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Do Human Capital and Renewable Energy Consumption Matter for the EKC Hypothesis in the Case of SAARC Countries?

Swarnadeep Roy^{1a}¹ Department of Liberal Arts, Indian Institute of Technology Hyderabad, IndiaKeywords: CO₂, Economic growth, Human capital, Renewable energy consumption, PCSE

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This study reassesses the Environmental Kuznets Curve (EKC) hypothesis, emphasizing the influence of human capital and renewable energy consumption in SAARC countries. By employing the panel-corrected standard error (PCSE) model, the results suggest that enhancing human capital and shifting towards renewable energy sources significantly contribute to reducing carbon dioxide emissions. The paper advocates nuanced policies to address environmental issues without hindering economic growth, emphasizing the shift to renewable energy sources and improving human capital through skill-based education curricula to instill environmental awareness.

I. Introduction

Environmental issues have garnered global attention, prompting scholars and policymakers to scrutinize their origins. Although the EKC hypothesis has been widely studied, there is limited research examining the linkage between renewable energy consumption and human capital in connection with economic growth and how they impact the Environmental Kuznets Curve in both the short term and long term. Rahman et al. (2021) analyzed how growth, energy use, and human capital affect CO₂ emissions in newly industrialized countries, finding that while growth and human capital lower emissions, energy consumption worsens environmental damage, with no evidence for the EKC hypothesis. Mahmood et al. (2019) examined how economic growth, clean energy, and human capital influence CO₂ emissions in Pakistan, finding that growth and human capital lower emissions, while renewable energy reduces pollution. Similarly, Afolayan et al. (2020) investigated how carbon emissions and human capital investment affect Nigeria's economic development, revealing that a 1% rise in health investment enhances growth by 0.008%, while a 1% rise in CO₂ emissions lowers it by 0.1%. According to Akram et al. (2020), "there is a link between improved human capital and reduced energy use." Khan (2020) also observed that "the effect of economic growth on carbon emissions is influenced by the level of human capital."

This study explores the impact of renewable energy and human capital on the EKC hypothesis. This research primarily examines the countries within the "South Asian Association for Regional Cooperation (SAARC)", as this region

is among the world's poorest, characterized by low per capita income and limited human capital. Further, SAARC countries have demonstrated high economic growth rates over the last two decades. As countries move towards a high growth path, it clearly reveals that energy consumption, particularly in the form of non-renewable energy, is driving the growth. As a result, higher growth can be accompanied by a rise in CO₂ emissions. Most of the countries in the world need to target achieving the UN's SDGs, particularly goal 7 and goal 13, in the long run. The SAARC countries are no exception in targeting this goal, and hence, maintaining high economic growth and low carbon emissions becomes a trade-off for these countries. Similarly, by keeping endogenous growth theory in mind, the SAARC also aims to raise its human capital through high educational attainment and more years of schooling, with the intention of fostering long-term economic growth. Therefore, this study fills a research gap by exploring how renewable energy consumption, human capital, and economic growth contribute to reducing carbon emissions within this region. To our knowledge, no prior study has examined this relationship for SAARC countries in the existing literature.

The following sections delve deeper into the analysis. Section II provides a concise description of the selected model and explains the data utilized in the study. Section III provides the estimation technique. Section IV examines key findings, while Section V offers concluding remarks.

a Corresponding author email: swarnadeep.598@gmail.com

II. Data and Methodology

To achieve the objective of the study and in line with earlier studies, the following model is suggested to capture the direct influence of human capital:

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln PCGDP_{it} + \beta_2 \ln PCGDP_{it}^2 + \beta_3 \ln RENG_{it} + \beta_4 \ln EDC_{it} + e_{it} \quad (1)$$

where CO_2 represents carbon dioxide emissions per capita (in metric tons) and serves as a proxy for environmental degradation. $PCGDP$ is GDP per capita (2015, constant US \$) is used as an indicator of economic growth, while $PCGDP^2$ is its squared term. $RENG$ refers to renewable energy consumption as a percentage of total final energy consumption, and EDC represents gross secondary school enrollment (%), serving as a proxy for human capital. The error term is shown by e_{it} . All variables are transformed into their natural logarithmic form, denoted by “ln.” The data for all the variables is sourced from the World Development Indicators published by the World Bank.

Equation (1) is extended by incorporating the interactive term to capture the moderating role of human capital (Ehigiamusoe et al., 2020) as follows:

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln PCGDP_{it} + \beta_2 \ln PCGDP_{it}^2 + \beta_3 \ln RENG_{it} + \beta_4 \ln EDC_{it} + \beta_5 (\ln RENG_{it} \cdot \ln EDC_{it}) + e_{it} \quad (2)$$

The term $\ln RENG_{it} \cdot \ln EDC_{it}$ captures the interactive effect between consumption of renewable energy and human capital. In this study, EDC is utilized as a proxy for measuring human capital. We assume that β_1 is positive while β_2 is negative to support the hypothesis of the environmental Kuznets curve. In contrast, the environmental Kuznets Curve hypothesis is unsupported if β_1 is negative and β_2 is positive. This paper utilizes yearly data spanning from 1990 to 2020 for SAARC member countries.

III. Estimation strategy

Prior to the main analysis, the study first uses a cross-sectional dependence (CD) test to find whether CD exists among these countries. Given the likelihood of having common traits and units near proximity, there is a very high chance of cross-sectionally dependent panels. Biased estimations and conclusions will result from the presence of CD (Pesaran, 2021). To address potential CD issues, the paper utilizes the CD test developed by Pesaran (2021), which can be used with both small and large panels, and it is the best option when the cross-section unit is less than the time-period. To prevent erroneous results arising from CD, the panel unit root test is employed. Pesaran (2007) developed the “Im, Pesaran, and Shin (IPS)” test, which is cross-sectionally augmented. In the second stage, Chudik & Pesaran’s (2015) CS-ARDL test is employed which accounts for CD by taking averages of cross-sectional units.

Given the identification of CD and cointegration within the data, PCSE model is used for the estimation. The technique offers a robust approach by addressing both serial correlation and heteroscedasticity. The basic equation is as follows,

$$y_{it} = x_{it}\beta + \epsilon_{it}; \forall 1 \leq i \leq N; \forall 1 \leq t \leq T \quad (3)$$

The dependent variable y_{it} depends on explanatory variables (x_{it}) indexed by both units (i) and time (t). PCSE is thus obtained by taking the square root of the diagonal elements of

$$PCSE = (X^T X)^{-1} X^T \hat{\Omega} X (X^T X)^{-1} \quad (4)$$

where $\hat{\Omega} = \widehat{\Sigma} \otimes I_T$ ($\otimes$ is kronecker product) and $\widehat{\Sigma} = \frac{E^T E}{T}$; E is the matrix of error terms of order $T \times N$ and, hence, the estimator of Ω . Ω represents a block diagonal matrix. Each block along the diagonal is an $N \times N$ matrix representing the contemporaneous covariance Σ between the residuals for each cross-sectional unit. The robustness check is performed by employing Feasible Generalized Least Squares (FGLS) technique.

To conclude the analysis, Dumitrescu Hurlin (DH) panel causality test (2012) is employed to explore the potential causal relationships among the variables. This test can be applied with great flexibility to heterogeneous panels as well as where the cross-section unit is less than the time periods. One of its main benefits is that it takes allowance for cross-sectional dependency.

IV. Empirical Results

The result of the CD test confirms the existence of CD among SAARC countries. As a result, this study applies the CIPS panel unit root test to evaluate the stationarity of the variables in Equation 2. The result shows that all variables are nonstationary at their levels but attain stationarity after first differencing, classified as I (1). [Table 1](#) shows the results of both CD and panel unit root tests.

In the subsequent stage, the CS-ARDL test is applied. The results reject the EKC hypothesis, showing that economic growth initially lowers CO_2 emissions but later increases them at higher income levels. Renewable energy and human capital both reduce emissions. The interaction term has a negative moderating effect on energy use. The adjustment term ECT (-0.788, $p < 0.01$) suggests a 78.8% speed of adjustment toward equilibrium annually, confirming a stable long-run relationship. [Table 2](#) summarizes CS-ARDL results.

[Table 3](#) presents the findings derived from the PCSE model, while the results from the FGLS method are included as a robustness check. The PCSE estimates reveal that $PCGDP$ has a notable negative effect on CO_2 emissions. However, its squared term yields a positive and significant coefficient. These findings suggest a deviation from the EKC hypothesis, implying that growth alone does not necessarily resolve environmental concerns in these countries. Additionally, the analysis demonstrates that renewable energy and human capital both have significant negative effects on carbon emissions. However, the analysis reveals a significant positive coefficient for the interactive term. This finding suggests that human capital plays a negative moderating role in energy usage. The findings of FGLS corroborate the results obtained from PCSE.

Finally, the DH causality test results presented in [Table 4](#) reveal some interesting dynamics. Per capita GDP exhibits a unidirectional causal relationship with carbon dioxide emissions, suggesting that economic growth may drive

Table 1. CD and Panel unit root tests results

CD test		Panel unit root test	
Variable	Statistic	Variable	Statistic
$\ln CO_2$	24.392***	$\ln CO_2$	0.52
$\ln PCGDP$	25.371***	$\Delta \ln CO_2$	-8.42***
$\ln PCGDP^2$	25.371***	$\ln PCGDP$	1.04
$\ln RENG$	23.707***	$\Delta \ln PCGDP$	-5.57***
$\ln EDC$	12.468***	$\ln RENG$	2.32
$\ln RENG.\ln EDC$	0.047***	$\Delta \ln RENG$	-8.55***
		$\ln EDC$	1.18
		$\Delta \ln EDC$	-6.93***

Source: Author's calculation from cross-sectional dependence (CD) test and panel unit root test results. Here $\ln$ represents natural logarithm of the variable and Δ stands for the first difference of the variable. *** corresponds to 1 percent level of significance.

Table 2. CS-ARDL result

Variable	Short run	Long run
$L. \ln CO_2$	0.212*** (0.709)	
$\ln PCGDP$	-0.082*** (0.032)	-0.107*** (0.055)
$\ln PCGDP^2$	0.734** (0.063)	0.437** (0.053)
$\ln RENG$	-11.635** (5.763)	-12.597*** (4.628)
$\ln EDC$	-9.033** (4.613)	-8.565** (4.372)
$\ln RENG.\ln EDC$	2.158** (1.721)	2.102** (1.072)
$ECT (-1)$	-0.787*** (0.071)	

Source: Author's calculation from CS-ARDL test result. L stands for the lagged value of the dependent variable. $\ln$ is the natural logarithm of the variable. ***, **, and * represents statistical significance at 1%, 5%, and 10% levels, respectively. The value in parentheses indicates standard errors.

Table 3. Results of PCSE and FGLS tests

Variable	PCSE	FGLS (robustness check)
$\ln PCGDP$	-0.497*** (0.093)	-0.176*** (0.127)
$\ln PCGDP^2$	0.306*** (0.063)	0.638** (0.328)
$\ln RENG$	-0.714* (0.341)	-0.105** (0.805)
$\ln EDC$	-0.035** (0.263)	-0.017* (0.791)
$\ln RENG.\ln EDC$	0.091** (0.077)	0.019** (0.198)
$R\text{-squared}$	0.655	

Source: Author's calculation from PCSE and FGLS test results. $\ln$ is the natural logarithm of the variable. ***, **, and * represents statistical significance at 1%, 5%, and 10% levels, respectively. The value in parentheses indicates standard errors.

Table 4. DH causality test result

Null Hypothesis	Zbar-Stat
$\ln PCGDP \neq \ln CO_2$	4.088*
$\ln CO_2 \neq \ln PCGDP$	0.736
$\ln RENG \neq \ln CO_2$	2.121*
$\ln CO_2 \neq \ln RENG$	3.055**
$\ln EDC \neq \ln CO_2$	2.115*
$\ln CO_2 \neq \ln EDC$	5.146***
$\ln RENG \neq \ln PCGDP$	1.707
$\ln PCGDP \neq \ln RENG$	4.770***
$\ln EDC \neq \ln PCGDP$	0.549
$\ln PCGDP \neq \ln EDC$	21.328***
$\ln EDC \neq \ln RENG$	0.727
$\ln RENG \neq \ln EDC$	6.228***

Source: Author's calculation from DH panel causality test result. $\neq$ indicates the absence of a causal relationship. $\ln$ is the natural logarithm of the variable. ***, **, and * represents statistical significance at 1%, 5%, and 10% levels, respectively. The value in parentheses indicates standard errors.

emissions but not vice versa. Interestingly, both renewable energy consumption and human capital display bidirectional causality with carbon dioxide emissions. This implies that these factors can both influence and be influenced by emission levels.

V. Conclusion

This paper explores the dynamic interaction between environmental deterioration, the use of renewable energy, human capital, and growth in the economy in the case of SAARC countries, focusing on the moderating effect of human capital. The analysis does not provide evidence for EKC, suggesting that growth itself is not enough to improve environmental quality. Consequently, implementing sensible policies becomes essential to attaining prompt decrease in pollution-induced damage. However, it is important for governments to strike a balance by avoiding the stifling of growth through overly stringent environmental regulations that could potentially hinder future economic devel-

opment. Besides this, governments should develop strategies to shift from non-renewable energy consumption to adopting renewable, mostly in the form of clean energy sources. The moderating influence of human capital, measured by education, exacerbates environmental degradation across countries. Further, from a policy perspective, education may be linked with the adoption of clean energy, contributing to the long-term reduction of carbon emissions in SAARC countries.

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