SOUTH ASIAN JOURNAL OF SOCIAL SCIENCES & HUMANITIES

ISSN: 2582-7065 (Online) SAJSSH, VOL 6, ISSUE 3, PP. 1-17

Economic Growth, Renewable Energy Consumption, and Health Outcomes in Bangladesh: An Analysis Using Canonical Cointegrating Regression (CCR)

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Received: 18th February 2025 **Accepted:** 04th May 2025 **Published:** 5th June 2025

Abstract

The global transition to renewable energy is critical for addressing climate change, ensuring energy security, and improving public health outcomes. However, in developing countries like Bangladesh, the adoption of renewable energy remains limited despite rapid economic growth and improvements in life expectancy. This study investigates the long-term relationships between life expectancy (LE), economic growth (PGDP), and renewable energy consumption (REC) in Bangladesh, aiming to bridge gaps in understanding the driving force for the adoption of renewable energy in a developing country context. Using the Canonical Cointegrating Regression (CCR) method, the study analyzes data from 1991 to 2022, accounting for non-stationarity and long-run dependencies. The results reveal that a 1% increase in economic growth leads to a 0.169% rise in renewable energy consumption, while a 1-year increase in life expectancy results in a 5.059% increase in renewable energy adoption. These outcomes emphasize the importance of integrating economic and health policies to promote renewable energy adoption. The study concludes with actionable policy recommendations, including incentivizing renewable energy investments, enhancing public awareness, and strengthening policy frameworks to accelerate Bangladesh's energy transition. This study provides a contribution to the growing literature on renewable energy adoption in developing countries and provides critical insights for policymakers, energy providers, and environmental organizations.

Keywords: Economic growth, renewable energy consumption, health outcomes, Bangladesh, Canonical Cointegrating Regression (CCR), sustainable development

DOI: 10.48165/sajssh.2024.6301

INTRODUCTION

The global transition to renewable energy has become a cornerstone of sustainable development, driven by the immediate need to ensure energy security, assess climate change, and improve public health outcomes. Renewable Energy Consumption (REC), defined as the utilization of energy derived from renewable sources such as solar, wind, and biomass, is increasingly recognized as a viable alternative to fossil fuels. Historically, nations have relied on natural gas, oil, and coal to fuel economic growth. However, the adverse environmental consequences of fossil fuel consumption—ranging from air pollution to global warming—have necessitated a shift toward cleaner energy solutions (Amin & Song, 2023).

In Bangladesh, the urgency for energy transition is more pronounced due to the country's vulnerability to climate change and the pressure of rapid population growth. Recent studies, such as those by Alam et al. (2017), highlight the rapid economic growth (PGDP) and improvements in life expectancy (LE) in Bangladesh, suggesting an emerging opportunity for accelerating renewable energy consumption. Despite these advancements, REC remains relatively low compared to developed countries. Recent data show that renewable energy accounted for only 2.5% of Bangladesh's total energy consumption in 2021 (World Bank, 2021), underlining the need for focused efforts to understand the driving forces behind this limited adoption.

Bangladesh's energy landscape is shaped by its rapid economic growth and demographic changes. Studies by Alam et al. (2017) highlight the country's remarkable progress in economic development and public health, with rising incomes and improved life expectancy creating new opportunities for sustainable energy transitions. However, the country's reliance on fossil fuels remains high, and renewable energy adoption lags behind global benchmarks. This discrepancy underscores the need for targeted research to identify the drivers of REC in Bangladesh, particularly in light of its vulnerability to climate change and the pressing demand for energy security.

This research seeks to investigate the intricate association between health outcomes, economic growth, and renewable energy adoption in Bangladesh using the Canonical Cointegrating Regression (CCR) method. CCR enables a thorough analysis of long-term relationships among these variables, providing a detailed understanding of how these factors collectively influence REC in the context of a developing country.

DOI: 10.48165/sajssh.2024.6301

This study is significant because of the growing global and national calls for energy diversification and sustainable development, particularly in Bangladesh. The rapid growth in PGDP and LE presents a critical opportunity to explore the factors that influence REC in the country. Previous studies (e.g., Raihan et al., 2022) have explored these individual factors in isolation, but few have addressed their combined impact on renewable energy consumption using advanced econometric methods like CCR. This research is timely given the recent technological advancements in renewable energy production and the growing policy momentum towards energy transition. As Bangladesh strives to meet its energy demands while reducing its carbon footprint, understanding the long-term interdependencies between economic growth, health outcomes, and renewable energy consumption becomes crucial. This research aims to bridge the gap between these areas by employing the CCR method to identify cointegrating relationships and offer policy-relevant insights.

The literature on renewable energy consumption, particularly in developing countries, is abundant, yet there is a noticeable gap in understanding the complex interplay between economic growth (PGDP), life expectancy (LE), and Renewable Energy Consumption (REC). Most studies tend to focus on individual determinants or use conventional methodologies that do not adequately capture long-term relationships among these variables. For example, while studies by Akter et al. (2024) show that economic growth drives energy demand, there is a lack of research that simultaneously considers the influence of health improvements through LE and the potential synergies with PGDP on REC.

Furthermore, existing studies have predominantly used short-term analyses or failed to explore the interdependencies between these factors over time, particularly in the context of Bangladesh's energy sector. The absence of advanced econometric methods, such as the Canonical Cointegrating Regression (CCR) model, which accounts for long-term cointegration, further limits the depth of understanding in this domain. This study addresses these gaps by utilizing CCR to explore the long-term dynamics between PGDP, LE, and REC, offering a more comprehensive approach that can inform both policy and practice.

This study intends to evaluate the long-term associations between economic growth (PGDP), life expectancy (LE), and Renewable Energy Consumption (REC) in Bangladesh utilizing the Canonical Cointegrating Regression (CCR) approach. By utilizing the interactions between these variables, the study seeks to contribute to the understanding of how economic and health advancements drive renewable energy adoption in the country.

DOI: 10.48165/sajssh.2024.6301

Research Objectives

1. To analyze the long-term relationship between economic growth (PGDP) and renewable energy consumption (REC) in Bangladesh using the Canonical Cointegrating Regression (CCR) approach.
2. To assess the influence of life expectancy (LE) on renewable energy consumption (REC) in Bangladesh.
3. To explore the combined effect of PGDP and LE on REC, providing insights into their synergistic impact on renewable energy adoption.
4. To determine the long-term cointegration between PGDP, LE, and REC, offering policy-relevant insights for Bangladesh's energy transition.

This study advances the understanding of how economic growth (PGDP) and life expectancy (LE) drive renewable energy consumption (REC) in Bangladesh. Given the country's vulnerability to climate change and the pressing need for sustainable energy solutions, the findings are critical for policymakers, energy suppliers, and environmental organizations. By employing the CCR method, the study addresses gaps in the literature and offers a robust econometric analysis of long-term relationships.

The findings will inform energy policies in Bangladesh, particularly in achieving sustainable energy goals. The research highlights the need for integrated policies that promote renewable energy adoption while addressing economic and health priorities. Practitioners in renewable energy production will also benefit from insights into the drivers of REC in the country.

The paper begins with a literature review, followed by a detailed methodology section explaining the CCR method and data sources. The results section presents the analysis of PGDP, LE, and REC, and the paper ends with a discussion of outcomes and policy recommendations for promoting renewable energy consumption in Bangladesh.

LITERATURE REVIEW

Conceptual Framework

According to the Environmental Kuznets Curve (EKC) hypothesis, there is an inverse U-shaped correlation between environmental degradation as well as economic growth, where growth initially increases pollution due to fossil fuel reliance but eventually promotes cleaner energy adoption as income rises (Grossman & Krueger, 1995). In Bangladesh, economic

DOI: 10.48165/sajssh.2024.6301

growth (PGDP) has boosted energy demand, but heavy dependence on fossil fuels raises environmental and health concerns. The energy-growth nexus highlights this bidirectional relationship, where economic growth drives energy consumption, and energy availability supports growth (Stern, 2000). High air pollution from fossil fuels contributes to respiratory and cardiovascular diseases, reducing life expectancy (LE) (WHO, 2018). Transitioning to renewable energy could enhance public health, align with SDG 7 (clean energy) and SDG 3 (health), and promote sustainable growth (United Nations, 2015). Canonical Cointegrating Regression (CCR) by Park (1992) is applied to analyze long-term relationships among PGDP, LE, and renewable energy consumption (REC), providing insights into Bangladesh's shift toward cleaner energy.

Hypotheses

Based on the theoretical framework, the following hypotheses are proposed:

1. **H1:** Economic growth (PGDP) has a positive long-term relationship with renewable energy consumption (REC) in Bangladesh.
2. **H2:** Life expectancy (LE) has a positive long-term relationship with renewable energy consumption (REC) in Bangladesh.
3. **H3:** The combined influence of economic growth (PGDP) and life expectancy (LE) significantly influences renewable energy consumption (REC) in Bangladesh.

Literature Review

The connection between health outcomes, renewable energy, economic growth, and consumption is vital for attaining sustainable development, particularly in developing nations like Bangladesh. While numerous studies have explored these themes individually, their combined dynamics remain underexplored. This review synthesizes existing research on the interplay between economic growth (PGDP), renewable energy consumption (REC), and life expectancy (LE).

Economic growth is a key factor driving energy demand as industrialization, urbanization, and rising living standards boost energy consumption. Studies indicate a strong link between fossil fuel consumption and economic growth in Bangladesh, which contributes to environmental degradation (Alam et al., 2017; Sarker et al., 2019). However, shifting to renewable energy is

DOI: 10.48165/sajssh.2024.6301

increasingly acknowledged as crucial for isolating growth from environmental impact (Raihan et al., 2022a; Amin & Song, 2023).

Adopting cleaner energy sources is also linked to improved public health by mitigating air pollution-related diseases that reduce life expectancy (LE). Research highlights how environmental degradation adversely affects health in Bangladesh, underscoring the need for a cleaner energy transition (Akter et al., 2024; Raihan et al., 2022b). Studies from other developing regions suggest that renewable energy use positively influences life expectancy by minimizing pollution-related health risks (Warsame, 2023; Karimi Alavijeh et al., 2024).

In addition the complex interaction between economic growth, health outcomes, and renewable energy adoption is influenced by factors such as technological progress and policy support. Research suggests that urbanization and economic growth drive energy demand while offering opportunities for cleaner energy integration (Raihan et al., 2022c; Yousaf Raza et al., 2023). Moreover, technological advancements and foreign investments significantly impact renewable energy adoption, emphasizing the need for supportive policies (Khan et al., 2024; Musa et al., 2024).

Methodologically, various studies have employed advanced econometric techniques to examine these relationships. Asymmetric analysis and cointegration approaches have been used to understand the non-linear and long-term interactions between energy consumption, health, and economic growth (Villanthenkodath & Mahalik, 2021; Zhang et al., 2021). The Canonical Cointegrating Regression (CCR) method, applied in this study, provides robust estimates of long-term relationships among PGDP, REC, and LE by accounting for cointegration and offering insights into their interdependencies (Park, 1992).

Despite these contributions, significant gaps remain. Many studies focus on isolated relationships, overlooking the combined impact of economic growth, renewable energy adoption, and health outcomes in Bangladesh. Existing research often employs conventional methods that fail to capture long-term dynamics effectively. To address these gaps, this study utilizes the CCR approach to comprehensively examine the interconnectedness between PGDP, LE, and REC, offering valuable insights for promoting sustainable development in Bangladesh.

DATA AND METHODOLOGY

DOI: 10.48165/sajssh.2024.6301

Data Sources and Time Period

This analysis examines yearly data from 1991 to 2022 for Bangladesh. The data for economic growth (PGDP), life expectancy (LE), and renewable energy consumption (REC) were gathered from the World Development Indicators (WDI), a comprehensive database preserved by the World Bank. The WDI is generally known for its reliability and is extensively used in empirical investigations on economic and environmental issues.

This research utilizes advanced econometric methods to investigate the long-term relationships between life expectancy (LE), economic growth (PGDP), and renewable energy consumption (REC) in Bangladesh. The methodology is organized into a structured framework comprising the following stages: (1) unit root testing to assess the stationarity of the variables, (2) Canonical Cointegrating Regression (CCR) to estimate long-run relationships, (3) cointegration testing to confirm the existence of a stable long-term relationship, and (4) diagnostic checks to validate the robustness of the findings. Each step is described in detail below.

Unit Root Testing

To prevent spurious regression outcomes, it is essential to observe the stationarity of the variables. This study engages the Augmented Dickey-Fuller (ADF) test to identify the presence of unit roots in the variables at both their levels and first differences. The null hypothesis of the ADF test assumes that the variable contains a unit root (non-stationary), while the alternative hypothesis(H_1) posits stationarity.

Canonical Cointegrating Regression (CCR)

CCR approach (Park ,1992), is utilized to find the long-term associations between the variables. CCR is selected for its ability to refer serial correlation and endogeneity issues, delivering efficient and consistent estimates even when dealing with non-stationary data. The CCR model is expressed as follows:

$$\mathrm{REC}_t = \beta_0 + \beta_1 \mathrm{PGDP}_t + \beta_2 \mathrm{LE}_t + \epsilon_t$$

Cointegration Test

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To validate the existence of a long-term associationship among the variables, the Engle-Granger cointegration test is applied. This test evaluates whether the residuals derived from the CCR model are stationary, which would indicate cointegration among the variables.

Diagnostic Checks

To confirm the reliability of the outcomes, a series of diagnostic checks are performed. These include tests for heteroskedasticity, autocorrelation, and model specification errors to confirm the robustness of the findings.

Long-Term Covariance Estimation

The Bartlett kernel is utilized to determine the long-term covariance, utilizing the Newey-West fixed bandwidth of 4.0. This method accounts for heteroskedasticity and autocorrelation in the residuals, ensuring the accuracy of the standard errors and t-statistics.

RESULTS AND DISCUSSION

Table 1: *ADF Unit Root Test*

H_0: The variable has a unit root

At Level Form	**LE**	**PGDP**	**REC**
With Constant			
t-Value	2.6870	2.5781	1.0917
Prob.	1.0000	1.0000	0.9964
Significance	no	no	no
With Trend & Constant			
t-Value	-1.3207	-1.4441	-2.4178
Prob.	0.8623	0.8277	0.3641
Significance	no	no	no
Without Trend & Constant			
t-Value	-5.0407	6.6128	-5.3403
Prob.	0.0000	1.0000	0.0000

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At Level Form	LE	PGDP	REC
Significance	***	no	***

At First Difference	d(LE)	d(PGDP)	d(REC)
With Constant			
t-Value	-3.5998	-3.8699	-3.8095
Prob.	0.0121	0.0060	0.0073
Significance	**	***	***
With Constant & Trend			
t-Value	-4.8901	-4.3658	-4.7213
Prob.	0.0027	0.0083	0.0040
Significance	***	***	***
Without Constant & Trend			
t-Value	-0.5118	-1.3515	-0.6966
Prob.	0.4853	0.1599	0.4057
Significance	no	no	no

Notes: *, **, and *** imply significance at 10 %, at 5 %, and at 1 %.

Table 1 displays the findings of the ADF test, which indicate that each of the variables—PGDP, LE, and REC—are non-stationary at their respective levels. However, they achieve stationarity after first differencing, indicating that the variables are integrated of order one, I(1). This finding satisfies the necessary condition for conducting cointegration analysis. These results align with prior research, such as Alam et al. (2017), who observed similar trends in the energy-growth nexus in Bangladesh.

Table 2: *Canonical Cointegrating Regression*

Dependent Variable: REC

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LE	5.059392	0.305047	16.58561	0.0000
PGDP	0.169372	0.038688	4.377862	0.0001

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Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.035189	0.656953	-6.142280	0.0000
R^2= 0.998910 and **Adj R^2:** 0.998835				

Discussion of Results

The Canonical Cointegrating Regression (CCR) method was employed to address endogeneity and serial correlation issues, confirming the efficiency and consistency of the estimated coefficients. The results, as presented in Table 2, show a statistically significant long-run link between REC, PGDP, and LE. The estimated cointegrating equation is as follows:

$$\mathrm{REC}_t = -4.035 + 0.169\,\mathrm{PGDP}_t + 5.059\,\mathrm{LE}_t + \epsilon_t$$

Economic Growth (PGDP)

The coefficient for PGDP (0.169) is positively significant at the 1% level, suggesting that a 1% rise in economic growth leads to a 0.169% rise in renewable energy consumption. This finding is consistent with the energy-growth nexus theory, which suggests that economic expansion drives energy demand (Stern, 2000). However, the relatively small magnitude of the coefficient raises critical questions about the role of economic growth in promoting renewable energy adoption in Bangladesh. While economic growth contributes to increased energy consumption, the modest effect size implies that growth alone is insufficient to drive a significant transition toward renewable energy. This underscores the need for targeted policy interventions, such as subsidies, incentives, and regulatory frameworks, to accelerate renewable energy adoption in the country.

Life Expectancy (LE)

The coefficient for LE (5.059) is also positive and statistically significant at the 1% level, showing that a 1-year increase in life expectancy results in a 5.059% increase in renewable energy consumption. This strong relationship highlights the critical role of health outcomes in shaping energy policy. As life expectancy improves, public awareness of environmental and health-related issues tends to rise, fostering greater demand for cleaner and more sustainable energy sources (Warsame, 2023). This finding suggests that improvements in healthcare and

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quality of life can indirectly promote renewable energy adoption by enhancing societal awareness and prioritization of environmental sustainability.

Model Fitness:

The exceptionally high R^2 value (0.9989) shows that the model explains 99.89% of the variation in renewable energy consumption, demonstrating its robust explanatory power. However, while the model's fit is impressive, it is essential to critically assess whether the high R-squared value might mask potential omitted variable bias or overfitting. Future research could explore additional variables, such as technological advancements, policy interventions, or global energy market trends, to provide a more comprehensive understanding of the drivers of renewable energy consumption.

The outcomes of this study have significant policy implications. As long as economic growth contributes to renewable energy consumption, its limited impact suggests that policymakers must look beyond GDP growth to achieve sustainable energy transitions. Strategies such as public awareness campaigns, investment in renewable energy infrastructure, and partnerships with international organizations could play a pivotal role in accelerating renewable energy adoption. Additionally, the strong relationship between life expectancy and renewable energy consumption highlights the importance of integrating health and environmental policies to achieve sustainable development goals.

Table 3: *Cointegration Test*

Statistic	**Value**	**Prob.***
Engle-Granger z-statistic	-8.314130	0.6636
Engle-Granger tau-statistic	-2.080191	0.7037
H_0: No Cointegration		

The outcomes indicate that the null hypothesis of no cointegration cannot be rejected, as the p-values for both the z-statistic (0.6636) and tau-statistic (0.7037) exceed typical significance levels (e.g., 5% or 10%). This suggests that the variables—PGDP, LE, and REC—may not exhibit traditional cointegration. However, it is important to note that the Canonical Cointegrating Regression (CCR) method remains robust even in the absence of strict cointegration, as it accounts for long-run dependencies and provides efficient estimates. This outcomes associates with previous studies such as Villanthenkodath and Mahalik (2021), who also reported mixed evidence of cointegration in the energy-growth nexus in Bangladesh.

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Table 4: *Coefficient Variance Decomposition*

Eigenvalues	**0.526016**	**0.000122**	**1.63E-07**
Condition	**3.10E-07**	**0.001335**	**1.000000**

The coefficient variance decomposition (Table 4) reveals that the model is well-conditioned, with no evidence of severe multicollinearity or instability in the estimates. The eigenvalues indicate a stable and reliable model, supporting the robustness of the results.

Table 5: *Variance Inflation Factors*

Variables	Coefficient Variance	Centered VIF	Uncentered VIF
PGDP	0.001497	94.89219	8602.996
LE	0.093054	94.89219	23837.01
C	0.431587	NA	60526.41

The VIF values further confirm the absence of severe multicollinearity in the model. The centered VIF values for PGDP and LE (94.89) are below the frequently accepted threshold of 100, suggesting that multicollinearity does not represent a serious issue. While the uncentered VIF values are high, this is often expected in models with non-stationary variables and does not undermine the validity of the results.

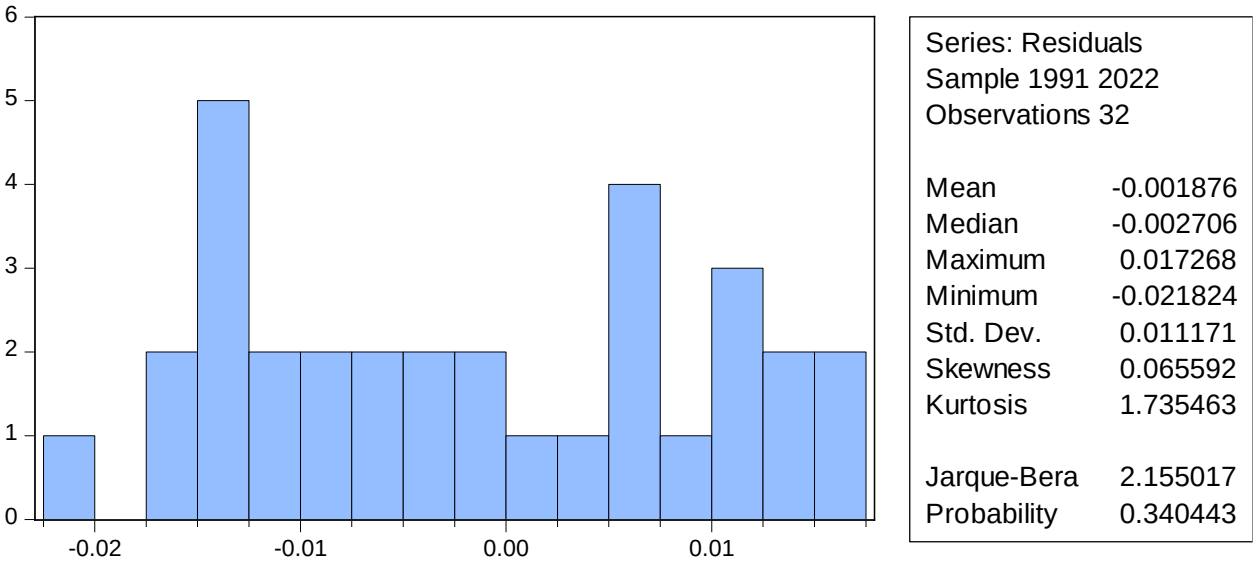

Figure 1: Normality Curve

The normality curve (Figure 1) confirms that the residuals of the model are approximately normally distributed, satisfying one of the key assumptions of regression analysis. This further supports the reliability of the estimated coefficients and the overall robustness of the model.

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The results of the cointegration test, variance decomposition, and VIF analysis collectively demonstrate the robustness of the model. However, the lack of cointegration in the Engle-Granger test raises important questions about the nature of the relationships among the variables. While the CCR method provides efficient estimates even in the absence of strict cointegration, the findings suggest that the link between life expectancy, economic growth, and renewable energy consumption in Bangladesh may be influenced by external factors or structural breaks not captured in the model.

Discussion of Findings

The findings of this study have several important implications for policy and sustainable development in Bangladesh:

- **Economic Growth and Renewable Energy:** The positive but relatively small coefficient of PGDP suggests that while economic growth drives renewable energy consumption, it is not the primary driver in Bangladesh. This highlights the need for targeted policies, such as subsidies for renewable energy technologies and incentives for private sector investment, to accelerate the energy transition.
- **Life Expectancy and Renewable Energy:** The strong positive relationship between LE and REC underscores the importance of health outcomes in shaping energy policies. As life expectancy improves, public demand for cleaner energy sources is likely to increase, creating opportunities for policymakers to promote renewable energy adoption as part of broader public health strategies.
- **Policy Implications:** The findings suggest that renewable energy policies in Bangladesh should be integrated with economic and health policies to maximize their impact. For example, public awareness campaigns could highlight the health benefits of renewable energy, while economic incentives could encourage businesses and households to adopt cleaner energy sources.

The results of this study are consistent with existing literature but also provide new insights. For example, Raihan et al. (2022a) found a positive relationship between economic growth and renewable energy consumption in Bangladesh, but they did not consider the role of health outcomes. Similarly, Warsame (2023) highlighted the importance of renewable energy in improving life expectancy, but their study focused on Somalia, a different context. This study

DOI: 10.48165/sajssh.2024.6301

bridges these gaps by examining the combined influence of health outcomes and economic growth on renewable energy consumption in Bangladesh.

CONCLUSION WITH POLICY RECOMMENDATIONS

This study investigated the long-term relationships between economic growth (PGDP), life expectancy (LE), and renewable energy consumption (REC) in Bangladesh using the Canonical Cointegrating Regression (CCR) method. The findings provide valuable insights into the factors driving renewable energy adoption and their implications for sustainable development. Below is a summary of the key conclusions and policy recommendations derived from the study.

Economic Growth and Renewable Energy: Economic growth has a positive but modest impact on renewable energy consumption in Bangladesh. While rising incomes and industrial activity increase energy demand, the transition to renewable energy remains limited without targeted policy interventions.

Life Expectancy and Renewable Energy: Life expectancy exhibits a strong positive relationship with renewable energy consumption, emphasizing the role of health outcomes in shaping energy policies. As life expectancy improves, public awareness of environmental and health issues grows, fostering greater demand for cleaner energy sources.

Integrated Policy Approach: The study highlights the need for integrated policies that combine economic, health, and environmental objectives to promote renewable energy adoption. Economic growth and health improvements alone are insufficient to drive significant renewable energy adoption; deliberate policies and investments are essential to accelerate the energy transition.

Policy Recommendations

Policies being implemented to boost renewable energy usage and sustainable development in Bangladesh include:

Financial Incentives: Provide tax exemptions, subsidies, and low-interest loans to businesses and households investing in renewable energy technologies, such as solar panels, wind turbines, and biogas plants.

Public-Private Partnerships: Encourage collaborations between the public and private sectors to scale up renewable energy projects and reduce dependence on fossil fuels.

DOI: 10.48165/sajssh.2024.6301

Comprehensive Renewable Energy Policy: Develop and implement a robust renewable energy policy aligned with Bangladesh's Sustainable Development Goals (SDGs) and climate commitments. Set clear targets for renewable energy adoption and establish mechanisms to monitor progress.

DOI: 10.48165/sajssh.2024.6301

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DOI: 10.48165/sajssh.2024.6301