

Assessing the Impact of Renewable Energy on Sustainable Development: An Empirical Analysis Using the ARDL Model with a Focus on Denmark

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Abstract:

To empirically assess the actual influence of renewable energies on sustainable development, this study utilizes the ARDL model. The analysis examines the short- and long-term relationships between the independent variables RENP, RDE, TRAD, MAV, and GDP—and the dependent variable, HDI, over the period 1990-2023. Focusing on Denmark, a pioneer country in terms of energy transition. The results obtained clearly show the positive effects of renewable energy, research and development expenditure, as well as gross domestic product on the sustainable development index. At the same time, trade and value-added in the manufacturing sector also have positive but insignificant effects. Therefore, public authorities must intervene to increase investments in this area to promote sustainable development.

Keywords: renewable energies, sustainable development, ARDL, energy transition, Denmark.

Jel Classification Codes : O15, P28, Q43

Introduction:

Light of the unprecedented environmental challenges facing our world today, renewable energy has become an essential means of ensuring a more sustainable future. Nowadays, sustainable development occupies a primordial place in our universe in the face of various contemporary environmental and economic issues. The adoption of renewable energies emerges as a crucial alternative for fostering a more sustainable future while safeguarding the development.

Energy plays a fundamental role not only in our daily lives but also in the industrial and economic management of nations. It serves as a cornerstone of sustainable development, driving the economic prosperity of modern societies. Additionally,

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energy plays a crucial role in supporting economic growth and driving socio-economic development.¹

For this, analyzing the socio-economic and environmental benefits of renewable energies, as well as their efficiency, has become a fascinating task both for researchers in economic and social sciences and for the government², with the aim of reducing environmental degradation, improving economic development, and further promoting economic growth. However, despite the many potential benefits of renewable energy, their actual impact on sustainable development remains, which remains a subject of debate.

Based on the above, the problem is formulated as follows:

To what extent have renewable energies truly contributed to sustainable development in Denmark between 1990 and 2023?

To address this primary question, the study is founded on the following hypotheses:

- A long-term relationship exists between the independent variables and the Human Development Index (HDI).
- Greater reliance on renewable energy and increased investment in research and development lead to significant improvements in the Human Development Index
- GDP and the value added by the manufacturing sector are pivotal in driving sustainable development

This research paper consists of an introduction, a theoretical concept of which we address the conceptual framing of renewable energies and sustainable development, then impact of renewable energies on sustainable development: previous studies, plus a practical case via the ARDL model, and at the end a conclusion and recommendations followed by references and the annex.

This article seeks to evaluate the influence of renewable energy on sustainable development in Denmark by applying the ARDL model. The objective is to shed light on the nature of the short- and long-term relationships among the various variables considered in the study.

I. Theoretical concept:

1. Renewable energies:

The contemporary era is marked by a growing awareness of environmental challenges and the importance of sustainable development, and in this context renewable energies occupy a primordial place, as they contribute to the transition towards a greener and sustainable economy.

An energy source is considered renewable when it can be used without reducing its future availability, in particular sources of natural origin such as solar, wind and hydraulic energy...etc.

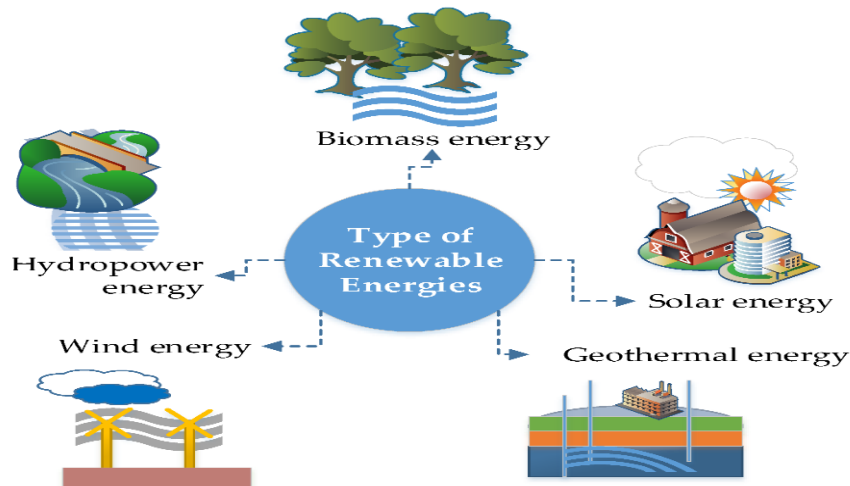
¹ Abdulkadir Abdurashid Rafindali, Ilhan Ozturk, (2017), Impacts of renewable energy consumption on the German economic growth: Evidence from combined cointegration test, Renewable and Sustainable Energy Reviews, 75, August, P 1130-1141. <https://doi.org/10.1016/j.rser.2016.11.093>

² Blazejczak, J., Braun, F.G., Edler, D., Schill, W.P, (2014). Economic effects of renewable energy expansion : a model-based analysis for Germany. Renew. Sustain. Energy Rev. 40 ,1070-1080. <https://doi.org/10.1016/j.rser.2014.07.134>

Unlike fossil fuels; coal, oil and gas, renewable energies are quickly replenished over time, plus they do not emit greenhouse gases, which supports environmental protection.

Renewable energy comes in various forms.

Figure 1. The types of renewable energy resources



Source: Ram Avtar,*, and al, 2019, Exploring Renewable Energy Resources Using Remote Sensing and GIS-A Review Resources 8(3):149; P2.

- **Solar energy:** A renewable energy source that transforms sunlight into electricity using photovoltaic panels, which is constantly replenished.
- **Wind energy**¹: operated for millennia through windmills, navigation is produced by the wind.
- **Hydraulic energy**²: an energy source that harnesses the kinetic force of water movement to generate electricity.
- **Biomass energy:** refers to energy produced from organic matter, it offers significant potential for a sustainable energy transition if its exploitation is responsible and ecological.
- **Geothermal energy:** A type of thermal energy stored in the rocks and fluids beneath the Earth's surface. It can be accessed from shallow soil layers to several kilometers below the surface, and even deeper in extremely hot molten rock, known as magma.

The adoption of renewable energies is essential for fostering a more sustainable and prosperous future. Their use not only helps preserve the environment but also supports economic and social development. The significance of renewable energies can be summarized as follows:

¹ In Greek mythology, Aeolus is the master of the winds. From the name Eole derives the adjective “wind” and the noun “wind”. Aeolus - Wikipedia (wikipedia.org)

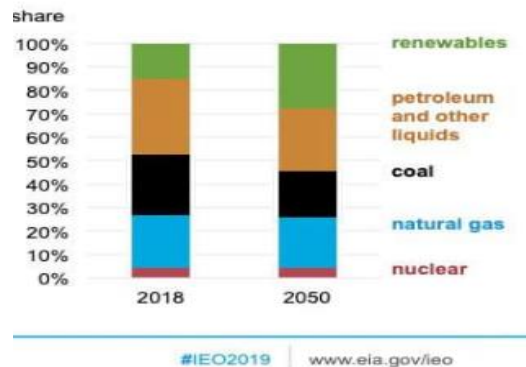
² A. W. Blakers and M. A. Green, (1986). 20-percent efficient silicon solar cell, Appl. Phys. Lett., vol. 48, P 215-217.

- They are a key strategy for reducing carbon emissions and advancing the energy transition from traditional sources to sustainable alternatives¹.
- They facilitate the creation of green jobs.

Figure 2. The types of renewable energy resources

- They decrease reliance on fossil fuels, helping to conserve limited resources like oil and natural gas.
- They reduce pollution by utilizing renewable technologies that produce less harmful waste.

The Energy Information Administration (EIA) projects that renewable energy will overtake oil as the leading primary energy source worldwide by 2050 (see the figure below).



Source: EIA (2019)

2. Sustainable development²:

The Brundtland Report, released in 1987 by the United Nations World Commission on Environment and Development, defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Given the worsening climate conditions, persistent pollution, and the overexploitation of natural resources, it is essential to adopt a new development model grounded in the principles of sustainable development, balancing environmental protection, social equity, and economic growth.

¹ Ari, I. Yikmaz, R.F (2019). The role of renewable energy in achieving Turkey's INDC. Renewable and sustainable Energy Reviews, P 105.

² <https://www.manutan.com/blog/fr/actualites/transition-energetique-et-developpement-durable-quels-enjeux-pour-les-entreprises>

Figure 3. The three pillars of sustainability



Source:

https://www.google.com/search?q=three+pillars+of+sustainable+development+pictures&oeq=&gs_lcrp=EgZjaHJybWUqCOgBECMYJxjqAjIJCAAQIxnGOoCMgkIARAJGCcY6gIyCOgCECMYJxjqAjIJCAMQIxnGOoCMgkIBBAjGCcY6gIyCOgFECMYJxjqAjIJCAYQIxnGOoCMgkIBxjGCcY6gLSAQ40NTQ2MjIyODEwajBqN6gCCLACAAQ&sourceid=chrome&ie=UTF-8#vhid=H8ToCiZOdFOk0M&vssid=mu2RZ-SeJOaK7NYPkqu78QI_38

Sustainable development aims to establish a sustainable model allowing everyone to live in a world of economic development, while guaranteeing a more equitable distribution of resources and preserving the planet's natural resources.

Sustainable development encompasses many issues:

- Fight against global warming
- Reduction of inequalities
- The guarantee of lasting economic growth
- Preserve natural resources
- Protect biodiversity
- Minimize greenhouse gas emissions

From the above, we conclude that sustainable development is essential for multiple reasons, all closely linked and essential to the well-being of our world and its inhabitants. And in this regard, renewable energies become the ideal alternative to preserve the environment and ensure a more sustainable future.

3. Impact of renewable energies on sustainable development: previous studies:

There has been a growing body of research in recent years centered on renewable energy and sustainable development. Numerous empirical studies have investigated the relationship between renewable energy development and sustainable development, which is widely considered the most viable path toward ensuring a sustainable future in the face of escalating environmental and economic challenges. A growing body of research confirms the beneficial link between renewable energy and sustainable development.

An overview of key studies and their findings:

Alavijeh et al. (2024)¹: Dissecting the Asymmetric Impact of Renewable Energy on Human Development: Evidence from Carbon Emissions, Economic Growth, and Urbanization in the EU: The study examined renewable energy consumption (REN), carbon dioxide emissions (CO₂), economic growth (GDP), and the urbanization rate (URB) as independent variables, with the Human Development Index (HDI) serving as the dependent variable. It employed regression of instantaneous quantities using the method of moments for EU countries (2000–2019). Findings: Positive relationships were observed between REN, GDP, and URB with HDI, while CO₂ emissions negatively affected HDI. Additionally, wealthier nations demonstrated greater capacity to finance renewable energy projects, enhancing human development.

Nguyen et al. (2023)²: "The Role of Renewable Energy Technologies in Enhancing Human Development: Empirical Evidence from Selected Countries" — This study explored the impact of renewable energy on the Human Development Index (HDI) across 77 countries, employing a panel-corrected standard error (PCSE) model over the period 2000–2019. The analysis considered renewable energy consumption, foreign direct investment (FDI), urbanization rate (URBAN), GDP growth rate (GDPGR), and the globalization index (GI) as independent variables. The study found a generally positive association between renewable energy consumption and the Human Development Index (HDI), though the strength of this relationship varied across countries. It highlighted the importance of adopting context-specific strategies based on income levels and patterns of renewable energy usage.

Haidy Amer (2020)³: This study employed a panel vector autoregression (PVAR) model to investigate the relationship between renewable energy consumption and human development. The Human Development Index (HDI) was used as the dependent variable, while renewable energy consumption (REC), energy intensity (EI), per capita CO₂ emissions (PCO₂), financial development (FD), and trade openness (TO) served as the independent variables. It analyzed data across countries with varying income levels. The findings revealed a positive relationship between renewable energy consumption (REC) and the Human Development Index (HDI) in low- and middle-income countries, whereas no such relationship was observed in middle- and high-income countries.

Wang et al. (2020)⁴: This research examined the relationship between renewable energy consumption and the Human Development Index (HDI) in BRICS countries over the period 1990–2016, utilizing cointegration and causality tests. The analysis

¹ Alavijeh, N, K, and al. (2024), «Asymmetric Impacts of Renewable Energy on Human Development: Exploring the Role of Carbon Emissions, Economic Growth, and Urbanization in European Union Countries», Journal of the Knowledge Economy, <https://doi.org/10.1007/s13132-024-01811-5>

² Nguyen, T, and al. (2023), «The role of renewable energy technologies in enhancing human development: Empirical evidence from selected countries», Case Studies in Chemical and Environmental Engineering, vol.8, 100496, <https://doi.org/10.1016/j.cscee.2023.100496>

³ Haidy, Amer. (2020), «The Impact of Renewable Energy Consumption on the Human Development Index in Selected Countries: Panel Analysis(1990-2015)», International Journal of Economy, Energy and Environment, Vol. 5, No. 4, P 47-68 <https://doi.org/10.11648/j.ijeee.20200504.12>

⁴ Wang, Z, et all. (2020), «The nexus between renewable energy consumption and human development in BRICS countries: the moderating role of public debt», Journal Pre-proof, <https://doi.org/10.1016/j.renene.2020.10.144>

incorporated GDP, renewable energy consumption (RNE), industrialization (IND), and public debt (DEB) as independent variables. Findings: Positive correlations were found between GDP, RNE, IND, and HDI. However, increased public debt negatively impacted HDI by reducing investments in human development sectors. Renewable energy consumption has a positive influence on the Human Development Index (HDI), a core component of sustainable development. However, the magnitude of this impact varies depending on a country's income level, stage of development, and the scale of investment in sustainable development initiatives.

II. The Applied Framework Using the ARDL Model

This study aims to evaluate the impact of renewable energy and other economic variables on human development in Denmark, employing the Autoregressive Distributed Lag (ARDL) approach, initially developed by Pesaran and Shin (1999) and later refined by Pesaran et al. (2001) and Shin et al. (2014). This model serves as a powerful analytical tool for examining both long-term and short-term dynamic relationships among economic variables.

Denmark, a global leader in renewable energy adoption, provides an exemplary case for analyzing these relationships. The study focuses on renewable energy as a central component of sustainable development, alongside factors such as trade, research and development expenditure, value-added manufacturing, and GDP.

Research Objectives:

- Analyze how renewable energy consumption influences human development in both the short and long term.
- Investigate co-integration among variables.
- Provide actionable recommendations to advance sustainable development.

The analysis uses annual data from reliable sources like the World Bank and international institutions, covering 1990–2023. This comprehensive approach offers an integrated perspective on the impact of renewable energy and economic factors on the Human Development Index (HDI)

The main variables included in the model are:

- **Human Development Index: (HDI)** It serves as the dependent variable in the model and measures the level of human development by capturing key dimensions such as education, health, and standard of living.
- **Renewable Energy: (RENP)** represents the ratio of energy produced from renewable sources to total energy consumption, and is an indicator of efforts made to achieve sustainable development.
- **Trade: (TRAD)** expresses the ratio of trade to GDP, and is considered an indicator of the openness of the economy to global markets.
- **Expenditure on Research and Development: (RDE)** measures the volume of investment in innovation and technical development, which contributes to improving economic efficiency.
- **Manufacturing added value: (MAV)** reflects the industrial sector's contribution to the economy, which is indicative of the level of manufacturing.

- **Gross Domestic Product: (GDP)** expresses the size of the economy and its general performance, and is a basic indicator in evaluating economic development.

Accordingly, the study model was formulated as follows:

$$\text{HDI} = f(\text{RENP}, \text{TRAD}, \text{RDE}, \text{MAV}, \text{GDP})$$

$$\text{HDI} = \beta_0 + \beta_1 \text{RENP} + \beta_2 \text{TRAD} + \beta_3 \text{RDE} + \beta_4 \text{MAV} + \beta_5 \text{GDP} + \mu_i$$

Based on the autoregressive lag distributed (ARDL) model, the general form of the equation becomes as follows:

$$\begin{aligned} \Delta \text{HDI}_t = & c + \beta_1 \text{HDI}_{t-1} + \beta_2 \text{RENP}_{t-1} + \beta_3 \text{TRAD}_{t-1} + \beta_4 \text{RDE}_{t-1} + \beta_5 \text{MAV}_{t-1} \\ & + \beta_6 \text{GDP}_{t-1} + \sum_{i=1}^p \alpha_i \Delta \text{HDI}_{t-i} + \sum_{i=1}^p \theta_i \Delta \text{RENP}_{t-i} + \sum_{i=1}^p \sigma_i \Delta \text{TRAD}_{t-i} \\ & + \sum_{i=1}^p \delta_i \Delta \text{RDE}_{t-i} + \sum_{i=1}^p \vartheta_i \Delta \text{MAV}_{t-i} + \sum_{i=1}^p \omega_i \Delta \text{GDP}_{t-i} + \mu \end{aligned}$$

First: unit root tests

Before starting to analyze the data, time series stability tests were conducted using the ADF and PP tests in order to ensure that all variables were stable to the zero degree (I(0)) or the first degree (I(1)) while ensuring that there was no integrated time series of the second degree until the condition of applying the ARDL model was met.

Table 1. ADF and PP tests were applied to assess stationarity.

As shown in Table 1, the Augmented Dickey-Fuller (ADF) test confirmed that all variables become stationary at the first difference, i.e., they are integrated of order I(1). The Phillips-Perron (PP) test yielded consistent results, indicating the same level of integration across all variables. Consequently, the use of the ARDL model is deemed appropriate for this analysis.

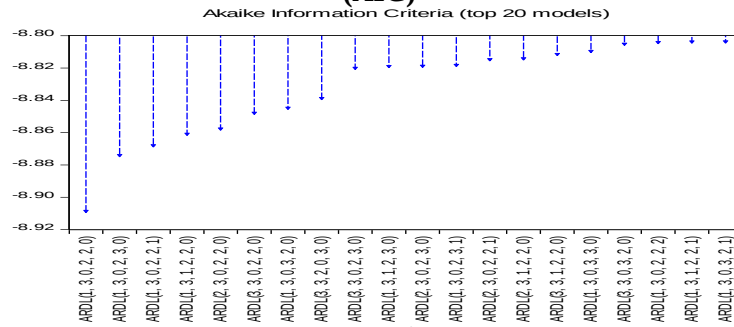
	LEVEL		1st difference		
	ADF	PP	ADF	PP	
HDI	-2.19 (0.21)	-2.57 (0.10)	-4.61 (0.00) ***	-4.61 (0.00) ***	I(1)
RENP	1.99 (0.99)	2.39 (0.99)	-5.88 (0.00) ***	-5.89 (0.00) ***	I(1)
TRAD	-0.05 (0.94)	1.51 (0.99)	-5.37 (0.00) ***	-7.59 (0.00) ***	I(1)
RDE	-1.21 (0.65)	-1.21 (0.65)	-5.11 (0.00) ***	-5.08 (0.00) ***	I(1)
MAV	-1.59 (0.47)	-1.59 (0.47)	-4.29 (0.00) ***	-4.33 (0.00) ***	I(1)
GDP	-0.84 (0.79)	-0.83 (0.79)	-5.07 (0.00) ***	-5.08 (0.00) ***	I(1)

Source: authors construction based on the output of Eviews 10

Second: Choosing the best lag periods for variables to estimate the ARDL model:

Choosing the best deceleration period according to the standard (AIC) according to the following figure:

Figure 1. Results of selecting the best idle intervals according to the standard (AIC)



Source: output of Eviews 10

Figure 1 indicates that the optimal ARDL model, based on the Akaike Information Criterion (AIC), is ARDL(1, 3, 0, 2, 2, 0).

Third: Bounds test:

Table No. (2) shows the results of the cointegration test using the bounds test methodology.

Table 2. Bounds testing

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	12.59554	10%	2.08	3
k	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

The results reveal that the computed F-statistic exceeds both the lower and upper critical bounds at the 10%, 5%, and 1% significance levels. Consequently, the null hypothesis of no cointegration is rejected in favor of the alternative hypothesis, which confirms the existence of a long-run equilibrium relationship between the independent variables and the Human Development Index (HDI).

Fourth: ARDL Model Estimation:

Table 3. ARDL model test results

Dependent Variable: HDI				
Method: ARDL				
Sample (adjusted): 1993 2023				
Included observations: 31 after adjustments				
Maximum dependent lags: 3 (Automatic selection)				
Model selection method: Akaike info criterion (AIC)				
Dynamic regressors (3 lags, automatic): RENP TRAD RDE MAV GDP				
Fixed regressors: C				
Number of models evaluated: 3072				
Selected Model: ARDL(1, 3, 0, 2, 2, 0)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
HDI(-1)	0.168617	0.134310	1.255429	0.2263
RENP	0.000848	0.000355	2.391325	0.0286
RENP(-1)	0.000462	0.000412	1.122781	0.2771
RENP(-2)	-0.000321	0.000450	-0.712507	0.4858
RENP(-3)	-0.001557	0.000378	-4.121728	0.0007
TRAD	0.000162	0.000175	0.925290	0.3686
RDE	0.010295	0.005842	1.762145	0.0960
RDE(-1)	-0.008251	0.007172	-1.150377	0.2659
RDE(-2)	0.020123	0.005375	3.743519	0.0016
MAV	0.000464	0.000935	0.496717	0.6258
MAV(-1)	0.005452	0.001641	3.323525	0.0040
MAV(-2)	-0.005547	0.001633	-3.397381	0.0034
GDP	0.163701	0.028748	5.694414	0.0000
C	-3.602808	0.650123	-5.541733	0.0000
R-squared	0.996494	Mean dependent var	0.911097	
Adjusted R-squared	0.993813	S.D. dependent var	0.030751	
S.E. of regression	0.002419	Akaike info criterion	-8.908682	
Sum squared resid	9.95E-05	Schwarz criterion	-8.261074	
Log likelihood	152.0846	Hannan-Quinn criter.	-8.697578	
F-statistic	371.6976	Durbin-Watson stat	2.574296	
Prob(F-statistic)	0.000000			

Source: output of Eviews 10

It is noted from Table No. (3) that the explanatory power of the coefficient of determination (R-squared) for this model reached 99.64%, meaning that the independent variables explain 99.64% of the changes occurring in the Human Development Index, and the rest of the percentage is due to other factors that were not included in the model.

Fifth: Model diagnostic tests:

Prior to estimating the long- and short-term relationships, it is necessary to perform a diagnostic test to identify any potential autocorrelation in the residuals—specifically, the Serial Correlation LM Test. The presence of autocorrelation would indicate model misspecification, rendering the proposed model unsuitable for examining the relationships among the study variables. The model's validity is further evaluated through diagnostic tests for autocorrelation, stationarity, the normality of residuals, and overall model specification.. These tests are essential for confirming the model's validity and reliability.

A. Detecting the absence of an autocorrelation problem between the estimated residuals:

Table 4. Autocorrelation test between the residuals

Breush-Godfrey serial correlation LM Test			
F-statistic	1.22	Prob. F(2.15)	0.32
Obs*R-squared	4.34	Prob. Chi-Square(2)	0.11

Source: Construction by the authors based on the EViews 10 output

As shown in Table 4, the results of the LM Test reveal a Fisher probability value of 0.32, which exceeds the 5% significance level. This allows us to accept the null hypothesis, "There is no autocorrelation in the residuals," and reject the alternative

hypothesis, "There is autocorrelation in the residuals." Consequently, the estimated model is deemed free from autocorrelation issues.

four. Contrast non-stationarity test:

Table 5. ARCH test

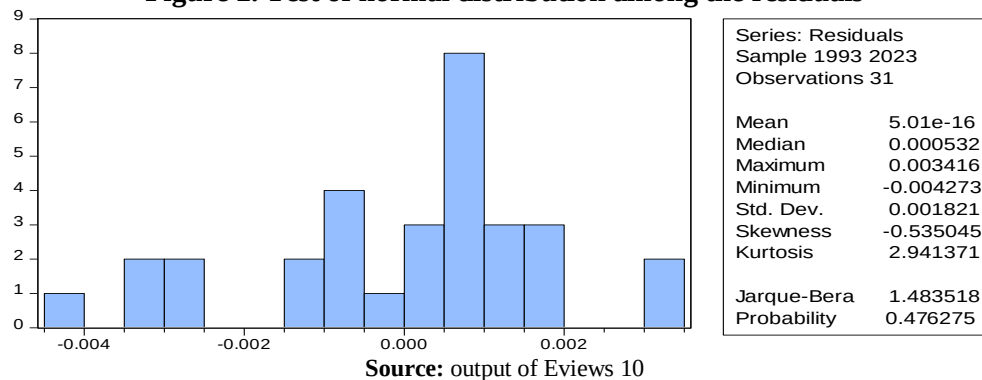
Heteroskedasticity Test ARCH			
F-statistic	0.82	Prob. F(1,28)	0.37
Obs*R-squared	0.86	Prob. Chi-Square(1)	0.35

Source: : Construction by the authors based on the EViews 10 output

The results of the ARCH test indicate a Fisher probability value of 0.37, which exceeds the 5% significance level. As a result, we accept the null hypothesis of "constant variance" and reject the alternative hypothesis. Therefore, the residuals do not exhibit heteroscedasticity (variance instability).

C. Testing for normality in the residuals:

Figure 2. Test of normal distribution among the residuals



As shown in the figure above, the Jarque-Bera probability value is 0.47, which exceeds the 5% significance level. Therefore, we conclude that the residuals of the regression estimate follow a normal distribution.

D. Model description

Table 6. Model description

Ramsey RESET Test			
	Value	Df	Probability
t-statistic	0.24	16	0.81
F-statistic	0.05	(1,16)	0.81

Source: authors construction based on the output of Eviews 10

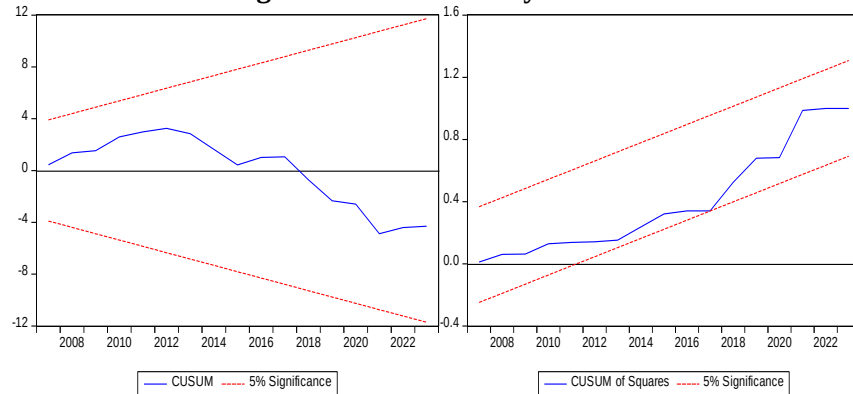
As shown in Table 6, the probability value of 0.81 exceeds the 5% significance level, confirming the acceptance of the null hypothesis: "The model is adequately and correctly specified."

Sixth: Model stability test:

To ensure that the data used in this study are free from structural changes, appropriate tests must be conducted, such as the Cumulative Sum of Residuals (CUSUM) and the Cumulative Sum of Squares of Residuals (CUSUM of Squares). Structural stability of

the estimated coefficients in the error correction model for the autoregressive distributed lag (ARDL) model is confirmed if the CUSUM and CUSUM of Squares test graphs remain within the critical limits at the 5% significance level.

Figure 3. Model stability test



Source: output of Eviews 10

As observed in Figure No. (3), both the Cumulative Sum of Recursive Residuals (CUSUM) test and the Cumulative Sum of Squares of Recursive Residuals (CUSUM of Squares) test remain within the critical region boundaries. This suggests that the model is stable at the 5% significance level. The results of these tests confirm the model's stability, ensuring consistency between the long-term and short-term outcomes.

Seventh: Results of estimating the relationship in the long and short term:

After ensuring that the model is safe from structural problems related to serial correlation and stability, we will conduct a test Long and short term.

Table 7. Results of estimating the relationship:

In the short run				In the long run			
Variable	Coefficient	t-Statistic	Prob	Variable	Coefficient	t-Statistic	Prob
REN	0.015	2.96	0.00	D(REN)	0.0008	2.39	0.02
TRAD	0.32	0.65	0.51	D(REN (-1))	0.0003	0.71	0.48
RDE	0.02	4.54	0.00	D(REN (-2))	0.0015	4.12	0.00
MAV	0.0004	0.28	0.77	D(TRAD)	0.0001	0.92	0.36
GDP	0.19	11.27	0.00	D(RDE)	0.01	1.76	0.09
C	-4.33	-9.89	0.00	D(RDE (-1))	-0.02	-3.74	0.00
				D(MAV)	0.0004	0.49	0.62
				D(MAV (-1))	0.005	3.39	0.00
				D(GDP)	0.16	5.69	0.00
				CointEq (-1)	-0.83	-6.19	0.00

Source: authors construction based on the output of Eviews 10

The estimation results of the ARDL model showed that: He findings from the study are summarized as follows:

- **Renewable Energy (REN) and Human Development Index (HDI):**

Renewable energy has a significant positive impact on the Human Development Index (HDI) in both the short and long term, with results significant at the 5% level. The long-term coefficient for renewable energy is positive and significant, at 0.015%,

indicating that a 1% increase in renewable energy usage results in a 0.015% improvement in HDI. In the short term, the effect is smaller, with a coefficient of 0.0008%. The increased consumption of renewable energy helps reduce air pollution, enhance environmental quality, and create new job opportunities, all of which contribute to better health and living standards, ultimately improving the HDI.

- **Research and Development (RDE) and HDI:** Expenditure on research and development (RDE) has a positive and significant impact on the Human Development Index (HDI). A 1% increase in RDE spending results in a 0.02% increase in HDI in the long term, and a 0.01% increase in the short term. The innovation and technological advancements driven by such investments directly enhance human development by improving quality of life and fostering social progress.

- **Trade (TRAD) and HDI:** The relationship between trade and the Human Development Index (HDI) was found to be positive but insignificant in both the long and short term at the 5% significance level. This indicates that while trade can contribute to economic opportunities and enhance living standards in terms of quality of life, it is not a primary driver of human development improvements when compared to other factors.

- **Gross Domestic Product (GDP) and HDI:** A positive and significant relationship exists between GDP and the Human Development Index (HDI) in both the short and long term. A 1% increase in GDP leads to a 0.19% improvement in HDI over the long term and a 0.16% improvement in the short term. An increase in GDP raises income levels, providing new resources for investments in critical sectors like health and education, directly improving human development.

- **Manufacturing Value Added (MAV) and HDI:** The relationship between manufacturing value added and HDI is positive but insignificant in the long term and shows a slight positive impact in the short term. This suggests that the manufacturing sector may not be as closely aligned with sustainable development goals, such as health, education, and income, when compared to other sectors.

- **Error Correction Coefficient (CointEq (-1)):** The coefficient of error correction was negative and significant at -0.83, indicating that the system adjusts for errors and deviations within less than a year, ensuring the stability of the model.

Diagnostic Tests :

- **Autocorrelation:** The Breush-Godfrey test showed no autocorrelation between model residuals, confirming the accuracy of estimates.
- **Variance Stability:** The ARCH test confirmed the variance stability of the model.
- **Normal Distribution:** The Jarque-Bera test confirmed that the residuals are normally distributed.
- **Model Stability:** The CUSUM and CUSUM of Squares tests confirmed the stability of the estimated coefficients over time.

Hypotheses Validation :

- **Long-Term Equilibrium Relationship:** The Bounds Test indicates the existence of a long-run relationship among the independent variables (RENP, RDE, GDP) and HDI, validating the first hypothesis.
- **Impact of Renewable Energy and Research Spending on HDI:** The significant positive relationship between renewable energy consumption and

RDE spending with HDI, both in the short and long term, confirms the second hypothesis.

- **Importance of GDP and Manufacturing for Sustainable Development:** GDP has a strong and direct impact on HDI, confirming its importance for sustainable development. However, the impact of value-added manufacturing on HDI is limited and inconsistent, partially confirming the third hypothesis. The manufacturing sector needs further development to have a more significant role in sustainable development.

Based on the results obtained, several important points can be concluded regarding the Danish economy:

- **Focus on renewable energy:** The results revealed that renewable energy influences on human development in both the short and long term. This reflects Denmark's success in adopting sustainable energy policies, which enhance the quality of life. It is recommended to continue investing in renewable energy projects, especially in the areas of wind and solar, while improving the related infrastructure.
- **The importance of research and development:** The study highlights that spending on research and development is a major driver of human development. It is necessary to increase allocations to research and development, with a focus on innovation in clean technology and sustainable industries. These investments could enhance Denmark's competitiveness on a global level.
- **The role of GDP:** GDP is one of the factors that positively influence human development. Economic policies should be adopted that promote economic growth while maintaining a balance between economic efficiency and environmental sustainability.
- **Improving value added in manufacturing:** Although the impact of value added in manufacturing has been limited in the long term, promoting sustainable manufacturing can contribute to achieving development goals. It is recommended to encourage clean industries and increase reliance on technological innovation in the manufacturing sector.
- **International trade:** The results indicate a weak impact of international trade on human development, which calls for a re-evaluation of trade policies. Denmark can strengthen the role of trade in development by diversifying trading partners and increasing high value-added exports.

Conclusion:

In a world of ongoing environmental and economic transformation, renewable energy serves as a key strategy to strike a balance between development and environmental sustainability. Renewable energy provides a critical opportunity for achieving sustainable development by meeting the current social needs without compromising the ability of future generations to meet their own needs. As such, the advancement of renewable energy is closely tied to sustainable development. Consequently, authorities must increase investments in this sector while fostering innovation in clean energy technologies.

Recommandations :

1. **Supporting innovation in renewable energy:** Encouraging research and development in renewable energy technologies, including advancements in energy storage solutions and enhancing the efficiency of wind turbines.
2. **Stimulating private investments:** Providing tax incentives and soft loans to companies that invest in renewable energy projects.
3. **Encouraging international partnerships:** Cooperating with other countries to exchange experiences in the field of developing and disseminating sustainable energy technologies.
4. **Community awareness:** Implementing awareness campaigns to enhance citizens' awareness of the importance of using renewable energy and sustainable practices.
5. **Expanding green infrastructure:** Building more efficient and flexible energy transmission and distribution networks, with a focus on integrating renewable energy sources.
6. **Adopting long-term policies:** developing national strategies aimed at achieving a higher percentage of reliance on renewable energy by 2030, while monitoring its role in improving human development indicators.

These recommendations demonstrate that promoting sustainable development requires concerted efforts between government policies and the private sector, with a focus on innovation and sustainability to ensure a sustainable improvement in quality of life.

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