDI and biomass energy consumption for the South Asian economy is the originality and novelty of this energy research study.

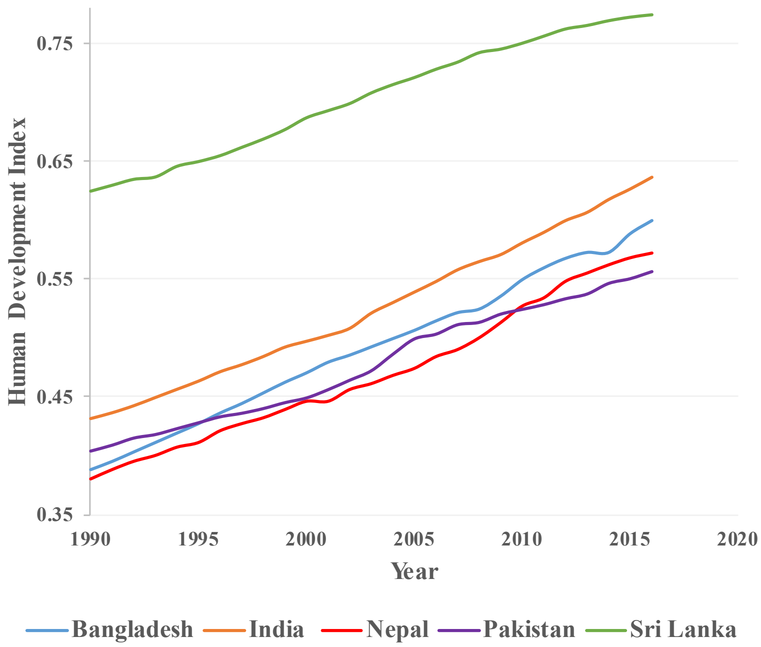

Fig. 1. Trend of human development index in South Asia in 1990 – 2016.

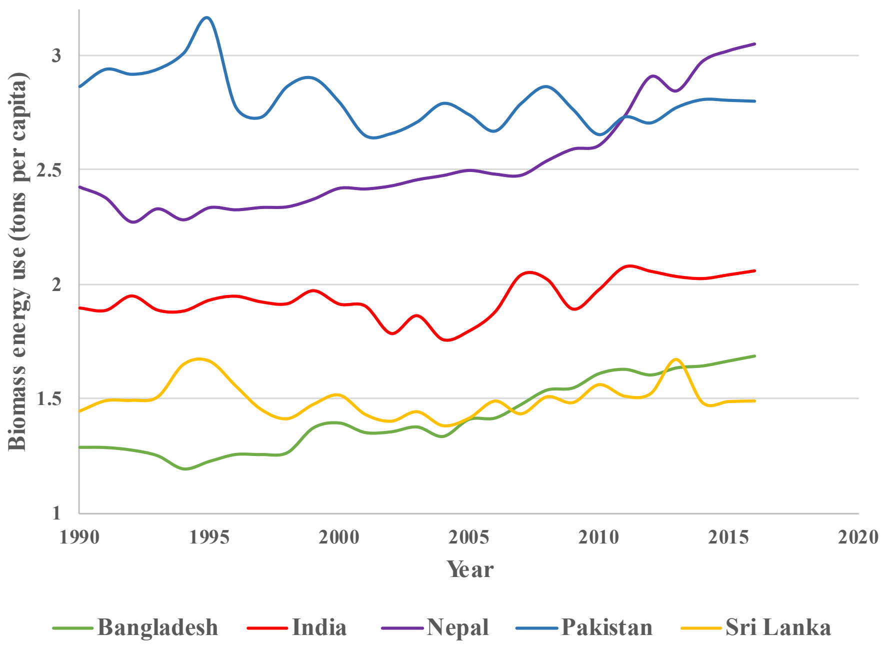

Fig. 2. Trend of biomass energy use in South Asia in 1990 – 2016.

Second, to the best of our knowledge, the relationship between biomass energy consumption and human development is rarely examined in the context of South Asia, where a large number of people depend on biomass energy sources. Biomass is a significant source of energy supply in rural areas, and energy poverty is a common scenario in the South Asian region. The current energy and human development situation in this region is at risk, and this region's energy crisis affects every aspect of the economy and human life. However, SDG-7 says that each country should ensure clean and affordable energy for all within 2030. As a result, South Asian countries require an evaluation of biomass's effects on sustainable human development. The worst condition regarding the energy and human development process in South Asian nations needs time to be managed. This study is an effort to enhance existing literature and help policymakers better understand the effects of biomass energy on the human development process in the South Asian context.

Understanding the importance of biomass energy consumption for human development and the existing energy use pattern in South Asia motivates us to investigate the link between biomass energy consumption, economic growth, and human development to measure whether biomass energy consumption affects the process of human development in this region. Thus, the innovative input of this study is to investigate the relationship between biomass energy use, economic growth, and human development, integrating trade ratio, industrialization, and foreign direct investment for South Asian nations.

2. BACKGROUND AND LITERATURE REVIEW

As the purpose of this paper is to explore the impact of biomass usage on human development, it aims to look in-depth at the related literature. Biomass sources will be instrumental in meeting the world's energy demand in the near future. For instance, IEA [24] points out that bioenergy demand would increase by 1.6% on average during 2010- 2035. Researchers have revealed that biomass energy can affect the environment, economy, and resources toward ensuring sustainable development. Energy consumption is often considered as one of the factors of human development. It has been assumed for a while that more energy use contributed to better human development.

Nevertheless, when environmental worries related to energy consumption are increasing, this view is no longer valid. The increased use of energy does not assure higher levels of human development [25]. Martínez and Ebenhack [26] led a study for 120 countries and revealed a robust relationship between energy use and human development. Ouedraogo [2] examined this relationship for 15 developing nations over the 1988-2008 period and found a negative relationship and unidirectional Granger causality between energy usage and human development. Contrary, Tran *et al.* [25] analyzed the relationship for 93 nations with data for the 1990-2014 period and suggested that energy usage does not lead to human development in developing and developed countries. Niu *et al.* [3] found the long-run bidirectional causality between the use of energy and human development for 50 countries for the period of 1990-2009.

The linkage between renewable energy usage and human development is less explored than the energy consumption-human development nexus. We found only studies [27], [28] relating to the impacts of renewable energy use on human development. But these scholars have presented contradictory findings. Pîrlogea [28] concluded that the use of renewable energy promotes human development. Meanwhile, Wang *et al.* [27] found that renewable energy causes the decline of the human development level. It was also pointed out that the higher the income of the country leads to a lower level of human development. Besides, Wang *et al.* [29] examined the effects of biomass on human development for BRICS countries for 1990-2015 and revealed that biomass energy usage increases human development in BRICS countries. The conclusion from the existing studies is controversial, and further research is required on the linkage between renewable energy use and human development. It can also be found from the literature that researchers have ignored the impact of biomass energy usage on human development. This linkage has also not been discussed in South Asian countries. Our research is attempting to fill in that gap.

The rest of this paper is organized as follows: Section 3 describes the methodological approaches used, Section 4 describes the results, while Section 5 outlines the conclusions and policy implications of the findings and addresses possible complementary steps.

3. METHODOLOGY

Econometric techniques are applied to check whether there exists a causal relationship between biomass energy consumption and human wellbeing. The methodology comprises the following steps: 1) Panel unit root tests are used to verify the stationarity assumptions of the selected variables. 2) After confirming the non-stationarity of these variables, suitable panel cointegration methods were employed to test whether a cointegrating relationship exists or not. 3) Ensuring the cointegration among variables, parameters are estimated via the dynamic ordinary least squares (DOLS) and the fully modified OLS techniques. 4) Lastly, the Dumitrescu-Hurlin [30] panel causality test is employed to identify one-to-one causal relationships.

3.1 Conceptual Framework

Economic growth is a crucial factor in human development. Ranis and Stewart [31] stated that economic progress provides human development resources. Income can be vastly correlated with education, health, and life expectancy, which stimulates HDI [32]. There is also evidence that economic growth is accompanied by a worsening of the environment and impacts the quality of living standards of present and future generations [33]. The effect of GDP on the HDI, in other words, remains a contentious issue. Some countries can accomplish high HDI with low GDP and vice versa [31].

Biomass energy, unlike other renewable energy sources, can influence economic growth and thus affect people's incomes, living standards, and purchasing power [12]. As the economy develops, access to health care and education services is made easier for people. In developing nations, biomass energy also supports creating job opportunities and raise the incomes of rural workers resulting in the reduction of poverty [13]. Energy derived from biomass sources is used in electricity generation, cooking, domestic heating, and transportation [5], directly or indirectly affecting human development. Biomass energy helps meet humanity's increasing energy needs, lowers energy costs, and decreases the reliance on fossil fuels [34]. Most specifically, biomass energy is a "carbon-neutral" energy source [35] because if we plant trees to generate biomass energy, it helps to remove CO2 from the atmosphere. Therefore, biomass energy contributes to mitigate air pollution and protect the environment, which impacts human well-being and life.

Economic growth in developed countries is closely correlated with the industrialization process. Concerning the impact of industrialization on human development, Qasim and Chaudhary [36] find that industrialization affects human development from various aspects. Industrial development impacts directly and indirectly on human health. First, the industrialization process raises labor demand and creates job opportunities [37]. It supports to reduce poverty, increase income, and improve the quality of living standard [38], [39]. Secondly, industrial development boosts the market for the skilled and trained workforce, which in turn raises the demand for education [38]. Also, industrialization may cause pollution, leading to the deterioration of the environment and affecting humans' health and quality of life [40], [41].

Trade openness and foreign direct investment, like industrialization, is regarded as the engine of economic development in developing nations. Trade openness helps to fill the resource gap of a country, whereas foreign direct investment helps fulfill capital needs and helps creates more job opportunities, and thereby helps to increase per capita income [27], [42]. Thus, there is reason to believe that trade openness and foreign direct investment impact the human development process.

Based on the above conceptual framework, the following empirical model used by Wang *et al.* [29] for BRICS countries are considered to examine the relationship between biomass energy consumption and human development for South Asian nations, incorporating economic growth, trade openness, industrialization, and foreign direct investment as control variables:

$$HDI_{it} = f\left(BIO_{it}, GDP_{it}, TRO_{it}, IND_{it}, FDI_{it}\right) \quad (1)$$

In Equation 1, HDI denotes the human development index, BIO refers to biomass energy consumption, GDP indicates economic growth, TRO means trade openness, FDI refers to foreign direct investment, while IND is industrialization.

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The single multivariate structure is considered to investigate the relationship among variables of interest. At the same time, natural logarithms form of data has been used to reduce variation and smooth the data [44]. This conversion also enables to overcome the problems of autocorrelation and heteroscedasticity and deliver more trustworthy and consistent findings than simple linear form [45]. Our empirical model can express in log-linear form as shown in Equation 1

$$\ln HDI_{it} = \tau_0 + \beta \ln BIO_{it} + \tau_1 \ln GDP_{it} + \tau_2 \ln FDI_{it} + \tau_3 \ln TRO_{it} + \tau_4 \ln IND_{it} + \varepsilon_{it} \quad (2)$$

Where i represents the number of countries (from1 to 5), t refers to the time (1990 to 2016). τ_0 is the intercept/constant term. The coefficients of biomass energy consumption, economic growth, foreign direct investment, trade openness, and industrialization are denoted by $\beta, \tau_1, \tau_2, \tau_3$ and τ_4, respectively. ε_{it} represents the random error term affecting the human development index. Our attention is focused on the coefficient β, which measures the partial effect of biomass energy usage on the human development index.

3.2 Panel Unit Root Test

The standard ordinary least square method is not suitable for unit root variables due to spurious regression [46], which makes invalid statistical inference. In this situation, it is important to find the degree of integration for each variable in Equation 1. There are several panel unit root tests used by researchers for identifying the stationarity of variables, such as Levin *et al.* [47], Im *et al.* [48], Breitung [49], and Hadri [50].

Two forms of panel unit root tests, LLC and IPS, are used for exploring the unit root [47]. The simple form of the LLC test for estimation is presented in Equation 3:

$$\Delta(HDI)_{it} = w_{it}\gamma_i + \rho(HDI)_{it-1} + \sum_{j=1}^{k_i}\varphi_{ij}\Delta(HDI)_{i,t-j} + \varepsilon_{it} \quad (3)$$

Where Δ is used as an operator of the first difference, w_{it} refers to the fixed-effects and varying time trends, and k is the lag order. The null hypothesis state that all series are non-stationary (H_0: $\rho = 0 \, \forall i$) versus the alternative that all variables are stationary (H_1: $\rho<0 \; \forall i$). However, LLC assumes $\rho_i = \rho \; \forall i$, *i.e.*, homogenous ρ for all i. Violation of the above assumptions makes the accuracy of the LLC test ineffective [49]. To overcome this problem, Im *et al.* (2003) suggested a unit root test (hereafter IPS), allowing ρ to vary overall i. The IPS model is shown in Equation 4:

$$\Delta(HDI)_{it} = w_{it}\gamma_i + \rho_i(HDI)_{it-1} + \sum_{j=1}^{k_i}\varphi_{ij}\Delta(HDI)_{i,t-j} + \varepsilon_{it} \quad (4)$$

The null hypothesis (Ho: $\rho_i = 0$) denotes that every variable in the panel has a unit root versus the alternative (H_1: $\rho_i < 0$), which implies that at least one variable is stationary in the panel.

3.3 Panel Cointegration Test

If the series has a unit root, a cointegration test can be used to examine the long-run causal relationship among the variables. There are some panel cointegration testing procedures, including Pedroni [51], [52], Kao [53], Maddala and Wu [54], and Westerlund [55]. In the current study, Pedroni and Kao's methods have been employed. Based on cointegration regression residuals from Engel and Granger (1987), Pedroni suggested seven different statistics, which include the panel ADF-statistic (Z_{ADF}), panel PP statistic (Z_{PP}), panel rho-statistic (Z_ρ), panel-ν statistic (Z_ν), group ADF statistic ($\tilde{Z}_{ADF}$), and group PP statistic ($\tilde{Z}_{PP}$), group rho statistic ($\tilde{Z}_\rho$). Among seven tests, four belong to within dimension, and the other three are considered between dimension tests. Within the extent, tests are further extended to weighted and unweighted statistics. The above statistics are calculated based on the mean of the individual autoregressive coefficients related to the residuals' unit root tests for all cross-sectional units. The long-run model for estimating the residuals for the above test is presented, as shown in Equation 5:

$$Y_{it} = \beta_i + \tau_i t + \sum_{j=1}^{m}\gamma_{ji}X_{jit} + \varepsilon_{it} \quad (5)$$

where, $i = 1,2,....N$; $t = 1,2,.....,T$ and $j = 1,2,....m$ represent the cross-sectional units, number of cases and number of predictors, respectively. The estimated residuals structure can be represented, as shown in Equation 6:

$$\varepsilon_{it} = \rho_i \varepsilon_{it-1} + u_{it} \quad (6)$$

All seven tests indicate that there is no cointegration (H_o: $\rho_i = 1 \; \forall i$) against the alternative (H_1: $\rho_i < 1$) suggests the existence of cointegration. The Kao test is also constructed in the same way as the Pedroni tests, considering the homogeneous slope coefficients in Equation 5, not allowing for differing individual panel members.

3.4 Panel DOLS and FMOLS Estimates

The long-run relationship coefficient can be estimated when the variables are confirmed as cointegrated in the panel data set. When the variables are cointegrated, the ordinary least squares (OLS) method is not appropriate for estimating the long-run coefficients. Nonetheless, dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS) methods are appropriate in these cases. The long-run coefficients in Equation 1 are estimated applying the group means dynamic OLS (DOLS) and fully modified OLS (FMOLS) estimators developed by Pedroni [52], [56].

The group-means FMOLS is known as a non-parametric approach, while the DOLS estimator is a parametric approach where explicitly estimated the lagged first-differenced terms [46]. Both DOLS and FMOLS techniques consider serial correlation and endogeneity. There is a conflict, whether FMOLS or DOLS is better. However, Kao and Chiang [57], for example, showed that the parametric DOLS method is better than the FMOLS method [52].

On the contrary, it shows that DOLS has a little smaller size distortion than the FMOLS. Therefore, in this study, we applied both DOLS and FMOLS methods and then test for statistically significant differences in the coefficient in Equation 1. Pedroni [52] suggests the following equation for cointegrated panel data:

$$Y_{it} = \alpha_i + \delta X_{it} + \varepsilon_{it} \tag{7}$$

Where *X* and *Y* have a long-run association. Pedroni [56] proposes an additional equation, which includes lagged differences as an independent variable to control for the endogenous response effect, as shown in Equation 8:

$$Y_{it} = \alpha_i + \delta X_{it} + \sum_{k=-k_i}^{k_i} \gamma_{ik} \Delta X_{it-k} + \varepsilon_{it} \tag{8}$$

Pedroni defines $\eta_{it} = \left(\hat{\varepsilon}_{it}, \Delta X_{it}\right)$ and long-run covariance $\varphi_{it} = \lim_{T\to\infty} E\left[1 \middle/ T\left(\sum_{t=1}^{T}\eta_{it}\right)\left(\sum_{t=1}^{T}\eta_{it}\right)'\right]$.

The decomposition of this covariance matrix can be presented as $\varphi_{it} = \varphi_i^0 + \omega_i + \omega_i'$, where, φ_i^0 denotes contemporaneous covariance and ω_i represents the weighted sum of autocovariance. Hence, the estimator of panel FMOLS is presented, as shown in Equation 8 below:

$$\hat{\delta}^*_{FMOLS} = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\sum_{t=1}^{T}\left(X_{it} - \bar{X}_i\right)^2\right)^{-1}\left(\sum_{t=1}^{T}\left(X_{it} - \bar{X}_i\right)Y_{it}^* - T\hat{\gamma}_i\right)\right] \tag{9}$$

where, $Y_{it}^* = Y_{it} - \overline{Y}_i - \left(\hat{\eta}_{2,1,i} / \hat{\eta}_{2,2,i}\right)\Delta X_{it}$ and $\hat{\gamma}_i = \hat{\omega}_{2,1,i} + \hat{\eta}_{2,1,i}^0 - \left(\hat{\eta}_{2,1,i} / \hat{\eta}_{2,2,i}\right)\left(\hat{\omega}_{2,2,i} + \hat{\eta}_{2,2,i}\right)$

3.5 Dumitrescu and Hurlin Panel Causality Test

For the support of policymakers, additional information can be gathered by examining the causal relationship between variables of interest using the Dumitrescu and Hurlin [30] panel causality test. To overcome the problem of heterogeneity and cross-sectional dependency [29], [59] and also to handle both situations where N < T and N > T as well as the unbalanced panel, this method is appropriate [60]. In this testing procedure, the following model has employed to assess the causal relationship between variable X and Y:

$$Y_{it} = \alpha_i + \sum_{k=1}^{K}\delta_i^{(k)} Y_{i,t-k} + \sum_{k=1}^{K}\gamma_i^{(k)} X_{i,t-k} + \varepsilon_{i,t} \tag{10}$$

Where α_i represents concept/intercept term, K denotes lag length, $\delta_i^{(k)}$ is a lag parameter $\gamma_i = \left(\gamma_i^{(1)}, \gamma_i^{(2)}, \ldots \gamma_i^{(K)}\right)$, while $\gamma_i^{(k)}$ is slope coefficient.

Cross-section unit differences are represented by δ_i^k and γ_i^k.

Assuming no causal relationship in the panel known as a null hypothesis against the causal relationship exists in at least one cross-section unit as an alternative hypothesis. The Wald statistic for all panel is measured by taking the average of all the individual Wald statistic for every cross-section:

$$W_{N,T}^{hnc} = \frac{1}{N}\sum_{i=1}^{N} W_{i,T} \tag{11}$$

Where $W_{i,T}$ represents the individual Wald statistic values for each cross-section.

In the case of T > N, the average statistic $W_{N,T}^{hnc}$ is suggested by Dumitrescu and Hurlin [30] as shown in Equation 12:

$$Z_{N,T}^{hnc} = \sqrt{\frac{N}{2K}}\left(W_{N,T}^{hnc} - K\right) \tag{12}$$

3.6 Data Sources

Twenty-seven years of annual data from 1990 to 2016 are collected for biomass energy consumption, human development index, per capita GDP, foreign direct investment, industrialization, and trade openness in five South Asian countries – Bangladesh, India, Nepal, Pakistan, and Sri Lanka. The human development index is measured from the database of UNDP [61], whereas data on biomass energy consumption is gathered from the Global Material Flows Database [62]. The remaining variables, such as GDP, foreign direct investment, trade openness, and industrialization, are derived from World Development Indicators [63]. Economic growth is measured as per capita GDP (in constant 2010 US Dollar); biomass energy consumption is calculated as tons per capita; the trade openness is considered as the ratio of total exports and imports to GDP (*i.e.*, as % of GDP); and industrialization is measured as the percentage of the value-added of the industry in GDP. Balanced panel data with N * T = 135 observations where N=5 and T=27 are considered in this study. The summary statistics of the analyzed data, including mean, standard deviations, and the minimum and maximum values, are detailed in Appendix A.

4. RESULTS AND DISCUSSION

The results for the entire sample are presented in this section. It is essential to check whether data are unit-roots or non-stationary as a precondition for testing of cointegration. In this study, the LLC (Levin, Lin, Chu) and IPS (Im, Pesaran, Shin) techniques were employed to identify the presence of unit roots in the series. A summary of these two test results is detailed in Table 1.

Table 1. Panel unit root tests.

Variable	LLC		IPS	
	Level	Ist difference	Level	Ist difference
InHDI	1.14 [0.87]	-4.03*** [0.00]	0.41 [0.66]	-3.79*** [0.00]
InBIO	-1.91*[0.09]	-9.82*** [0.00]	-0.58 [0.28]	-9.07*** [0.00]
InGDP	0.51 [0.69]	-5.64*** [0.00]	1.35 [0.91]	-5.57*** [0.00]
lnIND	-1.94*[0.08]	-5.70*** [0.00]	-1.35* [0.09]	-5.93*** [0.00]
lnTRO	-0.98 [0.16]	-9.66*** [0.00]	0.09 [0.54]	-8.95*** [0.00]
lnFDI	-0.43***[0.00]	-15.20***[0.00]	-4.18*** [0.00]	-14.69*** [0.00]

[] indicates p-value; Significant at (* 10% ** 5%, *** 1%) level.

Table 2. Panel cointegration tests.

Test	Statistics	P-value
Panel PP statistic	-2.062**	0.0196
Panel PP statistic (Weighted)	-1.782**	0.0374
Group PP statistic	-2.046**	0.0204
Panel ADF statistic	-2.254**	0.0121
Panel ADF statistic (Weighted)	-1.811**	0.0351
Group ADF statistic	-1.337*	0.0907
Kao test statistic	-2.144**	0.0160

Significance level (* 10% ** 5%, *** 1%) for rejecting the null hypothesis of no cointegration.

It is clear from both tests that there is no evidence to reject the null hypothesis at the level for all series, but at the first difference, the hypothesis is rejected at the 1% level for all series. Therefore, based on the LLC and IPS tests, all six variables seem to be I (1). Hence, all variables in Equation 1 consists of unit root properties, and the process is I (1).

Panel cointegration techniques are utilized to measure the long-run association among the variables in Equation 1, as the panel series in this study. A number of test results, containing Panel PP statistic, group PP statistic, Panel ADF statistic, group ADF statistic, and Kao attributable to Pedroni [51] and Kao [53], are displayed in Table 2. The hypothesis of no cointegration in the panel is rejected at 5% level based on the results in Table 2, supporting a long-run relationship exists among the studied variables.

Based on the long-run relationship identified among the studied variables, the next step is to assess the long-run coefficients in Equation 1. Two novel statistical estimation techniques, such as the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS), were applied for country-specific long-run parameter estimates based on assuming no trend and group estimation. The estimated coefficients, standard errors, and p-values of the predictor variables are detailed in Table 3, where the regressed variable is the human development index (lnHDI).

The effect of biomass energy consumption on human development (β) is of primary interest. Both approaches provide similar results suggesting biomass energy consumption has a negative impact on human development in the long-run. For all South Asian nations, negative relationships were identified, contrary to the findings obtained for BRICS countries by Wang *et al.* [29]. Nevertheless, the analysis conducted by Wang *et al.* [29] for BRICS countries found that a negative relationship with India supports our results. The production and consumption of biomass energy can cause loss of biodiversity, deforestation, depletion of resources, and food insecurity.

Table 3. Estimation of the long-run coefficient.

Nations	FMOLS					DOLS				
	Predictors									
	lnBIO	lnGDP	lnTRO	lnFDI	lnIND	lnBIO	lnGDP	lnTRO	lnFDI	lnIND
Bangladesh	-0.216	0.444***	0.089**	0.012**	-0.361*	-0.274	0.467	0.031	0.027	-0.290
	(0.149)	(0.090)	(0.034)	(0.005)	(0.179)	(0.297)	(0.233)	(0.042)	(0.013)	(0.474)
India	-0.112***	0.289***	0.037***	0.006***	-0.080***	-0.142*	0.283***	0.043*	0.004	-0.068
	(0.015)	(0.005)	(0.006)	(0.001)	(0.019)	(0.053)	(0.013)	(0.015)	(0.002)	(0.037)
Nepal	-0.429***	0.703***	-0.002	-0.001	-0.047***	-0.013	0.285*	0.216**	0.003**	-0.329**
	(0.084)	(0.046)	(0.028)	(0.001)	(0.035)	(0.152)	(0.115)	(0.063)	(0.001)	(0.062)
Pakistan	-0.347***	0.856***	-0.060*	-0.002	0.179**	-0.282**	0.955***	-0.064*	-0.008**	0.341***
	(0.067)	(0.031)	(0.033)	(0.006)	(0.048)	(0.059)	(0.034)	(0.025)	(0.002)	(0.057)
Sri Lanka	-0.096*	0.194***	0.031	-0.006	0.179***	-0.219**	0.182**	-0.003	0.003	0.102
	(0.047)	(0.017)	(0.022)	(0.006)	(0.062)	(0.066)	(0.038)	(0.050)	(0.028)	(0.136)

Significant at (* 10% ** 5%, *** 1%) level. Standard error represents in ().

Table 4. Dumitrescu-Hurlin panel causality tests, p-values are shown in parentheses.

Dependent variable	Independent variable					
	lnHDI	lnBIO	lnGDP	lnIND	lnTRO	lnFDI
lnHDI	-	4.347* (0.055)	5.104*** (0.009)	2.653 (0.697)	2.703 (0.665)	1.619 (0.587)
lnBIO	6.760*** (0.000)	-	6.366*** (0.000)	2.168 (0.961)	4.066* (0.097)	3.585 (0.219)
lnGDP	5.962*** (0.000)	4.539** (0.037)	-	2.136 (0.938)	1.934 (0.795)	1.231 (0.372)
lnIND	9.088*** (0.000)	7.818*** (0.000)	8.986*** (0.000)	-	7.775*** (0.000)	4.570** (0.034)
lnTRO	5.446*** (0.004)	2.897 (0.543)	4.175* (0.078)	5.160*** (0.008)	-	2.836 (0.580)
lnFDI	4.635** (0.029)	2.846 (0.574)	3.429 (0.277)	3.816 (0.151)	3.252 (0.353)	-

Significant at (* 10% ** 5%, *** 1%) level.

Moreover, traditional forms of biomass use, such as wood and waste, can affect both health and the environment. Collecting traditional forms of biomass for domestic cooking may also include women who refrain from participating in child care and education [22]. That may be the reason why the consumption of biomass energy in South Asian countries hampers human development. Policymakers may suggest reducing the use of traditional biomass, such as firewood and cow dung cake, to achieve sustainable development and improve the quality of life. On the other hand, the GDP coefficient is statistically positive and significant at the 5% significance level, which indicates that GDP has a positive impact on human development.

After measuring the long-run coefficients, we used Dumitrescu and Hurlin [30] technique to evaluate the causal relationships between variables taken in this paper. The results of the Dumitrescu-Hurlin heterogeneous panel causality test are presented in Table 4. These results reveal the presence of bidirectional causality between human development and biomass energy usage. The long-run coefficients estimated in Table 4 help policymakers to suggest clean energy sources by reducing traditional biomass energy for these South Asian countries to achieve SDG-7. This test also offers a two-way relationship between human development and economic growth. A similar finding is suggested by Wang *et al.* [29] and Sinha and Sen [64] in BRIC countries.

5. CONCLUSION AND POLICY IMPLICATIONS

The panel cointegration approach, along with a Dumitrescu-Hurlin panel causality test, has been used to examine the long-run linkage between biomass energy usage and human development for South Asian countries over the period of 1990-2016. The study reveals the existence of long-run causality between human development and biomass energy usage. However, biomass energy usage has an adverse effect on human development. Based on the results of this paper, policy implications can be drawn that excessive traditional biomass energy usage can play an adverse effect on human development, particularly in developing countries (in this case, South Asian countries). Clean energy (such as biogas and biofuel) and clean cooking technology can accelerate human development for South Asian countries and contribute to achieving SDG's goal-

7. The government should encourage people to adopt clean cooking technologies by ensuring the necessary policy and incentives. The government may also continue the awareness program for using improved cooking stoves in rural areas in South Asian countries. Our results also reflect that economic growth is a crucial factor for human development in the South Asian region. Therefore, policy initiatives are required to accelerate economic growth for human development. Governments in the South Asian region can offer more budgetary allocation for health services, education, poverty alleviation, environmental protection, and clean energy technology development.

Finally, notwithstanding the important results acknowledged in this paper, there are some limits worthy of exploration in future research. This study can be conducted for other case studies. Also, more informal measures, for example, interviews and household level investigation, can offer a robust additional finding. The effect of biomass energy use on human welfare in the context of advanced nations or other regions will support policymakers with a comprehensive policy guideline regarding the impact of biomass energy usage. Besides, we emphasize investigating the impact of biomass energy use on human development, ignoring the specific biomass energy source forms. This is the constraint of this study that can be explored in future research focusing on additional nations and economies over extended periods as data becomes available.

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APPENDIX A

Table A1. Summary statistics of national data during 1990-2016.

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
Bangladesh	HDI	0.491	0.063	0.388	0.599
	BIO	1.421	0.159	1.193	1.689
	GDP	635.059	195.191	411.165	1062.040
	FDI	0.628	0.551	0.004	1.74
	IND	23.649	1.836	20.146	27.346
	TRO	31.401	9.078	16.477	47.150
India	HDI	0.526	0.063	0.431	0.637
	BIO	1.938	0.087	1.758	2.077
	GDP	1035.67	387.534	575.502	1874.229
	FDI	1.17	0.885	0.027	3.62
	IND	28.348	1.590	26.442	31.137
	TRO	25.816	9.875	12.944	43.035
Nepal	HDI	0.471	0.060	0.380	0.572
	BIO	2.531	0.236	2.272	3.052
	GDP	505.597	115.770	354.258	731.999
	FDI	0.204	0.188	0.0001	0.548
	IND	28.348	1.590	26.442	31.137
	TRO	37.073	4.634	24.148	45.459
Pakistan	HDI	0.478	0.049	0.404	0.556
	BIO	2.810	0.117	2.653	3.159
	GDP	899.098	111.215	741.004	1117.518
	FDI	1.15	0.867	0.383	3.67
	IND	21.446	1.647	18.257	25.528
	TRO	31.114	3.240	24.124	37.815
Sri Lanka	HDI	0.704	0.050	0.625	0.774
	BIO	1.494	0.075	1.379	1.671
	GDP	2192.162	803.254	1189.664	3769.159
	FDI	1.233	0.495	0.430	2.85
	IND	27.844	1.449	25.850	30.642
	TRO	57.004	12.291	35.792	71.711

Data sources: UNDP [61], Global Material Flows Database [62] and World Development Indicators [63].