Connecting Higher Education and Renewable Energy to Attain Sustainability for BRICS Countries – A Climate Kuznets Curve Perspective

Journal:	*International Journal of Emerging Markets*
Manuscript ID	IJOEM-04-2023-0555.R1
Manuscript Type:	Research Article
Keywords:	economic growth, climate change, Global Warming, Education

Connecting Higher Education and Renewable Energy to Attain Sustainability for BRICS Countries – A Climate Kuznets Curve Perspective

Abstract

Purpose - Increased trapped heat in the atmosphere leads to global warming and economic activity is the primary culprit. This study proposes the nonlinear impact of economic activity on cooling degree days to develop a climate Kuznets curve (CKC). Further, this study explores the moderating role of higher education and renewable energy in diminishing the climate-altering effects of economic activity.

Design/Method/Approach - For this, all the selected BRICS economies are range from 1992 to 2020. The CKC analysis is conducted using a distribution and outlier robust Panel Quantile ARDL model.

Findings - Results confirmed a U-Shaped CKC, controlling for population density, renewable energy, and tertiary education enrollment, and innovation. The moderating role of renewable energy and education can be exploited to tackle the progressively expanding climate challenges.

Originality – This study is instrumental in developing the climate change based economic activity Kuznets curve and assessing the potential of higher education and renewable energy policy intervention.

Research Implications - This study highlighted the incorporation of climate change mitigating curriculum in education so that the upcoming economic agents are well equipped to reduce global warming which certainly needs to be addressed globally.

JEL Codes: Q2, Q3, H51

Key Words: economic growth; climate change; global warming; education; dynamic panel data models

1. Introduction

The economic performance of any country depends on its national income (Iqbal *et al*., 2021). Therefore, the desire of higher economic progress has brought the world to the brink of climate change (Nasir *et al*., 2019). A higher level of economic growth represents more production leading to environmenta; deterioration (Borojo *et al*. 2022) and, ultimately, climate change begins (Hassan *et al*., 2021). In particular, developing countries seem more vulnerable to climate change (Mertz *et al*., 2009). Brazil, Russia, India, China, and South Africa (BRICS countries) are growing fast economically, resulting in rapid climate change (Nawaz *et al*., 2021). Temperatures around the world have risen by more than 1.6 degrees Fahrenheit since global warming began in 1906.[1]. Moreover, worldwide increase in temperature is the result of manmade greenhouse gas emissions[2] which leads to severe weather damage and will also increase and intensify (Hansen *et al*., 2000) leading to gradual buildup of positive temperature deviations from 65^{o}F. The term cooling degree days (CDD) is coined to represent the degree of global warming spells the country is experiencing within a year (Spinoni *et al*., 2018).

This study has proposed the climate change and economic growth relationship and named it the climate Kuznets curve (CKC), derived from the environmental Kuznets curve (EKC). EKC describes a continuous increase in economic growth that first leads to environmental deterioration increases and then decreases (Wang *et al*., 2023). Sometimes it also depicts an inverse situation forming a U-shaped relation, resulting from overutilization of resources (Karahasan and Pinar, 2022). The narrative behind this new model is that change in climate takes a higher toll on human welfare compared to the depreciation of environmental quality. Though both are interrelated, climate change affects human life multidimensionally (Hof, 2015; Tol, 2018). The ongoing loss of biodiversity with a global temperature increase of just 1.5^{o} Celsius above the pre-industrial norm poses an irreversible threat to public health (Mckeever, 2021).

Using CDD as direct indicator of climate change in place of environmental quality as an antecedent, this study names phenomenon from EKC to CKC. It is because global warming is the

---

[1] https://www.nationalgeographic.com/environment/article/global-warming-effects
[2] https://climate.nasa.gov/effects/

outcome of deterioration in air quality[3]. Moreover, other forms of pollution occur due to expansion in economic activities (Arshed *et al*., 2021). It would be correct to say that economic activities are reasonable for global warming.

Now the question is how this analysis can be beneficial for climatic sustainability. As the CKC is a nonlinear phenomenon, it can be moderated towards sustainability growth (Haans *et al*., 2016). In this situation, the role of education and renewable energy can be considered (Shobande and Asongu, 2022; Usman *et al*., 2022). Raising awareness is a process that can be greatly aided by education. A structural shift in the consumption pattern of society may result from the preference of high-informed consumers for high-quality goods (Alamsyah and Othman, 2021). Education develops human capital which contributes to knowledge synthesis towards the betterment of people. Renewable power comes from resources that can be regenerated naturally. Its growing economy is a symbol of cleaner air and water which helps mitigate weather extremes. Renewable power comes from resources that can be regenerated naturally. Its growing economy is a symbol of cleaner air and water which helps mitigate weather extremes (Sarkodie *et al*., 2020). Renewable power comes from resources that can be regenerated naturally.

Other factors related to climate change are population density and technological innovations. Population density is a measurement of population per unit of land area and is deeply connected with ecosystems (Hanberry, 2022). An increased population or density would ultimately shorten the dwelling spaces, buildings, and green-belt shrinks which can lead to environmental deterioration (Gupta *et al*., 2022). On the contrary, technological innovations can improve environmental quality (Jahanger *et al*., 2022). Energy can be saved or its consumption lowered at the residential and commercial sectors through the proliferation of technological advancement, hence reducing its carbon impact. However, it may open the door to alternative forms of energy.

After unfolding the subject matter, the first objective is to empirically validate the CKC for BRICS countries with technological innovations and population density as controlling variables. Secondly, the education and renewable energy consumption are incorporated as climate improvers

[3] EPA.gov - https://www.epa.gov/air-research/air-quality-and-climate-change-research#:~:text=Changes%20in%20climate%20can%20result,ozone%20standards%20in%20the%20future.

and moderators of CKC. Thirdly this study proposes suitable policies for climate sustainability based on empirical findings. Using the economic activity intervention policy of education and renewable energy, policymakers could help in promoting sustainable economic activities with higher order awareness related to managing global issues.

After this section, this study is divided into four parts. The second section reviews the literature to understand the work done and identify the literature gap. In the third section, there is a discussion about the data and methodological techniques. The fourth section is a discussion of results. In the final section, concluding remarks with policy implications are provided.

This study innovates the discussion in this domain in the following ways:

- The application of CKC in BRICS countries focuses on the outcome rather than the source of climate change previously studied in EKC.

- Explores ways economic activity can become climate-friendly through the role of higher education and technological innovation as moderators to the CKC curve.

- Use of the panel quantile autoregressive distributed lagged (ARDL) model which can provide custom policy insights in terms of long-run/short-run effects, moderation size effects of higher education and innovation, and distributional position effect of cooling degree days in the country.

2. Literature Review

The concept of CKC is derived from EKC. It describes the relationship between economic growth and climate change which begins with the Kuznets curve relating economic growth and income inequality (Todaro, 2015). Later EKC was related to economic growth and environmental quality. However, previous studies like Grossman and Kruger (1991), Selden and Song (1994), and Stern *et al*. (1996) have documented this occurrence with economic progress and carbon emissions. Likewise, STIRPAT is another aspect of contextualizing the impact of economic activities on CO_2 emissions (York *et al*., 2003).

Some studies have covered EKC through climate change in their analysis. Destek and Sarkodie (2019) have confirmed an inverted U-shaped EKC using ecological footprints. Pincheira *et al*. (2021) have used seven climate change-related indicators including carbon dioxide emissions, biodiversity, ozone, fertilizers, fresh water, and land. According to their findings some indicators validate EKC whereas some do not. Youssef *et al*. (2020) and Ansari (2022) investigated EKC using ecological footprint and carbon emissions; the former study confirmed an inverted U-shaped EKC while the latter study confirmed an inverted U-shaped EKC but only with the ecological footprint. Dinga *et al*. (2022) have validated both inverted U-shaped and U-shaped EKCs using ecological footprints and overshoots. Chaudhry *et al*. (2022) have tried comprehensively covering climate change using carbon dioxide, nitrous oxide, methane emissions, deforestation, and footprints, and confirmed an inverted U-shaped EKC. Studies like Baležentis *et al*. (2019), Uche *et al*. (2022), Simionescu *et al*. (2022), and Bao and Lu (2023) have used greenhouse gas emissions to represent climate change and all have found inverted U-shaped EKCs. All of these studies, summarized in Table 1, focused on the fact that managing the environment would abate climate change but this study is assessing the direct link of economic anthropogenic activities to global warming.

STIRPAT provides the context for the selection of control variables. Literature is evident regarding the impact of population density on climate through different dimensions. Alola *et al*. (2019) and Quintana *et al*. (2021) have confirmed that urban population pressure is responsible for increasing global warming. Tromboni *et al*. (2021) have confirmed that population density is responsible for deteriorating water quality. Ahmed *et al*. (2022), Sahoo and Sethi (2022) and Gupta *et al*. (2022)

have found it responsible for encouraging ecological footprints and $PM_{2.5}$. Hanberry (2022) has confirmed the positive relationship between temperature and population density. Different studies have tested the role of technological innovations on climate. Sinha *et al*. (2020) have constructed an index using climate indicators like carbon dioxide, methane, nitrous oxide, $PM_{2.5,}$ and greenhouse gas and highlighted its importance in reducing these climate problems. Miśkiewicz (2021) pointed out its significance in reducing greenhouse gas (GHG) emissions. Kihombo *et al*. (2021), Majeed *et al*. (2022), and Jahanger *et al*. (2022) have validated their role in decreasing the ecological footprint. At the same time, Danish and Ulucak (2021), Chishti and Sinha (2022), and Xie *et al*. (2022) have highlighted the importance in confronting climate change by mitigating carbon emissions. Gupta *et al*. (2022) have found technological innovations in reducing the ecological footprint and $PM_{2.5}$.

Education is a valuable device for awareness construction. As such, Hassan *et al*. (2019) and Bashir *et al*. (2019) have emphasized its importance for climate change and Kalim *et al*. (2023) showed that education shifts the EKC downward. Romero and Gramkow (2021) have claimed the climate deteriorating aspect of education is through GHG emissions. Zhang *et al*. (2022) have argued that education is deteriorating the climate and is responsible for more carbon emissions while Shobande and Asongu (2022) have declared it crucial for environmental sustainability. Wang *et al*. (2022) have highlighted that it is deteriorating climate through an ecological footprint increase. Generally, renewable energy reveals favourable impacts on climate. Therefore, Sarkodie *et al*. (2020) have indicated the role of renewable energy for climate change by reducing greenhouse gas emissions. Sahoo and Sahoo (2020) and Salem *et al*. (2021) have incorporated renewable energy with their different subtypes and concluded their climate-friendly and worsening aspects. At the same time, Ahmed *et al*. (2021) have ratified its climate-worsening characteristics whereas Usman *et al*. (2022) and Huang *et al*. (2022) have recommended its climate-friendly aspect through ecological footprints. Lei *et al*. (2022), Khezri *et al*. (2022), and Murshed *et al*. (2022) have pointed out that their climate deteriorating aspect is by emitting carbon emissions. Recent studies by Kalim *et al*., 2023 and Xing *et al*., 2023) highlighted that renewable energy shifts the EKC curve downward.

Table 1 – Review of Literature

INSERT HERE

After reviewing the literature thoroughly, Table 1 is formed; this subject has been worked on in great detail in the context of CO_2, greenhouse gases, and ecological footprints. However, there is still scope for further work something that this study tries to fulfill. These discussed studies have measured the climate through commonly used instruments of environment or resource utilization.

This study fills the gap by introducing cooling-degree days as an instrument for climate change and global warming. CKC, a variant of EKC, is being innovatively tested in the study. Further, tertiary enrollment and the role of renewable energy is integrated to improve the climate outcomes of economic activity. This study has proposed that these climate-improving factors moderate the CKC towards climate sustainability to address the sustainable development goal of climate action.

3. Data and Methodology

3.1 Variables and Sample

This study is based on secondary data from 1992 to 2020. All the variables are selected from World Development Indicators (WDI) and cooling degree days are collected from the climate change knowledge portal (CCKP). Moreover, all the indicators are in natural log form. Table 2 below contains the name of the variable along with the symbol, definition, and source. Here the EG and EG^2 represent the EKC hypothesis (Stern *et al*., 1996) while the other variables are based on STIRPAT hypothesis (Arshed *et al*., 2021).

Table 2 – Description of the Variables

INSERT HERE

3.2 Theoretical Model

To comprehend the connection between proposed variables in CKC perception, studies such as Youssef *et al*. (2020), Pincheira *et al*. (2021), and Dinga *et al*. (2022) have validated an inverted U-shaped EKC. Based on these findings, it is assumed that the CKC is an inverted U-shaped phenomenon. Similarly, there are studies that have advocated the U-shaped effect of economic activity on carbon emissions. Arshed *et al*. (2021), Hassan *et al*. (2021) and Wang *et al*. (2021) stated that when there is over utilization of resources it deteriorates the quality of ecosystem. Another aspect of our model is attaining a downward shift of EKC. In this context education and renewable energy consumption are involved as moderators. Their existence in the model will ease exploring their role in reducing climate challenges. Additionally, the moderating effect will help to analyze shifting.

3.3 Models to be Estimated

Equations 1 and 2 in Table 3 show the long- and short-run coefficients respectively. Many studies, including Sadeqi *et al*. (2022), Kashki *et al*. (2022) and Abebea and Assefa (2022), have incorporated CDD as an instrument of climate change. Here, β_1 and β_2 are the coefficients of economic growth and its square to test the CKC. The square term is incorporated for the nonlinearity following Chiang and Wainwright (2005) and Iqbal *et al*. (2019). This relationship could be inverted U-shaped in view of the findings of Chaudhry *et al*. (2022), Simionescu *et al*.

(2022), and Bao and Lu (2023). However, studies also exist related to U-shaped relationships for example Dogan and Inglesi-Lotz (2020), Arshed *et al*. (2021) and Karahasan and Pinar (2022). Further, β_3, β_4, β_5 and β_6 are the coefficients of technological innovations, population density, education, and renewable energy consumption correspondingly. Aligned with Kihombo *et al*. (2021), Majeed *et al*. (2022) and Xie *et al*. (2022), this study has assumed that technological innovations have the potential to mitigate climate challenges. Studies like Quintana *et al*. (2021), Sahoo and Sethi (2022), and Gupta *et al*. (2022) have discussed the deteriorating climate aspect of population density. This study has considered education as an awareness-creation tool which can protect the climate as discussed by Hassan *et al*. (2019), Bashir *et al*. (2019), and Shobande and Asongu (2022). Studies like Sarkodie *et al*. (2020), Usman *et al*. (2022), and Huang *et al*. (2022) have successfully highlighted the implication of renewable energy for climate betterment. Hence, this research has assumed that renewable energy consumption can diminish the climate challenges.

The methodology of Arshed *et al*. (2021, 2022) combines the role of economic progress with education and the renewable energy is tested for climate change. The coefficient of interaction terms of economic growth with education and renewable energy is represented by β_7 and β_8 respectively. These interaction terms would provide ease in interpreting the change in climate change during a joint increase in growth, education, and renewable energy consumption. Further, Equation 2 consists of short-run coefficients including the speed of convergence. It is formulated using the following specification presented in Equation 2 where the coefficient shown by ω is the error correction term. The coefficient of error correction term must be negative and statistically significant to confirms the cointegration in the model.

Table 3 – Estimation Equations

INSERT HERE

3.4 Estimation Technique

Since the data is around 20 years per cross-sectio, it may show non-stationary behavior at the current level (Arshed *et al*., 2018). Hence, this study has used panel unit root tests like Levin *et al*. (2002) (LLC) and Pesaran (2007)'s cross-sectional augmented in pesaran shin (CIPS) and panel cointegration tests like Pedroni (2004) and Westerlund (2005). Presence of cointeration is compulsory if any variable is found to be non stationary.

The short-run and long-run regression coefficients are estimated using the panel quantile auto-regressive model (QARDL) approach, based on panel quantile regression (PQR) proposed by Cho *et al*. (2015). In the existence of cointegration, this technique helps analyze the regression coefficients at different distribution positions. Moreover, Mohammed *et al*. (2022) and Arshed *et al*. (2022) have discussed that this technique provides consistent coefficients in skewed and non-normal data. This panel QARDL model has used the specification of dynamic fixed effect model (DFE). This study used the error correction model method to estimate the short-run coefficients (Enders, 2012).

4. Results and Discussions

The descriptive aspect of the study is presented in Table 4. Here, the mean is greater than its standard deviation except for innovations. As a result, every variable is over-dispersed and innovations are under-dispersed. Negative skewness coefficients imply that variables are negatively skewed which is logical for the case of these specific countries. Coefficients of kurtosis nearing 3 reflect no outliers (while ≤ 3 and ≥ 3 mean too few and too many outliers). Moreover, the significant value (prob. < 0.05) of the Jarque-Bera (JB) test implies that variables are not normally distributed. Since the sample size is above 30 observations the central limit theorem led the authors to assume the data to be asymptotically normal (Lind *et al*., 2021).

Table 4 – Results and Discussions

INSERT HERE

Figure 1 is the nonlinear association between economic growth and global warming through a scatter plot. In comparison, Figure 2 (heat plot) is for association among all the variables. Since all correlations are below 0.94 there is no multicollinearity among variables (Gujarati, 2022).

Figure 1 – Climate and Economic Growth Scatter Plot

INSERT HERE

Figure 2 – Coefficient of Association Matrix

INSERT HERE

Table 5 – Panel Unit Root Tests

INSERT HERE

Table 5 provides the panel unit root test results using the LLC (first generation) and CIPS (second generation) tests. These tests confirm that all variables other than GW and RE are I(1). Further, Table 6 uses Pedroni (first generation) and Westerlund (second generation) panel cointegration tests to confirm conintegration in selected variables in the long run.

Table 6 contains long-run and short-run estimated coefficients using panel quantile ARDL. Pseudo R squared shows that these selected variables explain 82% of variations in global warming. In the long run the coefficients of economic growth are negative and its squared coefficient is positive; this shows the existence of U-shaped CKC. Similar outcomes using CO_2 are shown by Dogan and Inglesi-Lotz (2020), Arshed *et al*. (2021), and Karahasan and Pinar (2022). At the start, BRICS countries concentrated on ecologically friendly and innovative production techniques which led to diminishing the climate challenges. However, a massive expansion in output and overutilizing resources responsible for climate deterioration.

Population density has positively affected global warming in the long run. Literature has shown its role in deteriorating the ecosystem through deforestation, overcrowding, facilities, and natural resource depletion. These results are consistent with Hanberry (2022), Sahoo and Sethi (2022), and Gupta *et al*. (2022). Similarly, technological innovations have negatively affected global warming in the long run. Technology can help find environment-friendly resources and methods to reduce emissions and carbon footprints. This is consistent with Kihombo *et al*. (2021), Majeed *et al*. (2022), and Jahanger *et al*. (2022).

Lastly, renewable energy and education are independently responsible for climate deterioration. However, their negative interaction terms reflect their contribution to reducing the GDP effect on climate change. The findings of this research are consistent with Lei *et al*. (2022), Khezri *et al*. (2022), and Murshed *et al*. (2022). This shows that the installation of renewable energy has taken its toll on the climate but, once installed, it reduces the emissions in the energy production needed for economic activity (Sarkodie *et al*., 2020; Zahid *et al*., 2021). Similarly, education increase tends to quicken economic activity making them better climate change mitigating agents (Romero and Gramkow, 2021; Zhang *et al*., 2022).

The long run coefficients are validated from the convergence coefficient in short run presented in Table 6. Kao Augmented Dickey Fuller (ADF) test values from the residuals of long run and negative error correction model (ECM) are statistically significant thus indicating the presence of a long-run relationship complementing the cointegration test results. The positive constant term highlights that all excluded variables jointly lead to global warming. This indicates the importance of selected variables as possible climate change mitigating strategies. Granger causality tests confirmed that EG, IN, PD, and RE cause global warming in the form of cooling degree days.

Table 6 – Long Run, Short Run and Cointegration Test

INSERT HERE

Percentile-wise visualization of the education and renewable energy moderating effect is presented in Figures 9 and 10. These graphs are made by using five moderator observations at different distribution positions to generate the estimated dependent variable against changes in the GDP. Here, the shifting of CKC for education and renewable energy as moderators are visualized for their different quantile values. This outcome links with the study's objectives where CKC is depicting the U-shaped pattern and the moderators are reducing the global warming effect of GDP. In Figure 3 the role of education is shifting the CKC downward. This shows the ease of adaptability of the higher educated society towards climate change mitigating practices such that it reduces the global warming effect for each unit of GDP increase. In fFgure 4, renewable energy has shown the dampening effect on global warming produced at each unit of GDP. Comparatively, education is more potent in reducing the global warming generated by economic activity.

Figure 3 – Education as Moderator

INSERT HERE

Figure 4 – Renewable Energy as Moderator

INSERT HERE

Figure 5 provides the effects of long-run variables at different quantiles of global warming (dependent variable). This helps in assessing whether there is a change in marginal effects for higher and low global warming countries or times. Here the negative effect of EG (GDP) reduces and the positive effect also reduces the increase in global warming, showing that the marginal effect of economic activity reduces at high levels of global warming. Further, with the increase in global warming, the positive effect of population density, renewable energy, and education reduces while the negative effect increases. Lastly, Figure 6 shows that at a median level of global warming the convergence coefficient is most effective, showing the fastest rate of absorbing independent variables' effect on dependent variable.

4.1. Managerial Insights and Practical Implications

Population density creates global warming. Thus, policymakers should ease population pressure and implement control measures. Policymakers should invest in education and upgrade the higher education curriculum to generate awareness among people for sustainable production and consumption processes. Technological innovations can help in reducing global warming. Business leaders should prioritize resources and policymakers must provide securities and financial benefits to motivate businesses to become innovative.

This study suggests that BRICS countries must increase reliance on renewable energy consumption. The government must promote the purchase of renewable energy production equipment at household and firm levels to increase the transition from fossil energy to sustainable energy.

Figure 5 – Quantile Process Estimates
INSERT HERE

Figure 6 – Quantile Process Estimates for Convergence Coefficient (95% CI)
INSERT HERE

5. Conclusion and Policy Implications

This analyzed the impact of economic activities on the climate of BRICS countries. The U-shaped existence of CKC has been confirmed by the significant coefficients of EG and EG^2 showing overutilization of resources is causing climate change. The role of education and renewable energy is incorporated as moderators of CKC. Estimated results have provided suitable policies to overcome climate challenges for BRICS countries. First, there is a need to control the population pressure. Similarly, technological innovations are advantageous for climate sustainability. Estimated results validate that these countries are giving valuable attention to it. However, a significant amount should also be allocated to the budget. Further, administrative authorities should provide those institutions with various securities and financial benefits.

Education and renewable energy as independent determinants of climate quality have been found responsible for deterioration. However, a simultaneous increase in education and renewable energy with economic growth has reduced the climate warming. These countries should spend more on education as a tool for awareness generation among the people. Moreover, the moderating effect of education has also highlighted the significance of education for climate sustainability. In production, these countries should spend enormously on renewable energy. Per estimated results, climate deterioration due to renewable energy implies that BRICS countries are not significantly depending upon it. However, significant investment in this sector by the government and the private sector is required for climate sustainability. The government should accommodate professional individuals importing this technology by providing suitable subsidies.

The limitation of the study is that cooling degree days only indicate the energy households require for cooling. It may not encompass other aspects of climate change like precipitation and extreme weather events. Further, it does not account for how much cost a certain economy will bear to cool each increased degree of cooling degree days. Further studies should also account for the spatial effects of global warming in their analysis.

References

Abebe, S. and Assefa, T. (2022). Development of climatic zoning and energy demand prediction for Ethiopian cities in degree days. *Energy and Buildings, 260*, 111935.

Ahmed, Z., Ahmad, M., Rjoub, H., Kalugina, O. A. and Hussain, N. (2022). Economic growth, renewable energy consumption, and ecological footprint: Exploring the role of environmental regulations and democracy in sustainable development. *Sustainable Development, 30*(4), 595–605.

Ahmed, Z., Caglar, A. E. and Murshed, M. (2022). A path towards environmental sustainability: The role of clean energy and democracy in ecological footprint of Pakistan. *Journal of Cleaner Production, 358*, 132007.

Alamsyah, D. P. and Othman, N. A. (2021, July). Consumer awareness towards eco-friendly products through green advertising: Environmentally friendly strategy. In IOP Conference Series: *Earth and Environmental Science* (Vol. 824, No. 1, p. 012043). IOP Publishing.

Alola, A. A., Saint Akadiri, S., Akadiri, A. C., Alola, U. V. and Fatigun, A. S. (2019). Cooling and heating degree days in the US: the role of macroeconomic variables and its impact on environmental sustainability. *Science of The Total Environment, 695*, 133832.

Ansari, M. A. (2022). Re-visiting the Environmental Kuznets curve for ASEAN: A comparison between ecological footprint and carbon dioxide emissions. *Renewable and Sustainable Energy Reviews, 168*, 112867.

Arshed, N., Anwar, A., Kousar, N. and Bukhari, S. (2018). Education enrollment level and income inequality: A case of SAARC economies. *Social Indicators Research*, *140*, 1211-1224.

Arshed, N., Kalim, R., Iqbal, M. and Shaheen, S. (2022). Role of Real Sector and HDI: Does Competitiveness Contribute? *Journal of the Knowledge Economy*, 1-27.

Arshed, N., Munir, M. and Iqbal, M. (2021). Sustainability assessment using STIRPAT approach to environmental quality: an extended panel data analysis. *Environmental Science and Pollution Research, 28*(14), 18163-18175.

Arshed, N., Nasir, S. and Saeed, M. I. (2022). Impact of the External Debt on Standard of Living: A Case of Asian Countries. *Social Indicators Research*, 1-20.

Arshed, N., Sardar, M. S. and Iqbal, M. (2021). Can efficient transport moderate real sector productivity? Competitiveness Review: *An International Business Journal, 32*(6), 915-933.

Baležentis, T., Streimikiene, D., Zhang, T. and Liobikiene, G. (2019). The role of bioenergy in greenhouse gas emission reduction in EU countries: An Environmental Kuznets Curve modelling. *Resources, Conservation and Recycling, 142*, 225-231.

Bao, Z. and Lu, W. (2023). Applicability of the environmental Kuznets curve to construction waste management: A panel analysis of 27 European economies. *Resources, Conservation and Recycling, 188*, 106667.

Bashir, A., Thamrin, K. M. H., Farhan, M., Mukhlis, M. and Atiyatna, D. D. P. (2019). The causality between human capital, energy consumption, CO2 emissions, and economic growth: Empirical evidence from Indonesia. *International Journal of Energy Economics and Policy, 9*(2), 98-104.

Borojo, D. G., Yushi, J. and Miao, M. (2022). The impacts of economic policy uncertainties on carbon dioxide emissions of emerging and low income developing countries: the moderating role of institutional quality. *International Journal of Emerging Markets. Ahead of print.*

Castells-Quintana, D., Krause, M. and McDermott, T. K. (2021). The urbanizing force of global warming: the role of climate change in the spatial distribution of population. *Journal of Economic Geography, 21*(4), 531-556.

Chaudhry, I. S., Yusop, Z. and Habibullah, M. S. (2022). Financial inclusion-environmental degradation nexus in OIC countries: new evidence from environmental Kuznets curve using DCCE approach. *Environmental Science and Pollution Research, 29*(4), 5360-5377.

Chiang, C. A. and Wainwright, K. (2005). *Fundamental Methods of Mathematical Economics*. 4th edition Mcgraw.Hill International.

Chishti, M. Z. and Sinha, A. (2022). Do the shocks in technological and financial innovation influence environmental quality? Evidence from BRICS economies. *Technology in Society, 68*, 101828.

Cho, J. S., Kim, T. H. and Shin, Y. (2015). Quantile cointegration in the autoregressive distributed-lag modeling framework. *Journal of Econometrics, 188*(1), 281–300.

Destek, M. A. and Sarkodie, S. A. (2019). Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development. *Science of the Total Environment, 650*, 2483-2489.

Dinga, G. D., Fonchamnyo, D. C. and Achuo, E. D. (2022). Primal–dual approach to environmental Kuznets curve hypothesis: A demand and supply side analyses of environmental degradation. *Environmental Science and Pollution Research, 29*(11), 16484-16502.

Dogan, E. and Inglesi-Lotz, R. (2020). The impact of economic structure on the environmental Kuznets curve (EKC) hypothesis: evidence from European countries. *Environmental science and pollution research, 27*(11), 12717-12724.

Enders, W. (2012). Applied econometric time series. *Privredna kretanja i ekonomska politika*, *132*, 93.

Grossman, G. M. and Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement (No. w3914). *National Bureau of Economic Research*.

Gujarati, D. N. (2022). *Basic econometrics*. Prentice Hall.

Gupta, M., Saini, S. and Sahoo, M. (2022). Determinants of ecological footprint and PM2. 5: role of urbanization, natural resources and technological innovation. *Environmental Challenges, 7*, 100467.

Haans, R. F., Pieters, C. and He, Z. L. (2016). Thinking about U: Theorizing and testing U-and inverted U-shaped relationships in strategy research. *Strategic management journal, 37*(7), 1177-1195.

Hanberry, B. B. (2022). Global population densities, climate change, and the maximum monthly temperature threshold as a potential tipping points for high urban densities. *Ecological Indicators, 135*, 108512.

Hansen, J., Sato, M., Ruedy, R., Lacis, A. and Oinas, V. (2000). Global warming in the twenty-first century: An alternative scenario. *Proceedings of the National Academy of Sciences, 97*(18), 9875–9880.

Hassan, M. S., Iqbal, M. and Arshed, N. (2021). Distribution-based effects of disaggregated GDP and environmental quality—a case of quantile on quantile estimates. *Environmental Science and Pollution Research, 28*(22), 28081–28095.

Hassan, S. T., Baloch, M. A., Mahmood, N. and Zhang, J. (2019). Linking economic growth and ecological footprint through human capital and biocapacity. *Sustainable Cities and Society, 47*, 101516.

Hof, A. F. (2015). Welfare impacts of climate change. *Nature Climate Change*, *5*(2), 99-100.

Huang, Y., Haseeb, M., Usman, M. and Ozturk, I. (2022). Dynamic association between ICT, renewable energy, economic complexity and ecological footprint: Is there any difference between E-7 (developing) and G-7 (developed) countries? *Technology in Society, 68*, 101853.

Iqbal, M., Kalim, R. and Arshed, N. (2019). Domestic and foreign incomes and trade balance-a case of south Asian economies. *Asian Development Policy Review, 7*(4), 355-368.

Iqbal, M., ur Rehman, H., Arshed, N. and Sardar, M. S. (2021). The macroeconomic and demographic determinants of saving behavior in selected countries of Asia. *Journal global policy and governance, 10*(1), 49–65.

Jahanger, A., Usman, M., Murshed, M., Mahmood, H. and Balsalobre-Lorente, D. (2022). The linkages between natural resources, human capital, globalization, economic growth, financial development, and ecological footprint: The moderating role of technological innovations. *Resources Policy, 76*, 102569.

Kalim, R., Ul-Durar, S., Iqbal, M., Arshed, N. and Shahbaz, M. (2023). Role of knowledge economy in managing demand-based environmental Kuznets Curve. *Geoscience Frontiers*, 101594.

Karahasan, B. C. and Pinar, M. (2022). The environmental Kuznets curve for Turkish provinces: a spatial panel data approach. *Environmental Science and Pollution Research, 29*(17), 25519-25531.

Kashki, A., Karami, M. and Imanipour, H. (2022). Investigating the changes in cooling degree day requirements under climate change conditions in Southern Khorasan Province, Iran. *Arabian Journal of Geosciences, 15*(7), 1-11.

Khezri, M., Heshmati, A. and Khodaei, M. (2022). Environmental implications of economic complexity and its role in determining how renewable energies affect CO2 emissions. *Applied Energy, 306*, 117948.

Kihombo, S., Ahmed, Z., Chen, S., Adebayo, T. S. and Kirikkaleli, D. (2021). Linking financial development, economic growth, and ecological footprint: what is the role of technological innovation? *Environmental Science and Pollution Research, 28*(43), 61235-61245.

Lei, W., Xie, Y., Hafeez, M. and Ullah, S. (2022). Assessing the dynamic linkage between energy efficiency, renewable energy consumption, and CO2 emissions in China. *Environmental Science and Pollution Research, 29*(13), 19540–19552.

Levin, A., Lin, C. F. and Chu, C. S. J. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of econometrics*, *108*(1), 1-24.

Lind, D. A., Marchal, W. C. and Wathen, S. A. (2021). *Basic statistics for business and economics*. McGraw-Hill.

Majeed, A., Ye, C., Chenyun, Y. and Wei, X. (2022). Roles of natural resources, globalization, and technological innovations in mitigation of environmental degradation in BRI economies. *Plos one, 17*(6), e0265755.

Mckeever, A. (2021). Why climate change is still the greatest threat to human health. *National Geographic.* https://www.nationalgeographic.co.uk/environment-and-conservation/2021/09/why-climate-change-is-still-the-greatest-threat-to-human-health (Sept. 10, 2021)

Mertz, O., Halsnæs, K., Olesen, J. E. and Rasmussen, K. (2009). Adaptation to climate change in developing countries. *Environmental Management, 43*(5), 743-752.

Miśkiewicz, R. (2021). The impact of innovation and information technology on greenhouse gas emissions: A case of the visegrád countries. *Journal of Risk and Financial Management, 14*(2), 59.

Mohammed, K. S., Tiwari, S., Ferraz, D. and Shahzadi, I. (2022). Assessing the EKC hypothesis by considering the supply chain disruption and greener energy: findings in the lens of sustainable development goals. *Environmental Science and Pollution Research*, 1–13.

Murshed, M., Saboori, B., Madaleno, M., Wang, H. and Doğan, B. (2022). Exploring the nexuses between nuclear energy, renewable energy, and carbon dioxide emissions: The role of economic complexity in the G7 countries. *Renewable Energy, 190*, 664-674.

Nasir, M. A., Huynh, T. L. D. and Tram, H. T. X. (2019). Role of financial development, economic growth and foreign direct investment in driving climate change: A case of emerging ASEAN. *Journal of environmental management, 242*, 131-141.

Nawaz, M. A., Seshadri, U., Kumar, P., Aqdas, R., Patwary, A. K. and Riaz, M. (2021). Nexus between green finance and climate change mitigation in N-11 and BRICS countries: empirical estimation through difference in differences (DID) approach. *Environmental Science and Pollution Research, 28*(6), 6504–6519.

Pedroni, P. (2004). Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric theory*, *20*(3), 597-625.

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of applied econometrics*, *22*(2), 265-312.

Pincheira, R., Zúñiga, F. and Valencia, F. (2021). An environmental measurement for a dynamic and endogenous global environmental Kuznets curve in the global context. *Environmental Science and Pollution Research, 28*(46), 65573-65594.

Romero, J. P. and Gramkow, C. (2021). Economic complexity and greenhouse gas emissions. *World Development, 139*, 105317.

Sadeqi, A., Tabari, H. and Dinpashoh, Y. (2022). Spatio-temporal analysis of heating and cooling degree-days over Iran. Stochastic *Environmental Research and Risk Assessment, 36*(3), 869-891.

Sahoo, M. and Sahoo, J. (2022). Effects of renewable and non-renewable energy consumption on CO2 emissions in India: empirical evidence from disaggregated data analysis. *Journal of Public Affairs, 22*(1), e2307.

Sahoo, M. and Sethi, N. (2022). The dynamic impact of urbanization, structural transformation, and technological innovation on ecological footprint and PM2. 5: evidence from newly industrialized countries. *Environment, Development and Sustainability, 24*(3), 4244–4277.

Salem, S., Arshed, N., Anwar, A., Iqbal, M. and Sattar, N. (2021). Renewable energy consumption and carbon emissions—testing nonlinearity for highly carbon-emitting countries. *Sustainability, 13*(21), 11930.

Sarkodie, S. A., Adams, S. and Leirvik, T. (2020). Foreign direct investment and renewable energy in climate change mitigation: does governance matter? *Journal of Cleaner Production, 263*, 121262.

Selden, T. M. and Song, D. (1994). Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions? *Journal of Environmental Economics and Management*, *27*(2), 147–162.

Shobande, O. A. and Asongu, S. A. (2022). The Critical Role of Education and ICT in Promoting Environmental Sustainability in Eastern and Southern Africa: A Panel VAR Approach. *Technological Forecasting and Social Change, 176*, 121480.

Simionescu, M., Strielkowski, W. and Gavurova, B. (2022). Could quality of governance influence pollution? Evidence from the revised Environmental Kuznets Curve in Central and Eastern European countries. *Energy Reports, 8*, 809-819.

Sinha, A., Sengupta, T. and Alvarado, R. (2020). Interplay between technological innovation and environmental quality: formulating the SDG policies for next 11 economies. *Journal of Cleaner Production, 242*, 118549.

Spinoni, J., Vogt, J. V., Barbosa, P., Dosio, A., McCormick, N., Bigano, A. and Füssel, H. M. (2018). Changes of heating and cooling degree-days in Europe from 1981 to 2100. *International Journal of Climatology*, *38*, e191-e208.

Stern, D. I., Common, M. S. and Barbier, E. B. (1996). Economic growth and environmental degradation: The environmental Kuznets curve and sustainable development. *World Development*, *24*(7), 1151–1160.

Todaro, M. P. and Smith, S. C. (2015). *Economic Development*. 12th edition Pearson USA.

Tol, R. S. (2018). The economic impacts of climate change. *Review of Environmental Economics and Policy*. *12*(1).

Tromboni, F., Dilts, T. E., Null, S. E., Lohani, S., Ngor, P. B., Soum, S. and Chandra, S. (2021). Changing land use and population density are degrading water quality in the lower Mekong basin. *Water, 13*(14), 1948.

Uche, E., Das, N. and Bera, P. (2022). Re-examining the environmental Kuznets curve (EKC) for India via the multiple threshold NARDL procedure. *Environmental Science and Pollution Research*, 1-13.

Ulucak, R. (2021). Renewable energy, technological innovation and the environment: a novel dynamic auto-regressive distributive lag simulation. *Renewable and Sustainable Energy Reviews, 150*, 111433.

Usman, M. and Makhdum, M. S. A. (2021). What abates ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area and financial development. *Renewable Energy, 179*, 12-28.

Wang, M., Arshed, N., Munir, M., Rasool, S. F. and Lin, W. (2021). Investigation of the STIRPAT model of environmental quality: a case of nonlinear quantile panel data analysis. *Environment, development and sustainability*, *23*, 12217-12232.

Wang, Q., Li, L. and Li, R. (2022). Does improvement in education level reduce ecological footprint? A nonlinear analysis considering population structure and income. *Journal of Environmental Planning and Management*, 1-29.

Wang, Q., Zhang, F. and Li, R. (2023). Revisiting the environmental Kuznets curve hypothesis in 208 counties: The roles of trade openness, human capital, renewable energy and natural resource rent. *Environmental Research, 216*, 114637.

Westerlund, J. (2005). New simple tests for panel cointegration. *Econometric Reviews*, *24*(3), 297-316.

Xie, Q., Adebayo, T. S., Irfan, M. and Altuntaş, M. (2022). Race to environmental sustainability: Can renewable energy consumption and technological innovation sustain the strides for China? *Renewable Energy, 197*, 320-330.

Xing, L., Khan, Y. A., Arshed, N. and Iqbal, M. (2023). Investigating the impact of economic growth on environment degradation in developing economies through STIRPAT model approach. *Renewable and Sustainable Energy Reviews*, *182*, 113365.

York, R., Rosa, E. A. and Dietz, T. (2003). STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*, 46(3), 351–365.

Youssef, A. B., Boubaker, S. and Omri, A. (2020). Financial development and macroeconomic sustainability: modeling based on a modified environmental Kuznets curve. *Climatic Change, 163*(2), 767-785.

Zahid, T., Arshed, N., Munir, M. and Hameed, K. (2021). Role of energy consumption preferences on human development: A study of SAARC region. *Economic Change and Restructuring*, *54*, 121-144.

Zhang, C., Khan, I., Dagar, V., Saeed, A. and Zafar, M. W. (2022). Environmental impact of information and communication technology: Unveiling the role of education in developing countries. *Technological Forecasting and Social Change, 178*, 121570.

Table 1 – Review of Literature

Literature Review	Environment/Climate Indicator(s)	Relationship
Todaro (2015)	Economic growth, income inequality	Summarized Kuznets curve
Grossman and Kruger (1991), Selden and Song (1994). Stern *et al.* (1996), York *et al.* (2003)	Economic growth, environmental quality	Inverted U-shaped EKC
Destek and Sarkodie (2019), Youssef *et al.* (2020), Ansari (2022)	Ecological footprint, carbon emissions, and economic activity	Inverted U-shaped footprint EKC
Pincheira *et al.* (2021), Dinga *et al.* (2022), Chaudhry *et al.* (2022)	Carbon dioxide emissions, nitrous oxide, methane emissions, deforestation, biodiversity, ozone, fertilizers, fresh water, and land footprints.	Mixed findings
Baležentis *et al.* (2019), Uche *et al.* (2022), Simionescu *et al.* (2022), Bao and Lu (2023)	Greenhouse gas emissions	Inverted U-shaped EKC
Alola *et al.* (2019), Quintana *et al.* (2021), Tromboni *et al.* (2021), Sahoo and Sethi (2022), Gupta *et al.* (2022), Ahmed *et al.* (2022) Hanberry (2022)	Urban population and population density pressure	Responsible for global warming, climate change, deteriorating water quality, ecological footprint, $PM_{2.5}$ emissions, and temperature
Miśkiewicz (2021), Kihombo *et al.* (2021), Majeed *et al.* (2022), Jahanger *et al.* (2022), Danish and Ulucak (2021), Chishti and Sinha (2022)	Environment and technological innovations	Reducing greenhouse gas emissions, ecological footprint, and carbon emissions

Source: Authors' own work

Table 2 - Description of the Variables

Variables (Symbol)	Definition	Source
Cooling Degree Days (GW)	Annual number of degrees the temperature was higher than the reference temperature of 18.3^0C	CCKP
Economic Growth (EG)	Per capita GDP in constant US$ (2015)	WDI
Economic Growth Sq. (EG^2)	Square of per Capita GDP in constant US$ (2015)	WDI
Technological Innovations (IN)	Total of resident and nonresident patent applications	WDI
Population Density (PD)	Population per unit of total land area	WDI
Education (ED)	Tertiary school enrollment % of total.	WDI

Renewable Energy (RE)	Renewable energy consumption % of total	WDI

Source: Authors' own work

Table 3 – Estimation Equations

Formula	Inde
$GW_{it} = \beta_1 EG_{it} + \beta_2 EG_{it}^2 + \beta_3 IN_{it} + \beta_4 PD_{it} + \beta_5 ED_{it} + \beta_6 RE_{it} + \beta_7 (EG_{it} * RE_{it}) + \beta_8 (EG_{it} * ED_{it}) + \mathcal{E}_t$	Long Run Equat
$\Delta GW_{it} = \alpha_0 + \sum_{i=1}^{n} \beta_{01j} \Delta GW_{t-i} + \sum_{i=0}^{n} \gamma_{2j} \Delta EG_{i\ t-i} + \sum_{i=0}^{n} \delta_{3j} \Delta EG_{i\ t-i}^2 + \sum_{i=0}^{n} \theta_{4j} \Delta IN_{i\ t-i} + \sum_{i=0}^{n} \rho_{5j} \Delta PD_{i\ t-i} + \sum_{i=0}^{n} \tau_{6j} \Delta ED_{i\ t-i} + \sum_{i=0}^{n} \kappa_{7j} \Delta RE_{i\ t-i} + \sum_{i=0}^{n} \eta_{8j} (\Delta EG_{i\ t-i} * \Delta RE_{i\ t-i}) + \sum_{i=0}^{n} \eta_{9j} (\Delta EG_{i\ t-i} * \Delta ED_{i\ t-i}) + \beta_1 EG_{it} + \beta_2 EG_{it}^2 + \beta_3 IN_{it} + \beta_4 PD_{it} + \beta_5 ED_{it} + \beta_6 RE_{it} + \beta_7 (EG_{it} * RE_{it}) + \beta_8 (EG_{it} * ED_{it}) + \omega EC_{it} + \mu_{it}$	Short-run Equat

Source: Authors' own work

Table 4 – Results and Discussions

Statistic	Variables					
	GW	EG	IN	PD	ED	RE
Mean	7.085	8.321	-2.284	3.979	3.183	2.785
Median	7.209	8.636	-1.997	3.707	3.135	2.858
Maximum	8.531	9.225	0.101	6.130	4.458	3.997
Minimum	4.467	6.427	-5.371	2.165	1.031	1.156
Std. Dev.	1.307	0.810	1.148	1.344	0.797	0.956
Skewness	-0.607	-0.933	-0.579	0.151	-0.397	-0.488
Kurtosis	2.155	2.526	3.007	1.743	2.744	1.895
JB Test	11.861	20.098	7.277	9.057	3.777	11.776
Prob.	0.002**	0.000**	0.026*	0.010*	0.151	0.002**
Obs.	130	130	130	130	130	130

* significant at 5%, ** significant at 1%

Source: Authors' own work

Table 5 – Panel Unit Root Tests

Test Statistic	Specification	Variables					
		GW	EG	IN	PD	ED	RE

LLC	Level	-4.90 (0.00)**	-1.73 (0.04)*	-1.26 (0.10)	-1.84 (0.03)*	-3.77 (0.00)**	-1.63 (0.05)*
	First Difference	-10.77 (0.00)**	-1.42 (0.08)*	-5.06 (0.00)**	-1.48 (0.06)*	-3.04 (0.00)**	-2.03 (0.02)*
CIPS	Level	-3.36 (0.00)**	-3.71 (0.00)**	-1.70 (0.10)	-3.73 (0.20)	-1.76 (0.10)	-3.96 (0.00)**
	First Difference	-5.12 (0.00)**	-2.94 (0.00)**	-4.33 (0.00)**	-2.65 (0.00)**	-3.38 (0.04)*	-4.26 (0.00)**

* significant at 5%, ** significant at 1%

Source: Authors' own work

Table 6 – Long Run, Short Run and Cointegration Test

Long Run Coefficients		**Short Run Coefficients**	
Variables	**Coef. (Prob.)**	**Variables**	**Coef. (Prob.)**
EG	-4.284 (0.000)**	ΔEG	7.463 (0.196)
EG^2	0.549 (0.000)**	ΔEG^2	-0.474 (0.185)
IN	-0.436 (0.000)**	ΔIN	-0.019 (0.717)
PD	0.285 (0.000)**	ΔPD	-5.567 (0.192)
ED	7.126 (0.000)**	ΔED	-0.428 (0.022)*
RE	3.583 (0.000)**	ΔRE	1.389 (0.528)
EG*RE	-0.300 (0.001)**	Δ(EG*RE)	-0.177 (0.509)
EG*ED	-0.874 (0.000**	Δ(EG*ED)	0.000 (0.339)
		ECT_{-1}	-0.158 (0.000)**
		Const. (Fixed Effect)	0.069 (0.492)
Pseudo R squared	0.820	Pseudo R squared	0.090
Kao ADF on LR residuals	-4.906 (0.000)**	sample	130

Test Statistic	**Statistic value**	**Probability**
	Pedroni Test	
Modified Phillips Perron t	0.19	0.42
Phillips Perron t	-7.12	0.00**
Augmented Dickey-Fuller t	-6.82	0.00**
	Westerlund Test	
Variance Ratio	-1.99	0.02*

* significant at 5%, ** significant at 1%

Source: Authors' own work

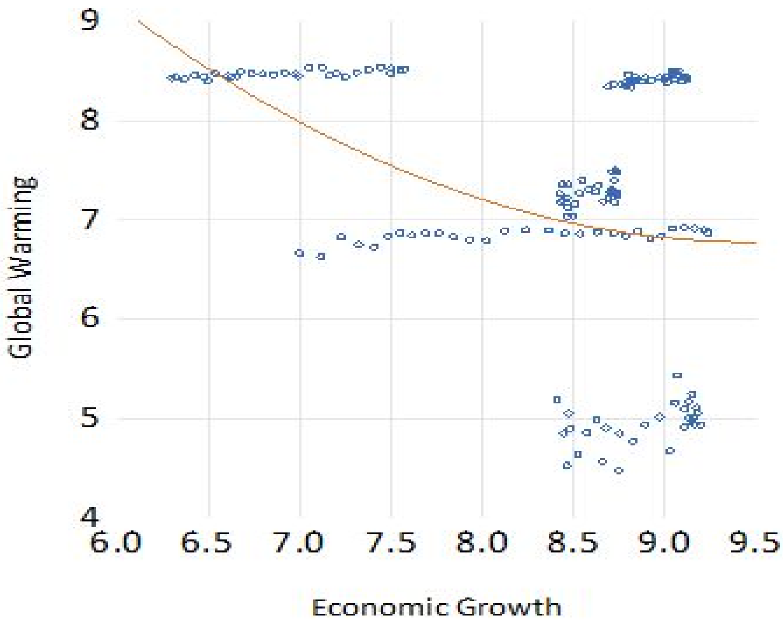

Figure 1 – Climate and Economic Growth Scatter Plot
Source: Author self-construction

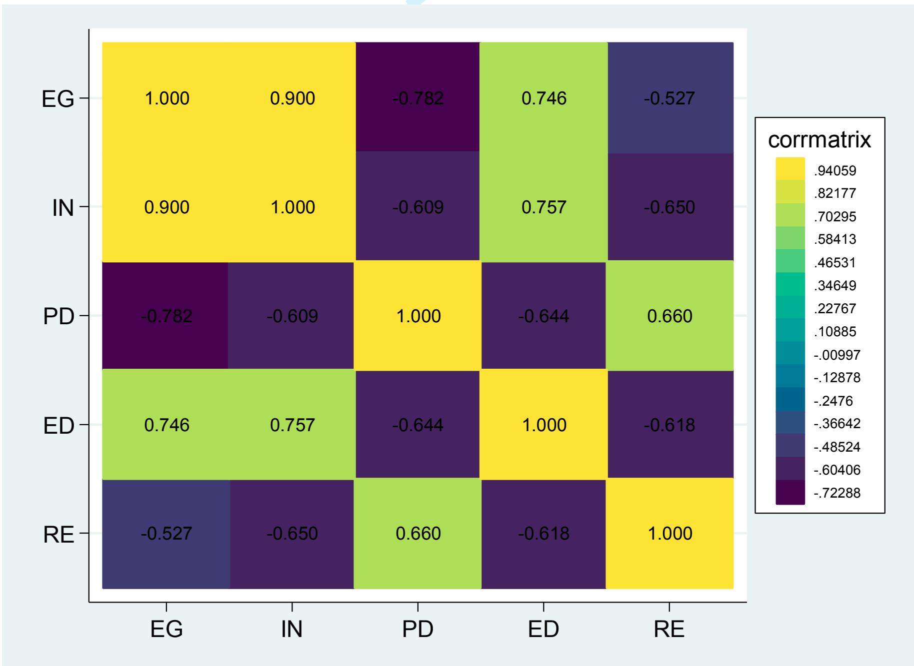

Figure 2 – Coefficient of Association Matrix
Source: Author self-construction

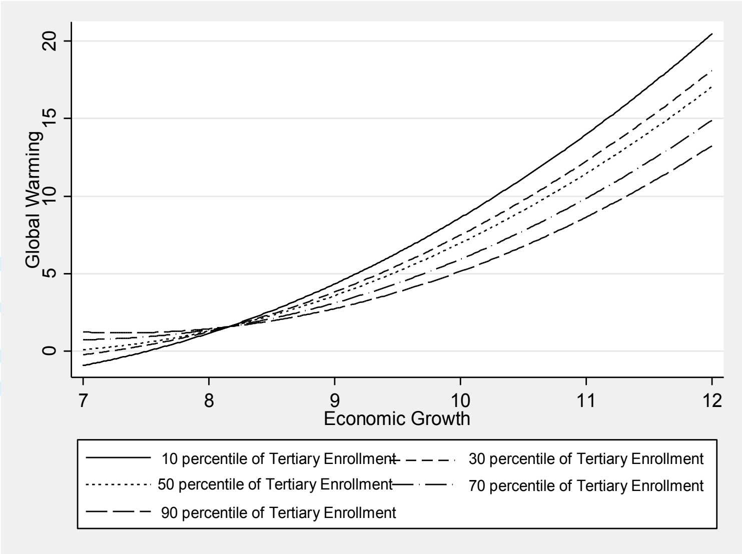

Figure 3 – Education as Moderator

Source: Author self-construction

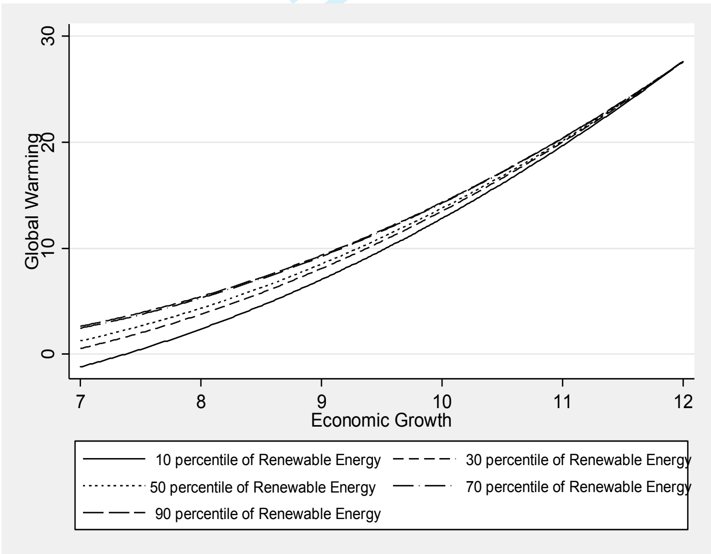

Figure 4 – Renewable Energy as Moderator

Source: Author self-construction

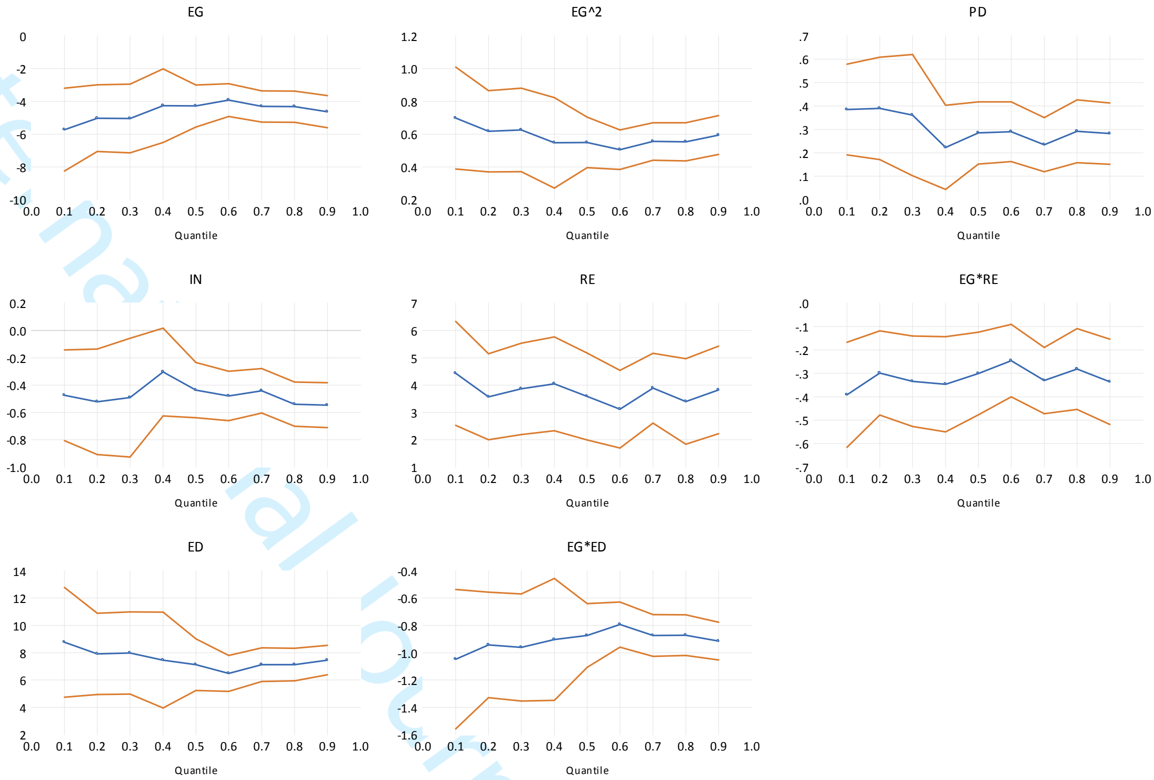

Figure 5 – Quantile Process Estimates
Source: Author self-construction

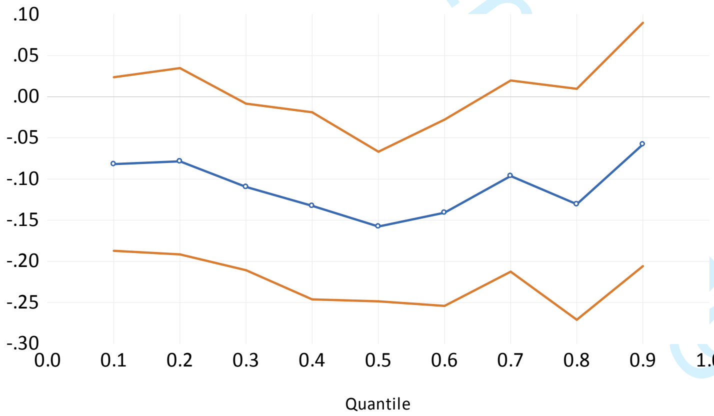

Figure 6 – Quantile Process Estimates for Convergence Coefficient
Source: Author self-construction