Vol. 3 No.2 2025

RECOGNIZED IN "Y" CATEGORY BY

Research Consortium Archive

P(ISSN) : 3007-0031

E(ISSN) : 3007-004X

https://rc-archive.com/index.php/Journal/about

THE IMPACT OF GREEN TECHNOLOGY ON HUMAN DEVELOPMENT IN PAKISTAN

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Publisher : EDUCATION GENIUS SOLUTIONS
Review Type: Double Blind Peer Review

ABSTRACT

This research examines the impact of green technology (HDI) and economic development on human development in Pakistan, using data from 33 observations. Key variables include GDP per capita, HDI, renewable energy, education, and life expectancy at birth. The table indicates that the variables Human Development Index (HDI), Gross Domestic Product (GDP), and Renewable Energy are non-stationary at their original level; however, all three variables become stationary after the first difference. The Auto Regressive Distributed Lag model was used for analysis. The adjustment coefficient (ECM term) indicates that short-run deviations from the long-run equilibrium are corrected at a speed of 54.2% per year. In the short run, negative and significant lagged changes in the Human Development Index (HDI) at the first and second lags reflect persistence in HDI movements. Furthermore, changes in life expectancy from the first to third differences are all negative and statistically significant, which shows that short-term volatility in health outcomes adversely affects the human development index HD. The effect of GDP per capita is positive and significant; hence, changes in income levels positively impact HD in the short run. School enrollment and Renewable energy did not reveal any significant effects on Human Development.
Key Words: HDI, renewable energy, health, education, GDP, ARD.

Introduction

Background

Green technology refers to the production of green energy, using different fuels and technologies that are less harmful to the environment than fossil fuels. Green growth is described as a way to achieve economic growth based on the sustainable use of resources (Bagheri et al, 2018). The human development index (HDI), compiled by the United Nations since 1990, measures various countries' levels of social and economic development. It is derived from four components: mean years of schooling, expected years of schooling, life expectancy at birth, and gross national income (GNI) per capita. Green technology and the Human Development Index (HDI) are closely connected in promoting sustainable development. Therefore, in recent years, cleaner growth has become increasingly important. Politicians have been addressing further difficult issues regarding the need for economic development and growth, supported by policies that protect the environment (Bagheri et al., 2018). On the other hand, regions rich in natural resources may face challenges in shifting toward clean development (Cheng et al., 2020b). Natural resources should be managed with criteria in place to prevent unequal impacts on the regional biosphere (Oliveira et al., 2020).

The adoption of green technology is positively correlated with human development, as evidenced by the study conducted by Lee et al. in 2020 and 2021. Asia is now more diverse in investing in green technology to enhance opportunities and standardize the quality of life across Asian countries, according to Wang and Lui in their 2019 research articles. If the government subsidizes the green technology sector, it could improve the environment and develop societies. Feng (2016) states that renewable energy improves the human development index (HDI) in developing countries through economic growth and leads to higher levels of human development. Without access to a clean, reliable, and systematic energy supply, it would be impossible for developing countries to achieve economic and social development (Yahya and Rafiq ,2020). It's said that green growth is the best way for emerging nations to attain sustainable economic growth because it can coexist with more environmental preservation and a more equitable society (Hairong Bai, 2022).

The Human Development, which gauges social wellbeing based on three fundamental factors: income, education, and health, can reveal various stages of development (Houssini & Geng, 2022). Before its introduction, a one-dimensional assessment approach that solely took economic data into account was widely employed (Arechavala,2013); hence, the introduction of the HDI enhances the meaning of Human Development. Multidimensional indicators are required to quantify human welfare because people's wants are diverse. In order to measure the HD, researchers presented a few novel indicator systems. As an illustration, consider the Sustainable Net Benefit Index (SNBI) (Lawn 2003), Genuine Progress Indicator (GPI) (Wen et al. 2007), Index of Sustainable Economic Welfare (ISEW) The eradication of extreme poverty is one of the eight goals of the Millennium Development Goals (MDGs), which were adopted at the United Nations (UN) summit. This is the first comprehensive effort to raise the global poverty line and give the impoverished greater chances to advance human growth on a worldwide scale (Man Liang,2018). Energy is a crucial component of production, promoting industrial growth and economic advancement, but excessive energy use raises CO2 emissions, which worsen the state of the environment (Alkhathlan and Javid 2013). These days, a lot of nations rely primarily on the use of fossil fuels, such as coal, oil, and natural gas, which seriously disrupts the ecological balance of the planet. In the same way, a 2016 EIA analysis projects that between 2005 and 2030, energy demand will increase by 50%. (Man Liang, 2018). Data demonstrates the G-8 region's attempts to lessen its dependency on coal and oil and increase its usage of gas, in addition to a general decline in energy consumption and CO2 emissions (Majeed & Muhammad, 2021).

Keeping in view the importance of renewable energy, this research has studied its impact on Pakistan's Human Development with other important variables: GDP, life expectancy at birth, and education. There is a growing need to understand how adopting green technologies can support human development. This research will offer valuable insights into how environmentally friendly innovations can enhance human development in Pakisatn. Furthermore, by examining the role of the Human Development Index, the study highlights the importance of investing in health, education, and improved living standards to strengthen human capital, which in turn contributes to human development. The findings are expected to guide policymakers in designing integrated development strategies that balance environmental sustainability with socio-economic goals. Additionally, the study addresses a gap in the existing literature by focusing specifically on Pakistan's unique context, offering localized evidence that can inform future policies and encourage greater adoption of green technology and human development initiatives. Ultimately, this research has the potential to contribute not only to academic knowledge but also to practical solutions for achieving inclusive and sustainable economic growth in Pakistan.

Objectives

1. To study the effect of economic development and Green technology on Human Development in Pakistan.
2. To study the effect of life expectancy ar birth and education on Human Development in Pakistan.

Research Questions

1. What are the effects of Green Technology and economic development on human development in Pakistan?
2. What policy measures can be implemented to maximize the benefits of green technology for improving HDI?

Literature Review

Literature shows an extensive work on green technology and its likely impacts. A grassroots-level study by Yang (2016) explores how government subsidies can incentivize firms to adopt green, emissions-reducing technologies. Anıl (2022), examines the relationships between green growth indicators (GGI) and the human development index (HDI) in 36 OECD countries in 2019. The analysis uses data from 16 selected GGIs and HDI indicators, focusing on three sectors: production, transport, and energy. The results highlight that CO2 emissions and intensity are significantly correlated with HDI subindicators, suggesting that longer education correlates with climate-friendly production and reduced CO2 emissions.

Megha and Aishwarya (2021) explore the relationship between South Asian nations' Environmental Performance Index (EPI) and Human Development Index (HDI). Particularly from 2002 to 2016. The study finds that higher HDI is associated with better environmental performance, refuting the Environmental Kuznets Curve hypothesis, which suggests that economic growth initially leads to environmental degradation before improving. Utilizing data from sources like the World Bank and Yale Center for Environmental Law & Policy, and employing dynamic panel modeling techniques like the system Generalized Methods of Moments (GMM), the study highlights the importance of human capital in addressing environmental issues. Policy recommendations emphasize low-emission technologies, environmental trading systems, and the promotion of renewable energy through initiatives like Green Bonds, suggesting that developing nations should follow the lead of developed countries in transitioning to sustainable energy sources.

Some studies addressed the effect of urbanization on the Human Development Index and found that urbanization generally enhances HDI by increasing employment, productivity, education, and healthcare access, although it can lead to congestion problems if too many people reside in a country's largest city (Sabyasachi, 2021). Technological progress in the form of renewable energy was found to initially foster comparative advantages but eventually stifle them (Jain, 2017).

Ruqiya and Sami (2021) analyze the relationships between health spending, GDP, HDI, CO2 emissions, renewable energy, financial development, and electricity consumption in Brazil, India, China, and South Africa between the first quarter of 2000 and the fourth quarter of 2014. The study shows a two-way causal relationship between HDI and financial development, as well as between financial development and power use. The findings suggest policies to enhance HDI through health expenditure and renewable energy adoption.

A comprehensive study of the literature on Green Supply Chain Management was provided by Arif and Muhamad (2012) while highlighting emerging areas of research in the field.

Man Liang and Shuwen Niu's article(2018) "International Comparison of Human Development Index Corrected by Greenness and Fairness Indicators and Policy Implications for China" rates environmental sustainability and social fairness indicators. The study reveals that while overall HDI increased, significant disparities persisted among countries. China demonstrated notable development, but its ranking dropped when environmental and fairness factors were considered. The findings show that, despite overall HDI improvements, developed countries ranked higher, whereas Africa and South Asia lagged. Adjusting for environmental and social fairness factors led to a lower global HDI, with environmental corrections having a more significant impact.

Research has shown a great deal of environmental degradation due to economic growth, like Emmanuel (2019) finding a U-shaped Environmental Kuznet curve for Nigeria while concluding that Nigeria needs to prioritize cleaner industrial production and stronger sustainability efforts, particularly in water, sanitation, and air quality, to balance economic growth with environmental protection for the well-being of its people now and in the future. Similar findings by Isma and Muhammad (2022) show how a country's economic growth affects its environmental quality, measured by the ecological footprint. Studying 128 countries from 1971 to 2017, they found that as economies grow, environmental impact initially increases, then decreases as technology improves and awareness of environmental issues grows. Factors like energy use, urbanization, and life expectancy influence environmental quality, and better political institutions correlate with a better environment.

Muhammad and Naveed (2021) investigate the effects of trade, economic expansion, and energy use on the environment in two sets of nations: the G-7 (developed) and the D-8 (developing). The study reveals that in the D-8 countries, economic expansion, energy use (especially gas, coal, and oil), and trade initially contribute to environmental damage with improvements over time. Olympia (2016) examines the connection between environmental performance and income in 166 different nations and finds that higher income levels lead to better environmental health and ecosystem vitality, with increased investments in public health and infrastructure as countries develop.

The Human Development Index (HDI), Environmental Performance Index (EPI), per capita income, and CO_2 emissions in Bangladesh are all examined in Md. Arfanuzzaman's(2016) study. While there's no immediate impact from HDI or CO_2 emissions on environmental performance in the short term, income increases are associated with decreased environmental performance. Human development significantly affects environmental performance.

Emma (2019) discusses how going green can help companies save money through increased efficiency and reduced waste, despite initial costs. The article concludes that adopting eco-friendly practices not only benefits businesses financially but also enhances their reputation, attracts consumers, and encourages corporate responsibility. Zhao and Taghizadeh-Hesary (2023) highlight the role of green finance in supporting eco-friendly projects to reduce CO_2 emissions, emphasizing the importance of regional differences and targeted investment strategies.

Taqi's (2022) study seeks to fill the gap in the study by exploring the relationship between green technology adoption and improvements in HDI, with a specific focus on developing and developed nations. the increasing global focus on sustainable development has highlighted the importance of green technologies in addressing environmental challenges. Muhammad and Ahad's (2015) examine the idea of green growth (GG) and how it relates to environmental laws and economic policy uncertainty (EPU) in IEA member The study contends that green entrepreneurship is essential to the advancement of sustainable development because it generates positive social and economic effects. This view is reinforced by greater money allocated to sustainable projects, rising consumer awareness of environmental issues, and more stringent regulations.

Research Methodology

Data

The data used in this study are primarily sourced from the World Development Indicators (WDI) database, which provides comprehensive and reliable datasets on various socio-economic indicators across countries. Specifically, data on renewable energy, HDI, Gross Domestic Product, life expectancy at birth, and education is extracted. The study period is from 1990 to 2022.

Economic Growth Model

Let's propose a model to quantify the effect of renewable energy, economic growth, life expectancy at birth, and education on the Human Development Index

$$\mathbf{HDI=\beta_0+\beta_1 LEB+\beta_2 ER+\beta_3 GDP_{+}\beta_4 EDU_{+}\epsilon}$$

Where:

1. GDP is the Gross Domestic Product, a measure of economic growth.
2. HDI is the Human Development Index.
3. ER is the proportion of energy derived from renewable sources, representing green technology adoption
4. LEB is life expectancy at birth.
5. EDU is primary education as a dummy for educational attainment.
6. β_0 is the intercept term
6. β_1 up to β_4 are the regression coefficients, respectively.
7. ϵ is the error term

Econometrically, the model is represented

$$\boldsymbol{HDIt} = \beta 0 + \sum_{t=1}^{p} \beta 1\mathrm{HDIt} - 1 \sum_{j=0}^{q} \beta 2\mathrm{GDPt} - \mathrm{j} + \sum_{k=0}^{r} \beta 3\mathrm{kLEBt} - \mathrm{k} + \sum_{l=0}^{s} \beta 4\mathrm{EDUt} - \mathrm{l} + \sum_{l=0}^{j} \beta 5\mathrm{ERt} - \mathrm{l} + \varepsilon\mathrm{t}$$

Stationary Test and ARDL model

The study used the Augmented Dicky-Fuller (ADF) test for checking the stationarity. The variables were stationary at first difference, and hence the ARDL model was used for estimation.

Results and Discussion

Stationarity of Variables

The table shows that the variables human development index (HDI), gross domestic product (GDP), and Renewable Energy are non-stationary at their level values, as indicated by their respective probabilities. However, all three variables become stationary after the first difference, with significantly lower probabilities. This stationary trend continues after the second difference, with all variables having probabilities of 0.00. This suggests that differencing the data once is enough to achieve stationarity for these variables, indicating that the data sets have trends or other non-stationary behaviors that can be fixed through differencing.

Table 1: Stationarity of Variables

Variable	At Level	First Difference
HDI	-1.129 (0.073)	-3.565 (0.0065)
GDP	-1.784 (0.3884)	-2.992 (0.0354)
RE	-1.728 (0.416)	-4.581 (0.0001)
Education	-2.516 (0.1117)	-3.689 (0.0043)
Life Expectancy	-0.265 (0.930)	-3.835 (0.0026)

Bound Test Results

Table 2 shows the values for Bound test. the decision rule is that if the F statistic value is greater than I(1) bounds we weill reject null hypothesis. Since in this case the F = 6.657 > 5.06 (1% upper bound), the null hypothesis is rejected and confir that there is a long-run relationship.

Table 2a: ARDL Bounds Test for Cointegration

Significance Level	I(0) Bound	I(1) Bound
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06

Table 2b: ARDL Bounds Test for Cointegration

Significance Level	I(0) Bound	I(1) Bound
10%	−2.57	−3.66
5%	−2.86	−3.99
2.5%	−3.13	−4.26
1%	−3.43	−4.60

Decision Rule (t-stat): *Reject H_0 if t < I(1) bound.*

The ARDL bounds test confirms a long-run relationship as the F-statistic (6.657) exceeds the 1% upper bound (5.06).The null hypothesis of no cointegration is rejected, indicating stable long-term linkages among the variables. Despite the t-statistic (−1.003) being insignificant, the F-statistic provides stronger evidence of cointegration.

ARDL Bounds Test and Long-Run Relationship Analysis

The Autoregressive Distributed Lag (ARDL) bounds testing approach, as proposed by Pesaran, Shin, and Smith (2001), was employed to examine the existence of a long-run equilibrium relationship between the Human Development Index (HDI) and its key determinants: GDP per capita (PPP), renewable energy consumption, life expectancy at birth, and school enrollment as a proxy for education. The calculated F-statistic (6.657) surpasses the upper bound critical value at the 1% level (I(1) = 5.06), providing strong evidence to reject the null hypothesis of no level relationship, thereby confirming the presence of a long-run cointegrating relationship among the variables. Although the corresponding t-statistic (-1.003) does not reject the null at conventional significance levels, the F-statistic carries more weight in the ARDL bounds framework, affirming the model's support for a long-run association.

The adjustment coefficient (ECM term: -0.5423, p = 0.019) is statistically significant and negative, indicating that short-run deviations from the long-run equilibrium are corrected at a speed of 54.2% per year. The short-run dynamics reveal that lagged changes in the Human Development Index (HDI) at the first and second lags are significant and negative, reflecting persistence in HDI movements. Additionally, changes in life expectancy from the first to third differences are all negative and statistically significant, suggesting that short-term volatility in health outcomes adversely affects the human development index HD.

Table 3: ARDL Regression Results

Variable	Coefficient	Std. Error	t-Statistic	P-value	95% Confidence Interval
Adjustment Term					
HDI (L1)	-0.5423	0.2041	-2.66	0.019	[-0.9800, -0.1045]
Long-Run Coefficients					
Renewable Energy Consumption	0.0017	0.0012	-1.41	0.180	[-0.0044, 0.0009]
Life Expectancy at Birth	0.0323	0.0088	3.68	0.002	[0.0135, 0.0511]
School Enrollment	0.0001	0.0005	-0.28	0.781	[-0.0012, 0.0009]
GDP per Capita (PPP)	0.00003	0.00002	-1.80	0.093	[-0.00007, 0.00001]
Short-Run Dynamics					
ΔHDI (Lag 1)	-0.6106	0.2167	-2.82	0.014	[-1.0753, -0.1458]
ΔHDI (Lag 2)	-0.3511	0.1910	-1.84	0.087	[-0.7607, 0.0585]
ΔLife Expectancy (Current)	-0.0170	0.0040	-4.30	0.001	[-0.0255, -0.0085]
ΔLife Expectancy (Lag 1)	-0.0144	0.0040	-3.60	0.003	[-0.0230, -0.0058]
ΔLife Expectancy (Lag 2)	-0.0104	0.0033	-3.18	0.007	[-0.0175, -0.0034]
ΔLife Expectancy (Lag 3)	-0.0059	0.0028	-2.10	0.055	[-0.0120, 0.0001]

ΔGDP per Capita (Current)	0.00002	0.00001	2.64	0.019	[0.000004, 0.000041]
ΔGDP per Capita (Lag 1)	0.00002	0.00001	1.79	0.096	[-0.000004, 0.000047]
Constant	-0.7254	0.1657	-4.38	0.001	[-1.0808, -0.3700]

Dependent Variable: ΔHDI
Sample: 1995–2022 Observations: 28
R-squared: 0.7612 Adj. R-squared: 0.5395 Root MSE: 0.0034
Log-likelihood: 128.74

In contrast, the first difference of GDP per capita is positive and significant ($p = 0.019$), implying that increases in income levels positively impact the human development index HD in the short run. The model's overall fit is strong, with an R-squared of 0.7612 and an adjusted R-squared of 0.5395, while the log-likelihood value of 128.74 and a low Root Mean Squared Error (MSE) of 0.0034 indicate good precision and robustness. As for long-run coefficients, Renewable energy has a positive but statistically insignificant long-run effect. The same goes for education. Life expectancy has a significant and positive effect on HDI; a 1-year increase in life expectancy increases HDI by 0.032.GDP per capita has a marginally significant effect at the 10% level of significance.

Diagnostic Tests

The following results were obtained for diagnostic tests that prove the model and results as valid.

Model Diagnostic Tests

Table 4: Breusch Breusch-Godfrey LM Test for Autocorrelation

Lags (p)	Chi²	Degrees of Freedom (df)	Prob > Chi²
1	2.257	1	0.1330

Fail to reject the null hypothesis (H_0). No evidence of serial correlation.

Table 5: Breusch–Pagan / Cook–Weisberg Test for Heteroskedasticity

Test Statistic	df	Prob > Chi²
$\chi^2(1) = 0.01$	1	0.9387

Interpretation: Fail to reject H_0. No evidence of heteroskedasticity.

Table 6: Cumulative Sum (CUSUM) Test for Parameter Stability

Type	Test Statistic	Critical Value (1%)	Critical Value (5%)	Critical Value (10%)
Recursive	0.3626	1.1430	0.9479	0.8499

Interpretation: Test statistic is below all critical values. No evidence of structural break.

Table 7: Shapiro–Wilk W Test for Normality

Variable	Obs	W	V	Z	Prob > z
R	28	0.93222	2.047	1.475	0.07015

Marginal evidence against normality ($p > 0.05$), indicating residuals

are approximately normally distributed.
The diagnostic tests collectively support the key classical linear regression assumptions. The Breusch-Godfrey LM test indicates no evidence of autocorrelation (p = 0.1330), while the Breusch-Pagan/Cook-Weisberg test confirms homoskedasticity of residuals (p = 0.9387). The CUSUM test for parameter stability reveals no structural break, as the test statistic falls well below all critical values. Additionally, the Shapiro-Wilk test suggests that the residuals are approximately normally distributed (p = 0.07015). Overall, the model satisfies the assumptions of no autocorrelation, constant variance, stability over time, and normality of errors.

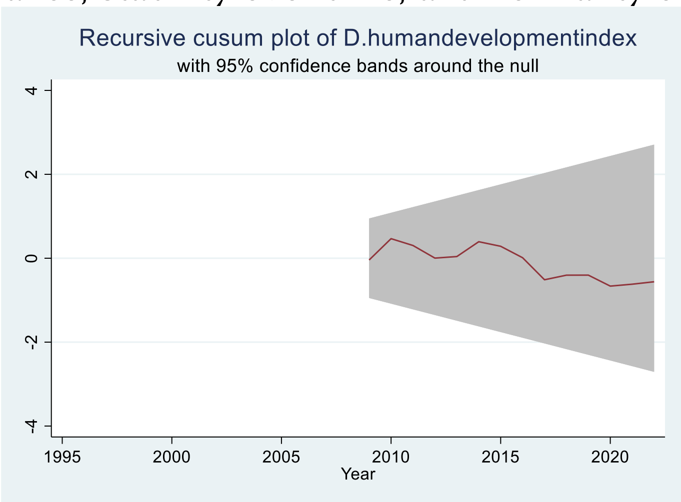

Figure 1: CUSUM Test for Structural Breaks

Conclusion

This research explores the relationships between the human development index and green technology (HD) using a comprehensive analysis of data from 33 observations. The study examines key variables such as GDP per capita, human development HD, renewable energy education, along life expectancy at birth. While the short-run dynamics indicate significant interactions between GDP, human development HD, and renewable energy, the long-run implications are less clear. The insignificant long-run coefficients suggest that investments in renewable energy and improvements in human development HD alone may not be sufficient to drive sustainable economic growth. Policymakers should consider a multifaceted approach that includes enhancing education, adopting eco-friendly technologies, and implementing sustainable urban planning and trade policies to improve environmental quality and support long-term economic development. this research contributes to the understanding of the complex relationships between economic growth, human development, and green technology, providing valuable insights for policy formulation in the context of developing economies. Utilizations of renewable energy sources (solar, wind, hydro, geothermal) can lead to sustainable economic growth by reducing environmental impact, fostering technological innovation, and improving energy security.

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