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Research Article

The Multidimensional Assessment of Sustainable Energy Poverty and its Impact on Economic Development

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Abstract: This study constructs an integrated and comprehensive review of worldwide sustainable energy poverty. On one hand, the hefty disparity in energy poverty is found in different economies. Energy accessibility, affordability, and clean-ability are the main blockages to improving sustainable energy poverty. The impact of sustainable energy poverty on human economic development is estimated using ARDL. High-income panels have lower sustainable energy poverty than low-income economies. Sustainable energy poverty has a significant but negative impact on economic development in all economies. The findings can facilitate policymakers in making sound policies.

Keywords: Sustainable energy gap, ARDL, Granger causality, energy poverty, economic development
JEL Classification Codes:Q56, F63

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1 Introduction

The presence of an extensive energy gap shows a frightening issue for the current energy structure worldwide. This gap is distinct in the unavailability of sufficient, affordable, and clean energy for daily use as well as development activities purpose. Energy (poverty) poses a hazard to sustainable improvement in social sectors like education and health. The description of such poverty or energy gap described in the west in the early nineties which open up sustainable energy-gap research, ensuring variants patterns and requirements of sustainability. Therefore, the United Nations (UN) adopted the motto of cleanable, and affordable energy for each individual at the beginning of the 20th century (2001) to tackle the universal poverty in the energy sector. It has been further highlighted in sustainable development goals (SDGs-2030) as the 7th agenda of SDGs. Energy is important for not only economic development but also for social activities. This issue may have different magnitude across the world but its outcomes are similar for everyone. For example, developed countries face high energy costs while developing countries lack access to modern-day energy (Hassan et al., 2021). The sustainable energy gap/poverty in two different income-based economies are presented in Figures 1 & 2 respectively.

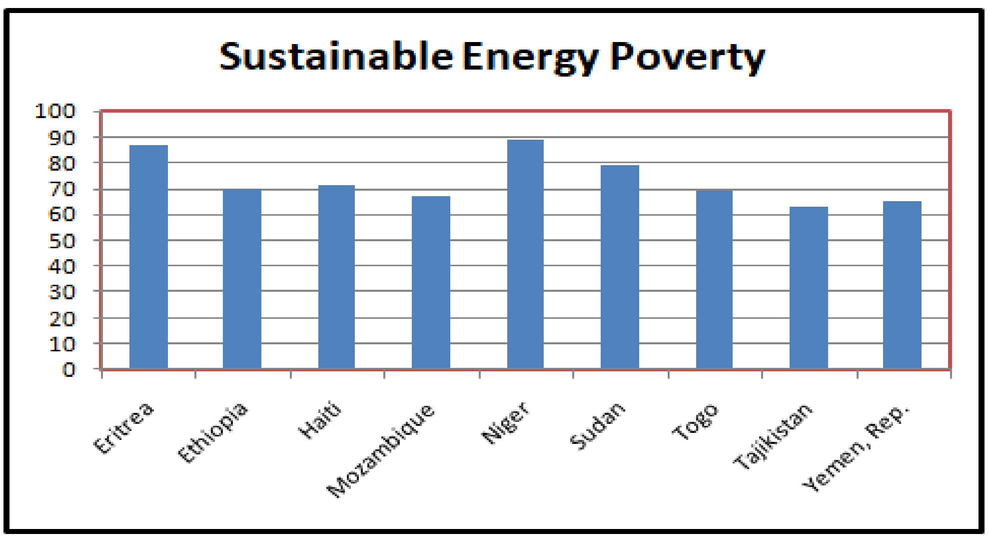

Figure 1: Energy gap/poverty in Low-Income Economies (LIC)

According to figure 1, sustainable energy poverty is subsisting in low income while there is also some footprint of this gap in the advanced economies as well (in figure ??). However, the condition of sustainable energy poverty in low-income is severe which can be an obstacle to attaining sustainable development. Moreover, fluctuation in this regard can be found within the same income classification. For example, Niger has higher sustainable energy poverty relative to Tajikistan even though both countries are in the same group. The high-income economies (as per WDI classification) are also facing sustainable energy poverty, however, economies such as Iceland, Bahrain, and the UK have a very low level of sustainable energy poverty.

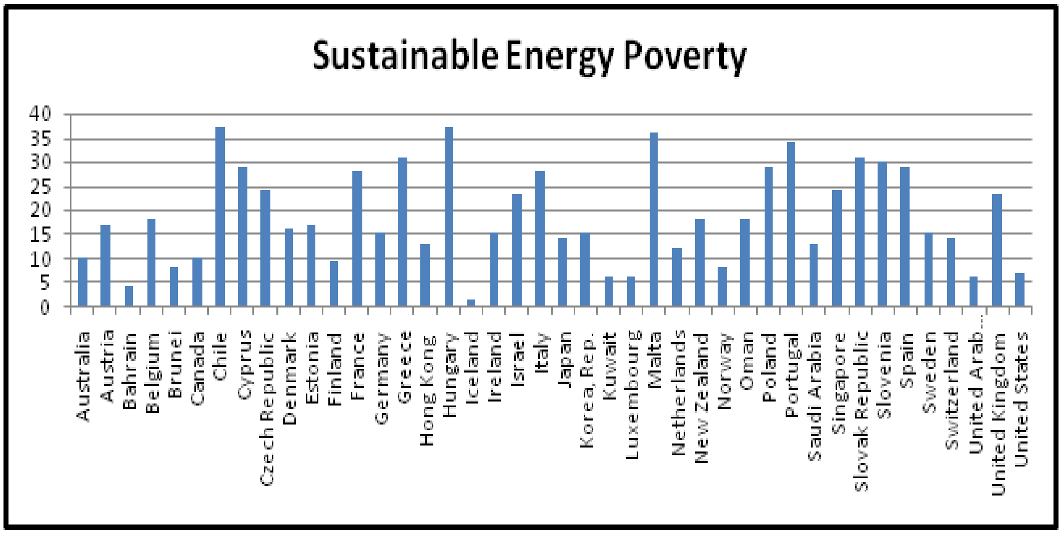

Figure 2: Energy gap/poverty in High Income Economies (HIC)

A comprehensive comparison of energy poverty evaluation processes was followed in this work, which sums up the current dispute on the procedures of energy poverty evaluation (Che et al., 2021). The concept of energy poverty or a shortfall in supply is considered complex. Different indications and impacts are brought together into a single number to control the weaknesses of previous approaches to evaluating energy gaps. There is, however, a need for a comprehensive assessment of the sustainable energy gap that takes into account several factors such as socioeconomics, energy, and the environment. There are only a few publications available on this topic in certain countries.

As part of this study, we will evaluate sustainable energy poverty across select economies and assess the influence of energy poverty on economic development. The current work depicts a global sustainable energy gap evaluation with an econometric analysis of selected economies, employing a variety of indicators. The results show that the global sustainable energy gap has had a significant impact on economic growth in all economies.

The study was distributed as follows. The relevant literature regarding the area of the field and its assessment methods have been discussed in the next section. Data, variables, and model specifications have been presented in the subsequent. Empirical outcomes based on econometric analysis have been presented and discussed in the next section. Finally, we concluded and suggested a line of action at the end of the manuscript.

1.1 Literature Review

For the purpose of evaluating, (Boardman, 1991) proposed the idea of the energy gap and developed a one-dimensional model that compares expenditure on energy and household earnings, in which the households are labeled poor if they consume 10% or more of their income on energy requirements. However, a new way of quantifying energy poverty was proposed by Foster, who looked at energy scarcity and using a demand-side approach based on primary review became tedious on a global scale (Baloch et al., 2020) (Khandker et al., 2012). It has been widely acknowledged that fossil fuels have been a major contributor to environmental degradation (Wang et al., 2018). Economic growth, largely as a result of the massive use of fossil fuels, has a significant impact on a wide range of societal elements as a result of climate change. Economies around the world are impacted and affected by the increasing growth of energy production and consumption. It's clear that energy is still an important part of economic development (Abbas Scholar Sharif Chaudhry, 2017) Bogdanov et al., 2021).

Economic expansion is alleged to increase environmental pollution because of increased energy use (Liu et al., 2021). To achieve other SDGs, such as economic growth and the preservation of the environment, a successful energy transition is essential (Zhuang et al., 2021). Sustainable development relies on a shift to clean energy services, which is widely accepted. Therefore, the transition to a more sustainable energy source makes the plan more environmental-friendly while also promoting long-term economic growth. While energy changes are taking place all across the world, sustainable solutions are being planned for the future. Fossil fuels are still the primary source of energy in many countries, resulting in significant levels of GHG emissions and pollution. The SDGs-2030 call for identifying new routes to accessing low-cost, environmentally friendly energy (Chen et al., 2019) (Abbas et al., 2020).

Studies on the link between the energy transition, sustainable development, and the environment are quite limited, and this is mostly due to the lack of data. To that end, this study contributes to the current literature by concentrating on how the energy transition, economic development, and a sustainable environment are intertwined. This study examined economic growth and environmental protection as two of the Sustainable Development Goals (SDGs) (Shen et al., 2021). There will be a discussion of the economic implications of the energy transition in different locations. In addition, the benefits of this energy shift will be assessed in terms of its impact on the economy as well as the environment (Wu et al., 2021) . This research also looks at the relationship between certain economies' economic growth and the sustainable energy poverty transition. Panel quantile regression (Khan et al., 2020) (Padhan et al., 2020) and causality in quantiles (Song Taamouti, 2020) can also be utilized to verify the robustness of the empirical results in this work. The Energy Consumption Matrix (ECM) is used to estimate how much energy the population has access to (Pachauri et al., 2004). The energy gap index measures the difference between the amount of energy that families use and the amount of energy they lose in order to meet their basic energy needs (Mirza Szirmai, 2010) (Wei et al., 2021). The International Energy Agency in 2013 Method has also been utilized to evaluate the growth of different economies in their evolution to conventional energy and the degree of development (International Energy Agency, 2013). Using the Index of multi-indicators (Nussbaumer et al., 2012), it was found that if the aggregate score of energy availability exceeds a specific threshold, a household is considered to be poor. Energy availability to the population was proposed and published by (Poor People ' s Energy Outlook 2012, 2012). As an additional strategy for determining the energy gap and procuring the required modern energy, International Energy Agency uses an easy-to-follow approach (International Energy Agency, 2013).

2 Data and methodological discussion

The study makes use of secondary sources to compile a composite index of indicators for E-2030. A panel of economic factors, energy, and climate data from 120 economies used in the study, which run from 2000 to 2017. The countries are chosen on the basis income status (LIC, LMIC, MIC, and HIC) as per World Bank classifications of each country. The Sustainable Development Index (SDI) was developed utilizing various metrics from the SDGs-2030. The data for this study were obtained from the International Energy Agency (IEA), the World Development indicator (WDI), the British Petroleum database (BP), the International Monetary Fund (IMF), the Organization for Economic Cooperation and Development (OECD), and the Penn World tables (PWT 10.0). The purpose of this study is to develop a composite index that reflects the sustainable indices of socioeconomic growth, the environment, and the transition to a low-carbon economy. As a result, this study selected a set of relevant indicators taking into consideration the wide range of possible combinations based on the experience of predecessors.

2.1 Assessment of Performance towards Sustainable Energy Poverty Eradication

Initially, this study builds the following matrix:

$$\Theta = [aij]m \times 9 \quad (1)$$

and bij = -aij is used to make positive indicators. Secondly, Θ is the procedure to make a decision matrix and the standard matrix is:

$$C = [cij]m\times \quad (2)$$

This study computes

$$c_i j = (b_{ij}^t - b_{j,min}^{t_0})/(b_{j,max}^{t_0} - b_{j,min}^{t_0}) \quad (3)$$

where b_{ij}^t is the basic value for jth vector of economies i in year t,t_0 is the standard year, $b_{j,min}^{t_0}$ and $b_{j,max}^{t_0}$ are the minimum and maximum of the jth dimension in year $t_0.cij < 0$ denotes the jth variable of economies *i* in year is better than that in year t_0, whereas $c_i j = 1$ shows the jth variable of economies *i* in year *t* is not good than that in year t_0.

2.2 Integrated sustainable energy gap index

The purpose of this study is to investigate the influence and direction of globalization on human beings in a number of different economies.
The WAEPI (Equation 4) used in this work is constructed as follows:

$$SustainabilityEnergyGap/poverty_{year} = 100 - \sum(w1 * Accessibility_n + w2 * Affordability_n + w3 * Cleanability_n) \quad (4)$$

X=Country; n=Normalized indicator

$$\sum_{1}^{4} Wi = 1 \quad (5)$$

The Multidimensional Sustainable Gap/Poverty in Energy (EP) Index was achieved in the following ways: by using the EP, which indicates a country's lack of the degree of accessibility, affordability, and clean-ability of energy. Making a subtraction of EP from 100 yields, a monetary value for the sustainable energy gap that the economy wishes to bridge. EP calculates the value of a region's sustainable energy gap. After then, various tests are used to determine whether or not the data is stationary.

2.3 Proposed Models

To scale up the impact of sustainable Energy poverty on human development of selected economies.

$$HDI = f(EP, EP2, EXP, TRD, IND) \tag{6}$$

2.4 Panel unit roots tests

Different panel approaches for stationarity were used in this work in order to observe the stationarity independent of the preferred variables, including Bruiting; ADF; PP Fisher; Im, Pesaran and Shin; Levin; Lin and Chu; and Hadri. Finding the stationarity property of the variables can be accomplished through the use of several stationarity approaches. The LLC (1993, 2002) technique, which is based on the Augmented Family test, is the most often used panel stationarity test today. LLC makes the assumption that all groups have the same autoregressive (AR) coefficient under both the null and alternative hypotheses (Levin et al., 2002).

$$\Delta HDI_{it} = \rho HDI_{it} + \alpha_{0i} + \alpha_{1i}t + u_{it} \tag{7}$$

i = 1,2,...,N ,t = 1,2,...,T

Where t is time tendency $(\alpha_{1i}t)$ as well as individual special effects (α_i) are included. u_{it}, is supposed to be distributed but independently across each and follow a stationary, ARMA procedure for every individual.

$$u_{it} = \sum_{j=1}^{\infty} \theta_{ij} u_{it-j} + \epsilon_{it} \tag{8}$$

It supposes a homogeneous group. The test is developed by Im, Pesaran, and Shin (2003) by making the supposition of homogeneous group. The method adjusts the heterogeneity and finds *t*-statistics value from augmented Dickey Fuller (ADF) regression. For the observation N group and time period, *T*, the IPS panel stationarity (Barbieri, 2016) regression can be written as follows (Behera, 2021);

$$\Delta EP_{it} = \alpha_i + \pi_{it} + \beta_i EP_{i,t-1} + \sum_{j=1}^{k} \varphi_{it} \Delta EP_{i,t-1} + \epsilon_{it} \tag{9}$$

The Hadri test is based on residual, where residuals from OLS are attained by an outcomes on a constant (Hadri, 2000).

$$HDI_{it} = \delta_{mi} d_{mt} + \epsilon_{it} \tag{10}$$

m= 2,3

The Hadri tests suppose a no stationarity as a null hypothesis.

2.5 Panel Co-integration

Panels of cointegration introduced by Pedroni (2004), Johansen (1995), and Kao (1999) are based on Engle and Granger formations. Pedroni came up with a new set of tests that can handle a wide range of samples (Asteriou Hall, 2007). The pooling of residuals yields seven separate tests, four inside the dimension and three between the dimensions, which are organized into two dimensions (Pedroni, 1999). The Pedroni suppose dependence in cross-section. It is defined as:

$$fp_{it} = \alpha_i + \beta_{1i}EP + \beta_{2i}EP + - - - + \beta_{mi}EP_{mit} + \epsilon it \quad (11)$$

where is the un-witnessed single economies effect, t = 1,2,3,—–T i= 1,2,—-N t is the time, i is economies units and it represents error term. The robustness of Pedroni cointegration analysis is tested using the Johansen Fisher (1995) and Kao (1999) tests. However, asymptotic equality violates the "independent variables" endogeneity condition in Kao (1999) analysis, allowing variability among vectors. The most likelihood is used in Fisher's non-parametric technique (Karaman, 2007). Finally, using panel-based cointegration results, the lag length is essential. Johansen Fisher (1995) has the type of a VAR and can be written as:

$$y_{it} = \alpha_i + A_1HDI_{it-1} + - - +A_\rho HDI_{it-\rho} + \mu it \quad (12)$$

The short-run terms in cointegration can be articulated as:

$$\Delta HDI_{it} = \alpha_i + \Pi HDI_{it-1} + \sum_{j=1}^{\rho} \Gamma \Delta HDI_{t-j} + \mu_{it} \quad (13)$$

Following the discovery of cointegration in the second level's outcomes, this investigation looks into the relationship between energy poverty and human development. So, ARDL and panel quantile regression are two of the techniques used in this work.

2.6 Panel Dynamic Autoregressive Distributed Lag

If the regressors indicate a mix of separate stationarity trends, ARDL is carried out (Pesaran and Shin 1998). Human development and the sustainable energy gap are two of the most common outcomes of panel ARDL approaches.

$$HDIit = \alpha_i + \sum_{l=1}^{P} \beta_0 HDI_{i,t-j} + \sum_{l=0}^{q} \beta_1 d_{i,t-j} + \sum_{l=0}^{q} \beta_2 EP_{i,t-j} + \mu_i \quad (14)$$

by reparametrizing:

$$\Delta HDI_{it} = \alpha_i - \phi i(HDI_{i,t-j} - \Phi_2 x_{1,t-1} + \sum_{l=1}^{P-1} \lambda_{il} HDI_{i,t-l} + \sum_{l=0}^{q-1} \lambda'_{il} \Delta EP_{i,t-l} + \mu_i \quad (15)$$

There are two types of independent vectors: the short-term lagged dependent variable coefficients λ, and the long-term independent vectors λ'. The control regressors and cointegration coefficients are ϕi and $\phi 2$. Additionally, displayed is the rate at which the data is changing. According to (Pesaran et al., 1999), ARDL (Analysis of Relative Development

Levels) may be used to look at the consequences of energy poverty and HDI in a number of countries from 200 to 2017.

$$HDIit = \sum_{j=1}^{P} \lambda_{ij} \Delta HDIi_{t-j} \sum_{j=0}^{q} \delta_{ij} \Delta EPi_{t-j} + \mu i + \epsilon it \quad (16)$$

where EPit are vector of independent variable, δ_{ij} are coefficient vectors of the regressors, HDIit is the dependent vector, λij is the coefficients of the lagged of HDIit and μi show the fixed effects, *i*=1,2,.....,*N* and *t*=1,2,.....,*T*. the coefficients of long run relationship are:

$$\Delta HDI_{it} = \phi \Delta HDI_{i,t-1}, t-1 + \beta i^{'} EPit + \sum_{j=1)}^{P-1} \lambda_{ij}^{*} \Delta HDIi, t-j \sum_{j=0}^{q-1}, \delta_{it}^{*} \Delta EPi_{t-j} + \mu i + \epsilon i \quad (17)$$

where

$$\phi i = -(1 - \sum_{j=1}^{P} \lambda_{ij}); \Delta HDIi, t-j); \beta i = \sum_{j=1)}^{q} \delta_{i}j); \lambda_{ij}^{*} = \sum_{m=j+1)}^{P} \delta_{im}),$$
$$j = 1, 2, .., p-1; \delta_{i}t^{*} = \sum_{m=j+1)}^{q} \delta_{im}), j = 1, 2, .., q-1 \quad (18)$$

Long-term stability makes it possible to respond to divergence in a cointegration relationship in a unique way. Using the regressor and regressand characteristics, it was found that the short-term values of the regressors and regressors in the system are affected by deviations from equilibrium. As an example, the following is how the error correction model looks:

$$\Delta HDIit = \theta ECT + \sum_{j=1}^{P-1} \lambda_{ij}^{*} \Delta HDIi * \Delta HDIi, t-j + \sum_{j=0}^{q-1}, \delta_{it}^{*} \Delta EPi_{t-j} + \mu i + \epsilon it \quad (19)$$

2.7 Panel Granger Causality

To study the vector of causality, this paper employed a causality test for the pragmatic relationship. The current study employed a causality test via the lagged value of dependent variables. It is written as:

$$\Delta EP = \alpha_{1i} + \sum^{L} = 1\gamma_{1iL} \Delta EP_{it-L} + \sum^{L} = 1\gamma_{1iL} \Delta HDI + \epsilon_{1it} \quad (20)$$

$$\Delta HDI = \alpha_{2i} + \sum^{L} = 1\gamma_{2iL} \Delta HDI_{it-L} + \sum^{L} = 1\gamma_{2iL} \Delta EP + \epsilon_{2it} \quad (21)$$

Where, α & γ, are fine-tuning coefficients L is lags numbers.

3 Results and Discussion

Descriptive data on these factors can be found in Table 1. Their averages have a substantial margin of error. ′ The standard deviations decrease when all variables are transformed into the natural logarithm. It is important to reduce the impact of data volatility on empirical analysis by utilizing every natural logarithm variable. Also, the kurtosis, which evaluates the peakiness or flatness of the series distribution, reveals that the series peaked to the surface or leptokurtic relative to the normal distribution. It is clear that the IND and TRD skewness values (long right tail) point to higher-than-average values for these variables, while the EP skewness value (long left tail) points to lower values than the sample average.

Table 1: Descriptive Statistics of the variables

Variable	No of Obs.	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
HDI	2322	0.72	0.74	0.95	0.26	0.15	-0.57	2.55
EP	2322	3.74	3.8	4.31	-0.13	0.41	-2.62	19.91
EXP	2322	1.96	2.03	3.19	-0.53	0.48	-0.67	3.79
IND	2322	3.3	3.26	4.44	1.9	0.37	0.18	4.08
TRD	2322	4.33	4.33	6.09	2.78	0.52	0.32	3.68

Explanatory variables were evaluated for possible multicollinearity by calculating variance inflation factors (VIFs) for all of the variables. As shown in Table 2, our model has a mean of 1.80 and a maximum of 7.36, which indicates that multicollinearity is not a problem in this dataset. There is no empirically significant multicollinearity among the variables that have a VIF of less than 2 in most cases, which suggests a modest correlation between the independent variables (Bao et al., 2021)(Deller et al., 2021).

Table 2: Results of multicollinearity based on variance inflation factor (VIF) test

Variables	HDI	EP	EXP	IND	TRD
HDI	—				
EP	7.36	—			
EXP	1.73	1.56	—		
IND	1	1.01	1.08	—	
TRD	1.11	1.11	1.01	1	—

Table 3 shows the results of the various panel stationarity analyses, as seen below. At constant with-trend and at the first differenced variables, the results show characteristics of stationarity. Only EP and EXP (at trend) are significant at the 1%, 5%, and 10% levels for the Levin, Lin Chu stationarity test (H0: series has a unit root). T-statistics of HDI, EP, and EXP are significant at 1%, 5%, and 10% levels at trend. Fisher stats of all variables cannot be rejected at 1%, 5%, and 10% significance levels at the level of significance (trend). Without the Hadri and Heteroskedasticity consistent z-stat check that has the no unit root as a null hypothesis, the PP-Fisher of all variables cannot be rejected at 1%, 5%, and 10% significance at level (trend). This study uses two separate tests to determine robustness in the 2nd Generation stationarity test. EXP is a constant in the CIPS test, while in the

PESADF test all variables except IND are constant. There is no significant difference in the first difference between CIPS and PESADF at the 1% significance level.

Table 3: Unite root tests for data stationarity

1st Generation Stationarity Tests							
Variables	Null Hypothesis: Unit root.					Null Hypothesis: no unit root.	
	LLC	Breit	IPS	ADFF	PPF	Hadri	Z-Stat
HDI	-10.17***	———	4.12	226.26	856.79***	29.27***	28.95***
HDI(Trend)	-1.94**	5.55	4.19	204.54	200.05	22.76	20.51***
ΔHDI	-11.14***	———	-10.24***	541.81***	1324.65***	11.13***	10.85***
ΔHDI(Trend)	-12.60***	-5.35***	-7.70***	460.69***	1025.55***	17.43***	30.26***
EP	-6.95***	———	2	254.42	610.60***	27.58***	25.49***
EP(Trend)	1.32	6.05	7.86	133.71	197.73	22.56***	22.05***
ΔEP	-7.03***	———	-7.51***	436.98***	1087.19***	10.51***	11.98***
ΔEP(Trend)	-10.19***	-6.58***	-6.85***	427.56***	955.47***	19.19***	28.05***
EXP	-4.00***	———	-0.87	266.82	304.08**	19.97***	16.29***
EXP(Trend)	-4.18	0.1	-17.24***	778.02***	1845.22***	20.35***	18.79***
ΔEXP	-19.07	———	-17.24***	778.02***	1845.22***	7.14***	8.52***
ΔEXP(Trend)	-17.17***	-7.80***	-12.50***	600.16***	1165.59***	18.14***	38.93***
IND	-3.56***	———	0.63	233.15	284.69	16.37***	15.88***
IND(Trend)	-4.85***	2.31	0.86	248.19	300.55**	20.48***	18.27***
ΔIND	-17.75***	———	-17.17***	776.57***	1848.70***	5.19***	8.05***
ΔIND(Trend)	-16.16***	-10.63***	-13.62***	632.12***	1370.36***	15.85***	36.54***
TRD	-4.60***	———	-0.56	248.64	243.11	21.22***	16.96***
TRD(Trend)	-6.44***	0.8	-1.68**	317.52**	278.21	19.26***	18.60***
ΔTRD	-20.52***	———	-18.33***	820.29***	1523.60***	3.33***	7.93***
ΔTRD(Trend)	-18.62***	-11.70***	-13.96***	643.73***	1369.57***	14.31***	41.87***

***, **, * shows significance level at 1%, 5% and 10% respectively.

Results from the various panel stationarity analyses are displayed. Table 4 displays the results of numerous cointegration experiments. A significant difference between the null hypothesis of no cointegration for the panel rho-statistic and the null hypothesis for the other three weighted statistical tests can be detected. A long-term association between HDI and energy gap/poverty, development spending, industrial value addition, and trade is a strong potential in this investigation. Consequently, this work takes into account two additional first-age group cointegration procedures in table 4 for checking the strength of Pedroni results. Cointegration was clearly evident at 1%, 5%, and 10% significance, according to Kao statistics. There is a high acceptance of the hypothesis of cointegration with a 1% significance level in the results from the Fisher panel cointegration statistics produced from the two formations: max-eigen and trace statistics.

Table 4: Results of the Cointegration test

Pedroni Residual Cointegration Test				
Within-dimension	Statistic	Prob.	W. Statistic	Prob.
Panel v-Statistic	24.26***	0	14.29***	0
Panel rho-Statistic	-9.60***	0	0.11	0.91
Panel PP-Statistic	-3.57***	0	-6.29***	0
Panel ADF-Statistic	0.31	0.94	-2.39**	0.01
Between-dimension	Statistic		Prob.	
Group rho-Statistic	-12.79***		0	
Group PP-Statistic	-15.36***		0	
Group ADF-Statistic	-3.57***		0	
Kao Residual Cointegration Test				
ADF	-5.05***		0	

***, **, * shows significance level at 1%, 5% and 10% respectively.

As seen in Table 5 (the ARDL estimator), the error correction coefficients are negative and statistically significant, indicating that the process will converge in the long term. The long-run dynamics are examined using human development as the independent variable, and the results of this study reveal that the long-run relationship between energy poverty and the outcomes of human development in selected economies is statistically significant in all of the panels investigated. When measured at the 1% significance level, the existing situation of energy poverty increases the negative impact on human development. However, with the exception of upper-middle-income countries, the quadratic impact of long-term energy poverty on HDI is hindered in all of the panels studied. This shows that economies that are energy poor have a lower degree of human development on average than ones that are energy-rich. In terms of the control variables, the findings revealed that increasing long-run development investment increases HDI in all income group economies, with the exception of poor and middle-income nations, where long-run development expenditure has a significant negative impact on HDI. Within a short time, frame, EXP has a considerable, albeit negative, effect on HDI in high-income countries. According to the findings, IND has a statistically significant beneficial impact on HDI in low-income group economies, but in high-income group economies, IND has a statistically significant negative impact on HDI. TRD has a statistically significant favorable influence on HDI in low-, upper-, and high-income countries. A considerable and strong long-run association has been found between energy poverty, development spending, industrial value addition, and trade with HDI, according to the findings of the studies.

Table 5: Long run results of estimations

Long-run Equation (ARDL)				
Coefficients				
Variable	**LICs**	**LMICs**	**UMICs**	**HICs**
EP	2.85***	2.60***	0.89***	0.98***
EP2	-3.19***	-3.07***	-1.66***	-1.97***
EXP	0.02	0.01***	0.01***	0.17***
IND	-0.05	0.02***	0.03***	0.05***
TRD	0.04	-0.02***	0.05***	0.05***
Short-run Equation (ARDL)				
Coin-01	-0.17**	-0.14***	-0.15***	-0.42***
ΔEP	0.74	2.92**	2.2	0.62***
ΔEP2	-0.42	-2.37**	-2.13	-1.04***
ΔEXP	0.02	-0.03	0	0.01***
ΔIND	0.02	-0.05	0.01	0.02***
ΔTRD	-0.07	0.01**	0	0.05***
C	0.02***	0.02***	0.05***	0.25***

***, **, * shows significance level at 1%, 5% and 10% respectively

The plots are showing an in-depth analysis of the quadratic effect of EP on HDI using panel ARDL analysis. The 3D plots of ARDL offer all combinations. Here, it can be observed that an increase in Energy poverty will have a linear effect on HDI. But for the low-income economies where there is a greater occurrence of energy gap/poverty, an increase in Energy poverty tends to follow an inverted U-shaped pattern with HDI. They indicate the inverted U-shaped quadratic effect of Energy poverty on HDI in all panels except upper middle-income economies which shows a U-shape curve.

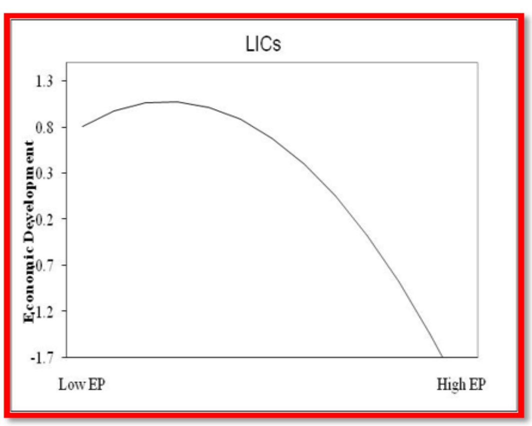

Figure 3

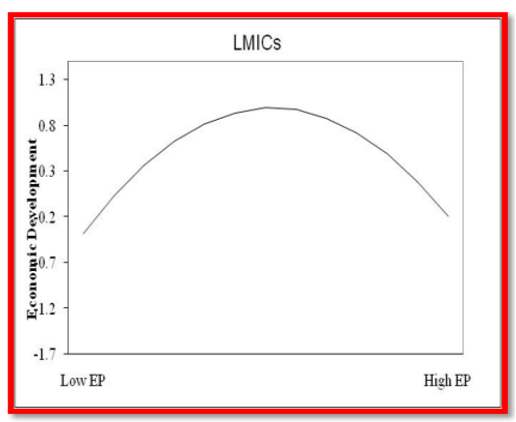

Figure 4

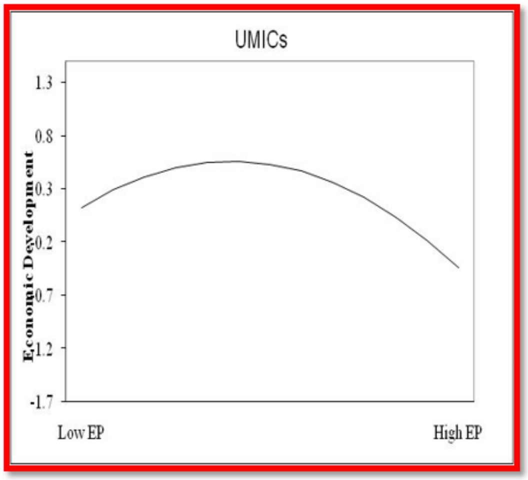

Figure 5

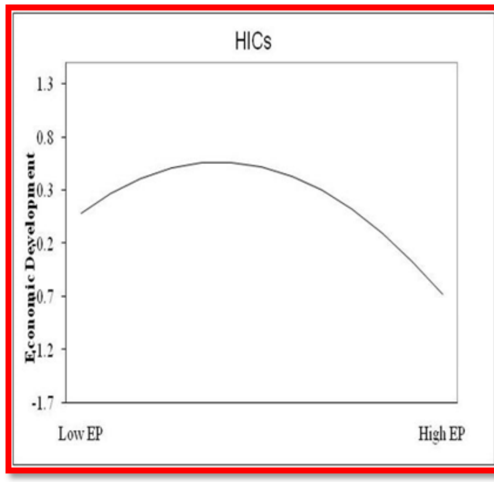

Figure 6

3.1 Pair wise Granger causality

The results of the granger causality test are provided in Table 6 and indicate that some variables do granger cause each other in the specified panel. The results show that EP does not granger cause HDI in low middle and high-income panels, but HDI does granger cause EP in low-income panels; EXP does not granger cause HDI in all selected panels, but HDI does granger cause EXP in upper-middle and lower-middle-income economies; IND does not granger cause HDI in all selected panels, except for low middle-income economies; and IND does not granger cause IND in all panels. TRD does granger cause HDI in all panels with the exception of high-income panels, while HDI does granger cause TRD in all selected panels. EP does granger cause EXP in all groups, but EXP does granger cause EP in all groups with the exception of low-income economies. EP and IND Granger cause each other in all panels, TRD and EP Granger cause each other in all panels except the low middle-income panel, but EP granger causes TRD in all groups except the low middle-income panel. The IND granger causes EXP, whereas the EXP granger causes IND only in panels with lower-middle and upper-middle incomes. Low-income economies are not affected by the granger cause of EXP, while TRD and IND are affected by each other in all income economies, with the exception of upper-middle-income nations.

Table 6: Results of pairwise Granger causality tests

Null Hypothesis:	LI	LMI	UMI	HI
	F-Statistic	F-Statistic	F-Statistic	F-Statistic
EP does not Granger Cause HDI	3.69**	0.59	6.21***	0.1
HDI does not Granger Cause EP	1.2	12.88***	3.13**	3.06**
EXP does not Granger Cause HDI	0.64	0.01	0.13	0.32
HDI does not Granger Cause EXP	7.08***	1.57	0.66	2.41*
IND does not Granger Cause HDI	0.26	2.64*	1.27	1.04
HDI does not Granger Cause IND	2.37	0.15	3.87	0.71
TRD does not Granger Cause HDI	1.59	1.69	1.83	3.56**
HDI does not Granger Cause TRD	1.36	0.26	3.23	2.24
EXP does not Granger Cause EP	4.48**	0.62	0.46	0.53
EP does not Granger Cause EXP	0.09	1.82	0.38	0.41
IND does not Granger Cause EP	0.09	1.18	1.08	0.22
EP does not Granger Cause IND	0.48	0.14	3.12	1.96
TRD does not Granger Cause EP	0.25	4.92**	1.41	0.26
EP does not Granger Cause TRD	1.63	0.4	3.94	0.63
IND does not Granger Cause EXP	0.33	0.64	3.7	0.18
EXP does not Granger Cause IND	2.89*	0.81	1.67	3.28**
TRD does not Granger Cause EXP	2.42*	7.21***	2.64*	3.61**
EXP does not Granger Cause TRD	2.45*	2.03	2.19	1.08
TRD does not Granger Cause IND	0.53	0.52	0.1	1.28
IND does not Granger Cause TRD	1.36	0.56	2.47*	0.87

***, **, * shows significance level at 1%, 5% and 10% respectively

4 Conclusion and policy implication

Sustainable energy poverty has risen to become the most pressing issue confronting the world's energy structure. The closing of the sustainable energy gap is unavoidable due to health concerns and economic exposure caused by the usage of traditional energy sources. As previously stated, the current study examines the methodology for evaluating comprehensive sustainable energy poverty since the systematic evaluation of sustainable energy poverty is widely recognized as a necessary first step in addressing these issues. The following are the most significant conclusions and policy recommendations: The panel dynamic ARDL outcomes indicate that human development and energy poverty hold a negative association in the selected economies. Energy-poor economies have lower sources of human development than highly developed economies. Therefore, the long-term effect of investment has a positive impact on the HDI in each group of economies. TRD has a negative impact on the HDI according to the outcomes of this study. Finally, energy poverty, industrial value addition, development spending, and trade have strongly been associated with the HDI of the underlined economies. According to the quadratic effect of energy poverty on HDI, the LICs economies show a sharp trend during the observation time framework. LIMCs hold the balanced shape of the inverted U curve, however, UMICs and HICs hold more scattered shapes of the inverted U curve in this time period. Finally, the results of pairwise Granger causality indicate that except a few indicators, most of the variables have a causality impact on other variables in almost every standard of economy.

4.1 Policy Implications

The insights gained from this study can be used to develop useful policies in the future. Low-income countries are unable to offer traditional energy, and sustainable energy is still in the early stages of development in these countries. High-income countries, on the other hand, have the smallest sustainable energy gap. Infrastructures in low-income countries are required for the provision of sustainable energy sources, therefore, this requires significant investment.

References

Abbas, Q., Khan, A. R., Bashir, A., Alemzero, D. A., Sun, H., Iram, R., and Iqbal, N. (2020). Scaling up renewable energy in africa: measuring wind energy through econometric approach. *Environmental Science and Pollution Research*, 27(29):36282–36294. https://doi.org/10.1007/s11356-020-09596-1.

Asteriou, D. and Hall, S. G. (2007). *Applied Econometrics- A modern approach using Eviews and Microfit*.

Baloch, Z. A., Tan, Q., Iqbal, N., Mohsin, M., Abbas, Q., Iqbal, W., and Chaudhry, I. S. (2020). Trilemma assessment of energy intensity, efficiency, and environmental index: evidence from BRICS countries. *Environmental Science and Pollution Research*, 27(27):34337–34347. https://doi.org/10.1007/s11356-020-09578-3.

Bao, Z., Zhang, J., Wang, G., Guan, T., Jin, J., Liu, Y., Li, M., and Ma, T. (2021). The sensitivity of vegetation cover to climate change in multiple climatic zones using machine learning algorithms. *Ecological Indicators*, 124(107443):107443. https://doi.org/10.1016/j.ecolind.2021.107443.

Barbieri, L. (2005). Panel unit root tests : A review ECONOMICHE E SOCIALI PANEL UNIT ROOT TESTS : A REVIEW laura barbieri. *Economia-Quaderno*.

Behera, C. (2021). Economic globalization and financial development. *Empirical Evidence from India and Sri Lanka*, 8:11–19. https://doi.org/10.13106/jafeb.2021.vol8.no5.0011.

Bogdanov, D., Ram, M., Aghahosseini, A., Gulagi, A., Oyewo, A. S., Child, M., Caldera, U., Sadovskaia, K., Farfan, J., De Souza Noel Simas Barbosa, L., Fasihi, M., Khalili, S., Traber, T., and Breyer, C. (2021). Low-cost renewable electricity as the key driver of the global energy transition towards sustainability. *Energy (Oxf.)*, 227(120467):120467. https://doi.org/10.1016/j.energy.2021.120467.

Che, X., Zhu, B., and Wang, P. (2021). Assessing global energy poverty: An integrated approach. *Energy Policy*, 149(112099):112099. https://doi.org/10.1016/j.enpol.2020.112099.

Chen, B., Xiong, R., Li, H., Sun, Q., and Yang, J. (2019). Pathways for sustainable energy transition. *Journal of Cleaner Production*, 228:1564–1571. https://doi.org/10.1016/j.jclepro.2019.04.372.

Deller, D., Turner, G., and Waddams Price, C. (2021). Energy poverty indicators: Inconsistencies, implications and where next? *Energy Economics*, 103(105551):105551. https://doi.org/10.1016/j.eneco.2021.105551.

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. 28:28081–28095.

Khan, H., Khan, I., and Binh, T. T. (2020). The heterogeneity of renewable energy consumption, carbon emission and financial development in the globe: A panel quantile regression approach. *Energy reports*, 6:859–867. https://doi.org/10.1016/j.egyr.2020.04.002.

Khandker, S. R., Barnes, D. F., and Samad, H. A. (2012). Are the energy poor also income poor? evidence from india. *Energy Policy*, 47:1–12. https://doi.org/10.1016/j.enpol.2012.02.028.

Levin, A., Lin, C.-F., and James Chu, C.-S. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of Econometrics*, 108(1):1–24. https://doi.org/10.1016/S0304-4076(01)00098-7.

Liu, H., Liang, S., and Cui, Q. (2020). The nexus between economic complexity and energy consumption under the context of sustainable environment: Evidence from the LMC countries. *International Journal of Environmental Research and Public Health*, 18(1):124. https://doi.org/10.3390/ijerph18010124.

Nussbaumer, P., Bazilian, M., and Modi, V. (2012). Measuring energy poverty: Focusing on what matters. *Renewable and Sustainable Energy Reviews*, 16(1):231–243. https://doi.org/10.1016/j.rser.2011.07.150.

Pachauri, S., Mueller, A., Kemmler, A., and Spreng, D. (2004). On measuring energy poverty in indian households. *World Development*, 32(12):2083–2104. https://doi.org/10.1016/j.worlddev.2004.08.005.

Padhan, H., Padhang, P. C., Tiwari, A. K., Ahmed, R., and Hammoudeh, S. (2020). Renewable energy consumption and robust globalization(s) in OECD countries: Do oil, carbon emissions and economic activity matter? *Energy Strategy Reviews*, 32(100535):100535. https://doi.org/10.1016/j.esr.2020.100535.

Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, 61(s1):653–670. https://doi.org/10.1111/1468-0084.61.s1.14.

Pesaran, M. H., Shin, Y., and Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, 94(446):621–634. https://doi.org/10.1080/01621459.1999.10474156.

Shen, H., Ali, S. A., Alharthi, M., Shah, A. S., Basit Khan, A., Abbas, Q., and ur Rahman, S. (2021). Carbon-free energy and sustainable environment: The role of human capital and technological revolutions in attaining SDGs. *Sustainability*, 13(5):2636. https://doi.org/10.3390/su13052636.

Song, X. and Taamouti, A. (2021). Measuring granger causality in quantiles. *Journal of Business and Economic Statistics*, 39(4):937–952. https://doi.org/10.1080/07350015.2020.1739531.

Wang, S., Li, G., and Fang, C. (2018). Urbanization, economic growth, energy consumption, and CO2 emissions: Empirical evidence from countries with different income levels. *Renewable and Sustainable Energy Reviews*, 81:2144–2159. https://doi.org/10.1016/j.rser.2017.06.025.

Wei, G., Asghar, N., Ahmad, I., Yin, W., Abbas, Q., Ur Rahman, S., and Farooq, F. (2021). Economic growth, fiscal imbalance, and environmental sustainability: What is desirable and undesirable for developing economies? *Environmental Science and Pollution Research*, 28(37):52283–52294. https://doi.org/10.1007/s11356-021-14379-3.

Wu, S., Alharthi, M., Yin, W., Abbas, Q., Shah, A. N., ur Rahman, S., and Khan, J. (2021). The carbon-neutral energy consumption and emission volatility: The causality analysis of ASEAN region. *Energies*, 14(10):2943. https://doi.org/10.3390/en14102943.

Zhuang, M., Lu, X., Peng, W., Wang, Y., Wang, J., Nielsen, C. P., and McElroy, M. B. (2021). Opportunities for household energy on the Qinghai-Tibet plateau in line with united nations' sustainable development goals. *Renewable and Sustainable Energy Reviews*, 144(110982):110982. https://doi.org/10.1016/j.rser.2021.110982.