Journal of Agricultural Science and Technology (2026) Vol. 28(3): 521-535

Energy Consumption Patterns, Environmental Sustainability and Human Development Outcomes in Iran

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ABSTRACT

A major goal of this study was to document how renewable and non-renewable energy consumption is related to human development in Iran. For this purpose, all variables were tested for structural breaks using the breakpoint unit root test. Additionally, long-run relationships are examined using the Auto-Regressive Distributed Lag (ARDL) bounds test. The outcomes of the diagnostic tests showed that the panel ARDL model parameters were stable, predictable, and reliable in the long term. Significant positive and negative relationships were found between renewable and non-renewable energy consumption and the Human Development Index (HDI), respectively. Additionally, the elasticity of renewable energy consumption was lower than that of non-renewable energy consumption. Human development in Iran has also been enhanced by CO_2 emissions. Conversely, economic growth and increased trade transparency would lower the HDI in Iran. To improve human development in Iran, energy consumption as well as clean energy production and consumption should be considered.

Keywords: Auto-Regressive Distributed Lag, Human Development Index, Non-renewable energy, Renewable energy.

INTRODUCTION

Economic growth is crucial for decreasing poverty and increasing resources for environmental and human development. However, economic growth alone does not reflect other aspects such as social health and welfare. To address this gap, Sen (2016) introduced the Human Development Index (HDI). Three factors, health and longevity (determined by life expectancy at birth), level of education (determined by average and expected years of education), and standard of living (determined by gross national income per capita), were used to calculate the HDI (Xu *et al*., 2024; Sarwar *et al*., 2024) with a range from 0 to 1 for individual countries (Chou *et al*., 2024). Hence, a high standard of living is achieved through human development, providing people with equal opportunities and fair choices so that they can live longer and receive better health care and education.

Nonetheless, economic growth and social development are impossible without energy consumption (Dehbidi *et al*., 2022; Gershon *et al*., 2024) because energy contributes to every aspect of human life (Sadorsky, 2009). In addition, energy, especially new energy, has always been considered the engine of economic growth. Therefore, human well-being depends on energy consumption and access to energy is a prerequisite for higher growth. However, the long-term effects of traditional energy use on human well-being

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are unclear. There is ongoing debate over whether non-renewable energy consumption will have negative effects over time. Sustained growth requires sustainable energy consumption.

On the other hand, the primary source of greenhouse gas emissions that pollute the environment is non-renewable energy consumption (Khan *et al*., 2019). Fossil fuels, as high energy intensity, are the most consumed source of energy worldwide, negatively impacting human health and welfare, driving carbon dioxide emissions and environmental degradation (Zafar *et al*, 2019; Danish *et al*, 2017). Consumption of fossil fuels has negative effects on economic growth, and associated climate change, global warming, and health problems (Yang, 2025). This has led countries to commit to reducing their greenhouse-gas emissions under the Paris Agreement.

As fossil energy reserves deplete and CO_2 emission rises, a shift to renewable energy sources has become increasingly necessary. Furthermore, the main principle of the worldwide energy security framework is the efficient utilization of non-renewable energy resources along with the gradual rise in the proportion of renewable energy sources (An and Mikhaylov, 2020). Therefore, renewable energy is crucial for the development of energy policies to combat climate change (Krechko and Mikhaylov, 2025). Any country can benefit from using renewable energy, and a sustainable economy must transition from non-renewable to renewable energy sources.

Increasing renewable energy sources, such as clean energy and low-carbon energy, are becoming an integral part of the energy supply system. The key role of this energy group is to reduce greenhouse gas emissions, such as CO_2. In 2023, renewable energy had a consumption share of 20% of global energy, but this share is expected to increase to 60% by 2050 (IEA, 2024). Increasing the use of renewable energy is a key element of sustainable development and will help countries achieve their economic, social, and environmental goals. They contribute to economic growth, employment, energy supply security, global warming reduction, and environmental improvements. A clear link exists between renewable energy, carbon dioxide, and greenhouse gas emission reduction. Although renewable energy can contribute to human development, its impact is not completely clear (Wang *et al*., 2020).

Among the Middle Eastern countries, Iran ranks second in terms of energy resources. Solar, wind, geothermal, and electricity are Iran's clean energy sources, in addition to natural gas and crude oil. Iran's five-year development plan emphasizes that fossil fuel extraction should be reduced and renewable resources should be widely used because of unstable oil reserves and environmental pollution (Ghorashi and Rahimi, 2011). An overview of Iran's share of renewable energy is presented in Figure 1.

From 1990 to 2020, Iran's renewable energy usage averaged 0.97 percent, with a maximum of 1.52 percent and minimum of less than 0.5% in 1993 and 2000, respectively. In 2020, it was 1.03 percent (Figure 1). The world average in 2020 was 19.77% (based on 196 countries). It is clear from this trend that Iran's goal of replacing fossil fuels with renewables requires serious planning. Based on Figure 2, Iran's average Human Development Index (HDI) was 0.71 (from 1990 to 2020), with a minimum of 0.60 in 1990 and a maximum of 0.79 in 2017. In 2020, the Iranian HDI reached 0.77. The global average HDI of the 189 countries was 0.73 in 2020.

Following Kraft and Kraft (1978), this study begans by reviewing the impact of energy use on economic growth. As the empirical literature in this area grows, each study seeks to add new, more comprehensive perspectives to relevant research. Subsequently, it was decided to divide the types of energy into renewable and non-renewable energy and evaluate their impact on economic growth. Furthermore, economic growth indicators were comprehensively considered when completing these studies. A review of the

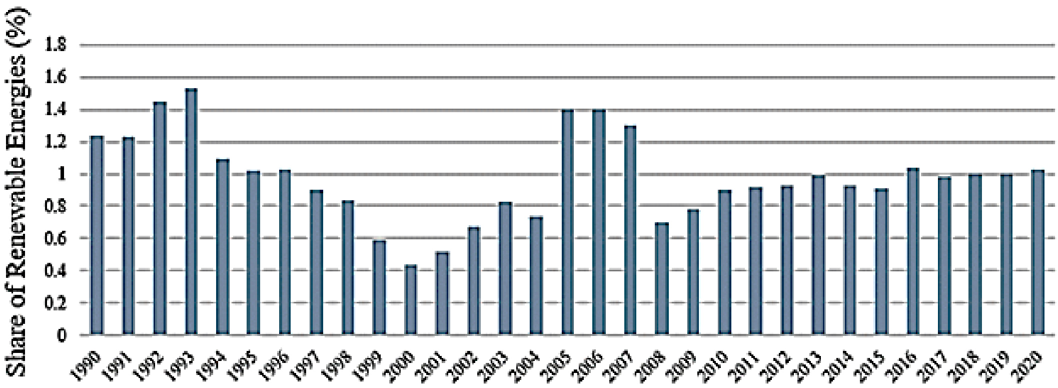

Figure 1. Share of renewable energies in Iran during 1990 to 2020.

studies also showed that the results were very different (Rahman, 2017) and that the disagreement between researchers in this regard was very clear (Apergis and Payne, 2012; Salim *et al*., 2014; Shahbaz. *et al*., 2020). Therefore, continuation of the related research on this subject will increase. Table 1 provides a summary of studies on the energy use and HDI nexus. Some researchers have focused only on the renewable energy use and HDI nexus. Pirlogea (2012) studied the nexus between energy and human development and concluded that renewable and non-renewable energies impact human development differently. In addition, Ouedraogo (2013) showed that higher electricity consumption decreases human growth and the HDI. According to Abdullah and Morley (2014), developed countries use considerable resources to produce clean energy, instead of allocating them to non-renewable sources. Wang *et al*. (2018) concluded that renewable energy does not improve human development in Pakistan. Furthermore, the results showed that carbon emissions improved the HDI. Trade openness is an obstacle to human development in Pakistan. Hashemizadeh *et al*. (2022) showed that GDP, urbanization, energy use, and globalization directly affect the HDI of G-7 countries. On a global scale, Adekoya *et al*. (2021) showed that renewable and clean energy adversely affects HDI in the MENA region, Central America, and the Caribbean. In addition, renewable energy has a significant impact on Europe's HDI, whereas it has relatively little impact in sub-Saharan Africa. In more recent studies, Kaewnern *et al*. (2023) demonstrated that renewable energy consumption, economic growth, total natural

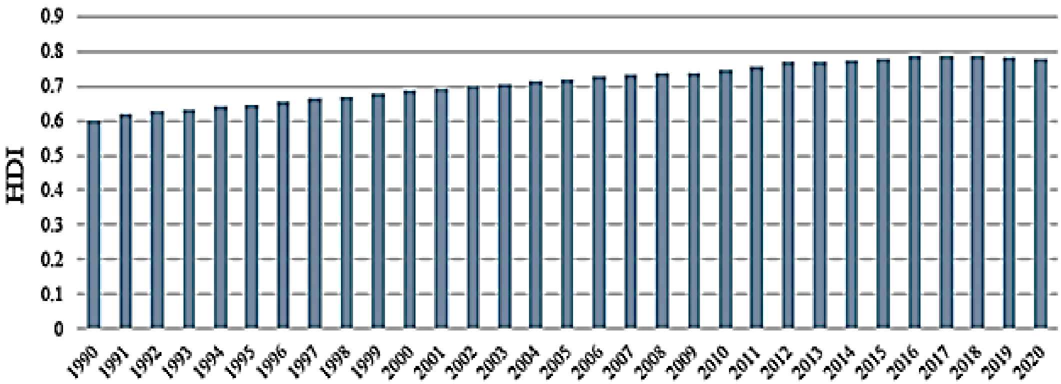

Figure 2. The trend of HDI in Iran during 1990 to 2020.

Table 1. Summary of studies modeling the link between HDI and energy.

No.	Author	Time period	Region	Variables
1	Mazur (2011)	1980-2006	21 industrialized countries	HDI, electricity consumption, energy consumption
2	Pirlogea (2012)	1997-2008	6 European states	HDI, renewable energy, fossil fuel consumption, CO_2, energy intensity
3	Nui *et al*. (2013)	1990-2009	50 countries	electricity consumption and five human development indexes
4	Ouedraogo (2013)	1988-2008	15 developing countries	HDI, electricity consumption
5	Kazar and Kazar (2014)	1980-2010	154 countries	HDI, renewable electricity
6	Sinha and Sen (2016)	980-2013	BRIC countries	HDI, GDP, CO_2 emission, trade
7	Soukiazis *et al*. (2017)	2004-2015	28 OECD countries	HDI, CO_2 emissions, R&D, human and physical capital.
8	Wang *et al*. (2018)	1990–2014	Pakistan	HDI, GDP, renewable energy consumption, CO_2 emissions
9	Soukiazis *et al*. (2019)	2004–2015	28 OECD countries	HDI, renewable energy, human and physical capital, R&D, CO_2 emissions
10	Sasmaz *et al*. (2020)	1990-2017	28 OECD	HDI, Renewable Energy
11	Amer *et al*. (2020)	1990-2015	101 countries	HDI, renewable energy, CO_2, energy intensity, financial development, trade openness
12	Azam *et al*. (2021)	1990-2017	30 developing countries	HDI, GDP, CO_2, information and communication technologies, renewable energy, remittances.
13	Basri *et al*. (2021)	1990-2015	Bangladesh	HDI, GDP, renewable energy consumption, CO_2, urbanization, liberalization trade
14	Wang *et al*. (2021)	1990-2016	BRIC countries	HDI, GDP, renewable energy consumption, public debt, Industrialization
15	Lekana and Ikiemi (2021)	1990-2019	EMCCA countries	HDI, CO_2 emissions, energy consumption, renewable energy consumption, public investment, private investment, external debt, human capital, Inflation.
16	Adekoya *et al*., (2021)	2000 to 2014	126 countries	HDI, GDP, renewable energy consumption, CO_2
17	Hashemizadeh *et al*. (2022)	1990–2015	G-7 countries	HDI, renewable and non-renewable energy consumption, urbanization, globalization, and economic growth
18	Acheampong *et al*. (2021)	1990–2018	79 countries	HDI, economic growth, trade openness, foreign direct investment, urbanization, access to credit and remittance, employment, industrialization, economic growth, ICT
19	Kaewnern *et al*. (2023)	1996–2007	10 human development countries	HDI, economic growth, renewable energy consumption, research and development expenditure, and natural resource rent
20	Nguyen *et al*. (2023)	2000–2019	77 countries	HDI, economic growth, renewable energy consumption, urbanization, financial development index
21	Karimi Alavijeh *et al*. (2024)	2000–2019	European Union countries	HDI, economic growth, CO_2, renewable energy, and urbanization
22	Metwally *et al*. (2024)	2002–2021	Nordic countries	HDI, economic growth, renewable energy, trade openness and urbanization
23	Tong (2024)	2000–2019	China	HDI, energy use, economic growth, urbanization, and greenhouse gas emissions

resources rent, and development expenditure tested positive on the HDI in the top ten human development countries. In addition, Nguyen *et al*. (2023) reveal a positive link between renewable energy and human development across three dimensions–education, health, and income–across 77 countries, including high-income and 33 middle-income countries. This connection holds for various renewable sources such as solar, hydropower, and wind energy. Moreover, Metwally *et al*. (2024) demonstrated that renewable energy (hydroelectricity) in Nordic countries has significant effects on human development, with negative impacts in the short term and positive impacts in the long term. Also, Tong (2024) finds a significant relationship among HDI, energy use, and greenhouse gas emissions over time in China.

According to the above discussion, there is no consensus among studies on the impact of different kinds of energy consumption on HDI. Although little research has been conducted on the effect of renewable energy consumption on human development, scientists cannot agree on the definitive impact of renewable energy, which serves as the basis for this study.

To determine whether energy consumption (both renewable and non-renewable) affects human development in Iran, this study examines that impact. To address gaps in previous research, this study aimed to ascertain whether energy sources (renewable and non-renewable) significantly affect human development. It is also important to note that there are still no answers to the key research questions in some areas, such as Iran. Therefore, this study is the first to investigate how renewable energy influences human development in Iran. Iran's planners and policymakers can utilize the findings of this study to enhance people's quality of life and foster sustainability through improved health care and higher education. Therefore, the paper makes a new and original contribution by focusing specifically on the context of Iran, a country with distinct energy and welfare challenges and opportunities.

MATERIALS AND METHODS

Variables in the Model

To examine the impact of energy use (renewable and non-renewable) on Iran's human development, various variables were evaluated. From the Human Development Report, data were compiled annually for the HDI from 1990 to 2018. A number of other variables, including GDP per capita, openness of trade, availability of energy sources (renewable and non-renewable), and the amount of greenhouse gas emissions per capita can also be derived from the World Development Indicators (WDI). Table 2 introduces the model variables.

METHODOLOGY

Model specification

According to Wang *et al*. (2018), Nguyen *et al*. (2023), and Karimi Alavijeh *et al*. (2024), Equation (1) explores the relationship between HDI and renewable and non-renewable energy use.

$$HDI = f(CO_{2t}, GDP_t\ , FOS_t\ , REN_t\ , TO_t\ ) \quad (1)$$

Where, t represents time. The empirical model can be expressed using Equation (2):

$$HDI = aCO_{2t}^{\beta 1} GDP_t^{\beta 2} FOS_t^{\beta 3} REN_t^{\beta 4} TO_t^{\beta 5} \quad (2)$$

Equation 3 expresses the natural logarithm specification of the empirical equation:

$$LnHDI = \alpha_0 + \beta_1 LnCO_{2t} + \beta_2 LnGDP_t\ + \beta_3 LnFOS_t\ + \beta_4 LnREN_t\ + \beta_5 LnTO_t\ + \varphi_t \quad (3)$$

Where, Ln is the natural logarithm and φ is the residual of the regression. Furthermore, parameter β indicates the long-term elasticity of each variable.

Table 2. The model variables.

Variables	Symbol	Definition	Unit	Data source
Human Development Index	HDI	Measured by health, education and standard of living	Unit free	Human development report
Per capita CO_2 emissions	CO_2	The ratio of CO_2 emissions and the total population	Metric tons per capita	WDI
Per capita GDP	GDP	The ratio of GDP and total population	PPP (constant 2017 international $)	WDI
Per capita non-renewable energy consumption	FOS	The ratio of non-renewable energy use and the total population	Gigajoule per capita	WDI
Per capita Renewable energy consumption	REN	The ratio of renewable energy use and the total population	Gigajoule per capita	WDI
Trade Openness	TO	The share of total import and export of goods and services value in GDP	Percent	WDI

In Equation 3, a positive correlation exists between HDI and economic growth in developed countries. In contrast, a negative relationship between HDI and GDP has been observed in some developing countries (Mustafa *et al.*, 2017; Saha and Zhang, 2017; Wang *et al.*, 2018). A positive coefficient is expected for renewable energy use, whereas a negative coefficient is expected for non-renewable energy use. There was no clear link between HDI and TO. Positive signs are expected if trade openness helps HDI. Conversely, trade openness correlates negatively with the HDI if unplanned trade development is led by low official capacity. CO_2 emissions can worsen human development. Therefore, the expected sign of β1 is negative.

Econometric Methodology

The effect of the independent variables on the HDI was examined using the ARDL method, which is a unique co-integration method developed by Pesaran (1997), Pesaran and Shin (1998), and Pesaran *et al*. (2001). The ARDL method has several advantages over other co-integration methods. Unlike other methods, this method utilizes stationary mixed degrees (I(0) and I (1)) of the variables (Behjat and Tarazkar, 2021). For this reason, the stationary variables using the unit root test are survived by Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF) test. These two tests are widely used in time series data (Mikhaylov and Bhatti, 2025). The ARDL Formulation is given by Equation 4.

$$\Delta LnHDI_t = \alpha_0 + \alpha_1 lnHDI_{t-1} + \alpha_2 LnCO_{2\,t-1} + \alpha_3 LnGDP_{t-1} + \alpha_4 LnFOS_{t-1} + \alpha_5 LnREN_{t-1} + \alpha_6 LnTO_{t-1} + \sum_{i=1}^{p} \beta_i \Delta lnHDI_{t-i} + \sum_{j=0}^{q} \beta_j \Delta lnCO_{2\,t-j} + \sum_{k=0}^{r} \beta_k \Delta lnGDP_{t-k} + \sum_{l=0}^{s} \beta_l \Delta lnFOS_{t-l} + \sum_{m=0}^{v} \beta_j \Delta lnREN_{t-m} + \sum_{n=0}^{w} \beta_j \Delta lnTO_{t-n} + \mu_t \quad (4)$$

Where, the optimal lag lengths of the dependent and independent variables are p, q, r, s, v, and w. The Schwarz Bayesian Criterion (SBC), Akaike Information Criterion (AIC), and Hannan-Quinn Criterion (HQC) criteria can be applied (Pesaran *et al*., 2001). However, the SBC method is preferred over HQC and AIC for small sample sizes (Pesaran and Shin, 1998; Fatai *et al*, 2003). Equation (4), Δ and μ are the first differences between the variables and error term, respectively. The F-statistic was also used to determine whether the independent and dependent variables of the model were related over time. Equation (5) represents the null and alternative hypotheses. In the null hypothesis, no long-term relationship was assumed.

$$\begin{cases} H_0: \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0 \\ H_1: \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq 0 \end{cases} \quad (5)$$

The F-statistics show a long-term relationship when the null hypothesis is rejected. In contrast, if the null hypothesis is not rejected, there is no long-term relationship between the variables (Pesaran *et al*, 2001). Equation (6) describes the long-term model.

$$LnHDI_t = \alpha_0 + + \sum_{i=1}^{p} \beta_i lnHDI_{t-i} + \sum_{j=0}^{q} \beta_j lnCO_{2\,t-j} + \sum_{k=0}^{r} \beta_k lnGDP_{t-k} + \sum_{l=0}^{s} \beta_l lnFOS_{t-l} + \sum_{m=0}^{v} \beta_j lnREN_{t-m} + \sum_{n=0}^{w} \beta_j lnTO_{t-n} + \mu_t \quad (6)$$

In addition, Equation (7) illustrates the ARDL-ECM or short-run version of ARDL.

$$\Delta LnHDI_t = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta lnHDI_{t-i} + \sum_{j=0}^{q} \beta_j \Delta lnCO_{2\,t-j} + \sum_{k=0}^{r} \beta_k \Delta lnGDP_{t-k} + \sum_{l=0}^{s} \beta_l \Delta lnFOS_{t-l} + \sum_{m=0}^{v} \beta_j \Delta lnREN_{t-m} + \sum_{n=0}^{w} \beta_j \Delta lnTO_{t-n} + \delta ECM_{t-1} + \mu_t \quad (7)$$

(ECM_{t-1}) is the error-correction coefficient. Additionally, the stability of the estimated coefficients was assessed using the CUSUM and CUSUMSQ.

RESULTS

An overview of the variables is given in Table (3).

Between 1990 and 2018, Iran's average carbon dioxide emissions per capita were 6.02 metric tons, with a minimum of 3.17 metric tons in 1990 (first value) and a maximum of 7.88 metric tons in 2014. A survey of GDP per capita from 1990 to 2018 showed that the average amount was 11503 $, with a minimum of 8630.8 $ in 1990 and a maximum of 14535.8 $ in 2017. The last amount of GDP was 13471.8 $. In comparison, the global average in 2018 for 196 countries was $ 166037.9 dollars (WDI, 2021). Iran's average trade openness was 44.24%, with a low of 29.22% in 1998 and a high of 65.05% in 2018. The WDI estimated global trade openness at 57.70% in 2018 for 186 countries. The average annual non-renewable energy consumption in Iran is 6.67 gigajoules, compared to 0.06 gigajoules for renewable energy. As of 2018, renewable energy was consumed in 0.11 units and non-renewable energies at 11.30 units per capita. Table (4) shows the results of breakpoint unit root tests.

As shown in Table 4, two structural breakpoints were found in 2004 and 2005 in Iran. During this period, fundamental changes began to occur in the Iranian educational system. These include increasing the number of universities and institutes in educational centers. Therefore, a dummy variable was added to the empirical model of Iran, with one for 2003 and 2005 and zero for all other years. As stated above, the ARDL method requires integration of degrees zero, I(0), and one I(1). Table 5 presents the results of the stationary test.

Table 3. Variables summary statistics.

Variables	HDI	CO_2	GDP	FOS	REN	TO
Mean	0.691	6.022	11503.11	6.673	0.064	44.247
Median	0.678	6.087	11764.10	6.538	0.050	43.770
Maximum	0.787	7.883	14535.87	11.305	0.113	65.050
Minimum	0.565	3.179	8630.835	2.879	0.022	29.228
Std. Dev.	0.068	1.552	1869.450	2.656	0.029	7.510
Skewness	-0.086	-0.236	0.040	0.114	0.280	0.353
Kurtosis	1.780	1.520	1.460	1.618	1.539	3.559
Jarque-Bera	1.834	2.915	2.871	2.369	2.958	0.983
Probability	0.399	0.232	0.237	0.305	0.227	0.611

Note: Symbols of HDI, CO_2, GDP, FOS, REN, and TO represent Human Development Index, Per capita CO_2 emissions, Per capita GDP, Per capita non-renewable energy consumption, Per capita Renewable energy consumption, and Trade Openness, respectively.

Table 4. Endogenous breakpoints unit root test

Variables	Break date	ADF test (T-stat)	Result
LnHDI	2005	-9.180***	Stationary at level with break point
$LnCO_2$	2002	-4.411	Not stationary
LnGDP	2002	-3.753	Not stationary
LnFOS	1999	-1.831	Not stationary
LnREN	2004	-4.631**	Stationary at level with break point
LnTO	2002	-4.013	Not stationary

*** and **: Represent significance at the 1 and 5% levels, respectively.

Table 5. Results of stationary tests.[a]

Unit root test	ADF test	PP test	Result
	t-stat	t-stat	
Level			
LnHDI	-2.476	-2.476	Non-stationary
$LnCO_2$	-1.465	-1.591	Non-stationary
LnGDP	-1.831	-1.899	Non-stationary
LnFOS	-1.407	-1.137	Non-stationary
LnREN	-2.058	-2.144	Non-stationary
LnTO	-2.271	-1.974	Non-stationary
First difference			
Δ(LnHDI)	-	-5.262***	I(1)
$\Delta(LnCO_2)$	-	-6.407***	I(1)
Δ(LnGDP)	-	-4.738***	I(1)
Δ(LnFOS)	-	-7.620***	I(1)
Δ(LnREN)	-	-4.438***	I(1)
Δ(LnTO)	-	-3.986**	I(1)

[a] I(0) denotes that the variable is stationary at level, and I(1) denotes that the variable is stationary after the first difference. *** and **: Represent significance at the 1 and 5% levels, respectively.

As shown in Table 5, no variable is integrated with a degree greater than I (1). Therefore, the ARDL method is suitable for estimating the co-integration relationship between the model variables. The co-integration bound test was used to determine whether the econometric model co-integrated. Table 6 shows the analysis results of ARDL co-integration.

Table 6 shows that F-statistic (5.473) is statistically significant at the 1% level of probability. As a result, the variables of the model have a long-run relationship. Also, the optimal lag length in the ARDL is derived using SBC criteria. Models for the short- and long-terms are shown in Table 7.

According to Table 7, the model successfully passed all diagnostic tests, such as the ARCH test (Heteroscedasticity), Breusche-Godfrey LM test (Serial correlation), JB test (Normality test), and Ramsey's RESET test (Functional form). The null hypotheses of the ARCH and LM tests were rejected at the 5% level. Additionally, the residual distribution of the model was normal based on the normality test. Ramsey's RESET test confirmed its functional form. As a result, the estimated model was econometrically appropriate.

Table 6. The results of ARDL co-integration bound test.

F-Statistic	5.473***			
Critical Value	10%	5%	2.5%	1%
Lower Bound I(0)	2.75	3.12	3.49	3.93
Upper Bound I(1)	3.79	4.25	4.67	5.23

***: Denotes significance at the 1% level.

Table 7. The results of the long-term and short-term models, ARDL (1,2,0,0,2,2).

Variables	Coeficents	Standard error	t-Statistic
Long-term			
LnCO2	0.388***	0.061	6.303
LnGDP	-0.067**	0.025	-2.656
LnFOS	-0.213***	0.067	-3.174
LnREN	0.025***	0.005	4.570
LnTO	-0.051***	0.011	-4.525
Break	-0.029***	0.005	-5.668
Trend	0.010***	0.001	6.100
Constant	0.078	0.224	0.351
Short-term			
Error correction(-1)	-1.102***	0.141	-7.768
Δ(LnCO2)	0.154**	0.053	2.896
Δ(LnCO2(-1))	-0.109**	0.046	-2.342
Δ(LnGDP)	-0.073**	0.028	-2.603
Δ(LnFOS)	-0.071	0.045	-1.574
Δ(LnFOS(-1))	0.081	0.048	1.666
Δ(LnREN)	0.028***	0.005	5.521
Δ(LnTO)	0.006	0.011	0.587
Δ(LnTO(-1))	0.045***	0.014	3.261
Δ(Break)	-0.032***	0.005	-5.606
Δ(Trend)	0.011***	0.002	4.455
R^2	0.998		
Adjusted R^2	0.997		
Akaike info criterion	-7.712		
Schwarz criterion	-6.992		
ARCH-test	0.009		
Prob(ARCH)	0.922		
LM-test	1.604		
Prob(LM-test)	0.231		
Normality test (JB)	0.509		
Prob (JB)	0.775		
Ramsey's RESET test	0.301		
Prob (Ramsey's RESET)	0.768		

*** and **: Represent significance at the 1 and 5% levels, respectively.

As shown in Table 7, CO_2 emissions have both short- and long-term positive impacts on HDI. Over the long term, when CO_2 emissions increased by 1%, Iran's HDI index increased by approximately 0.388 %. This is partly because of the high share of non-renewable energy sources (gas, oil, and coal) and the extensive pollution in the Iranian economy. Accordingly, this finding is in line with those of previous studies, such as Sinha and Sen (2016) in Brazil and India, Wang et al. (2018) in Pakistan, Lekana and Ikiemi (2021) in the Economic and Monetary Community of Central Africa (EMCCA), Basri et al. (2021) in Bangladesh, and Adekoya et al. (2021) in 126 countries. In addition, this result differs from those obtained by Karimi Alavijeh *et al*. (2024) in European Union countries.

GDP and HDI are negatively correlated in both the short and long terms. As a result, Iranian economic growth may adversely affect human development. The HDI decreases by 0.067% with every 1% increase in GDP in the long term. This finding suggesting that economic growth may not necessarily lead to improved human development outcomes in Iran. Similar findings have been obtained in Pakistan (Wang *et al.*, 2018), Asia countries (Mustafa *et al.*, 2017), and developing countries (Saha and Zhang, 2017). Furthermore, the results differ from those obtained by Acheampong *et al.* (2021) in 79 energy-poor countries, Basri *et al.* (2021) in Bangladesh, and Hashemizadeh *et al.* (2021) in G-7 countries.

The HDI is also negatively affected by non-renewable energy use. This means that for every 1% increment in non-renewable energy use per capita, the long-term HDI declined by 0.21%. However, HDI has been positively impacted by renewable energy over the short and long term. An increase of 1% in renewable energy utilization per capita will increase the HDI by 0.025 per cent over the long term. Several countries (Bulgaria, Romania, Portugal, Poland, Ireland, and the Netherlands, G-7 countries, EMCCA countries, Bangladesh) have similar results to these findings, including Ouedraogo (2013), Niu *et al*. (2013), Wang *et al*. (2020), Hashemizadeh *et al*. (2022), Lekana and Ikiemi (2021), Basri *et al*. (2021), Adekoya *et al*. (2021), Metwally *et al*. (2024), Karimi Alavijeh *et al*. (2024), and Kaewnern *et al*. (2023).

According to the results, trade openness and HDI are significantly negatively correlated in Iran. Over the long run, a 1% increase in trading values leads to a 0.051% decrease in HDI. In light of these effects, it is reasonable to conclude that commercial activities contribute to an increase in the standard of living of a small fraction of the population that can trade but not to the improvement of the quality of life of others in the community. There are no differences in these results between Saha and Zhang (2017), Mustafa *et al.* (2017), Wang *et al.* (2018), and Hashemizadeh *et al.* (2021) in G-7 countries, and Metwally *et al*. (2024) in Nordic countries; these results are inconsistent with those of Acheampong *et al.* (2021) in 79 energy-poor countries.

Based on Table 7, the negative error correction term shows that the dependent and independent variables have long-term relationships. Furthermore, a negative ECM illustrates the degree of adjustment to the equilibrium. Therefore, every year, 100% of the short-term deviation from the long-term deviation is corrected. Furthermore, the breakpoints detected in Iran are statistically significant and have a negative impact. Thus, structural breaks negatively impact the HDI in Iran. CUSUM (Cumulative Sum) and CUSUMQ (Cumulative Sum of Squares) tests were used to assess specification stability over time. In Figures 3 and 4 the CUSUM and CUSUMQ statistics are plotted.

The model shows long-term and short-term stability, as shown in Figures 3 and 4, respectively.

CONCLUSIONS

According to the empirical findings, Iran's HDI has been positively impacted by the use of clean and renewable energy in both the short and long term. In addition, non-renewable energy usage negatively impacts HDI. Furthermore, Iran ranks among the top

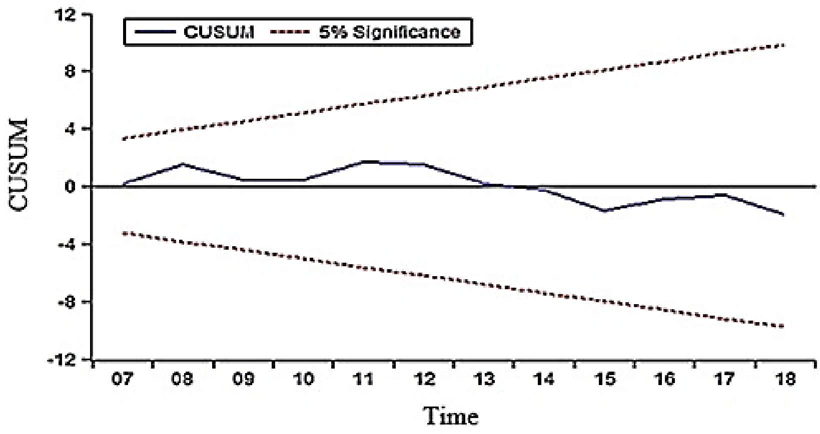

Figure 3. Cumulative Sum of Recursive Residual (CUSUM).

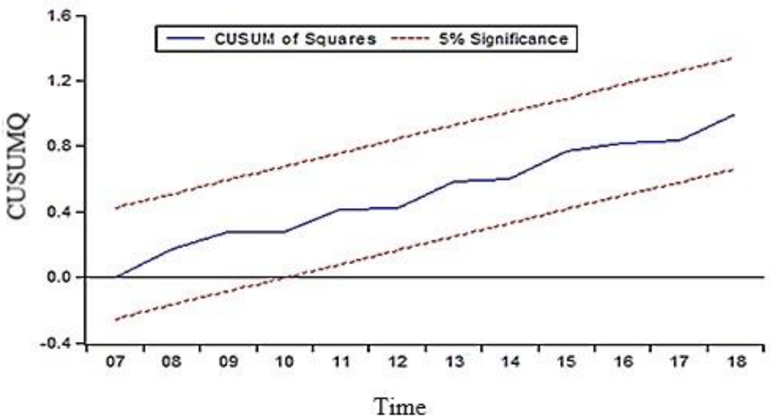

Figure 4. Cumulative Sum Squares of Recursive Residual (CUSUMQ).

greenhouse gas emitters in the Middle East, and the swift growth of its economy has greatly elevated emissions. Sources of renewable energy, like solar and wind power, can aid in lowering carbon dioxide emissions and adhering to global climate agreements. However, both economic growth and rising trade levels negatively affect HDI. Therefore, policymakers should prioritize incentives (e.g., tax exemptions, financing, technological support) for clean energy infrastructure, allocate more national budget to education and health, address income inequality, create rural jobs, and foster multi-sector collaboration. Data limitations restrict this study's ability to examine factors such as political stability, financial management on Artificial Intelligence (AI), income distribution, Digital Financial Assets (DFA), cryptocurrency mining, and institutional quality. Therefore, future studies should consider these factors, particularly in developing countries. Additionally, it is advisable to investigate the nexus of HDI, energy, and environmental sustainability in the context of panel data in future research. Finally, utilizing environmental sustainability indices, such as the Load Capacity Factor (LCF) or Ecological Footprint (EF), is recommended for future studies.

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الگوهای مصرف انرژی، پایداری محیط‌زیست و پیامدهای توسعه انسانی در ایران

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چکیده

هدف اصلی این پژوهش، بررسی ارتباط میان مصرف انرژی‌های تجدیدپذیر و تجدیدناپذیر با توسعه انسانی در ایران است. در این راستا، تمام متغیرها از منظر شکست ساختاری با استفاده از آزمون ریشه واحد نقطه شکست مورد ارزیابی قرار گرفتند. همچنین، برای بررسی وجود روابط بلندمدت از آزمون کرانه خودتوضیحی با وقفه‌های گسترده (ARDL) استفاده شد. نتایج آزمون‌های فوق نشان داد که پارامترهای مدل ARDL در بلندمدت پایدار، قابل پیش‌بینی و قابل اطمینان هستند. بر اساس نتایج، مصرف انرژی‌های تجدیدپذیر و تجدیدناپذیر به‌ترتیب تاثیری مثبت و منفی معناداری بر شاخص توسعه انسانی (HDI) دارند. همچنین، کشش مصرف انرژی‌های تجدیدپذیر کمتر از مصرف انرژی تجدیدناپذیر است. افزون بر این، توسعه انسانی در ایران همسو با انتشار گاز

دی‌اکسید کربن (CO_2) است. درمقابل، رشد اقتصادی و افزایش شفافیت تجاری سبب کاهش شاخص توسعه انسانی می‌شود. لذا در راستای بهبود شاخص توسعه انسانی در ایران، پیشنهاد می‌شود تولید و مصرف انرژی‌های پاک مد نظر قرار گیرد.