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

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Abstract

A major goal of this study is 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 is lower than that of non-renewable energy consumption. Human development in Iran has also been enhanced by CO2 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: HDI, Renewable energy, Non-renewable energy, ARDL approach.

1. 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

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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 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, 2024). 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 will have a consumption share of 20% of global energy, but this share is expected to increase to 60% by 2050 (IAE, 2023). 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.

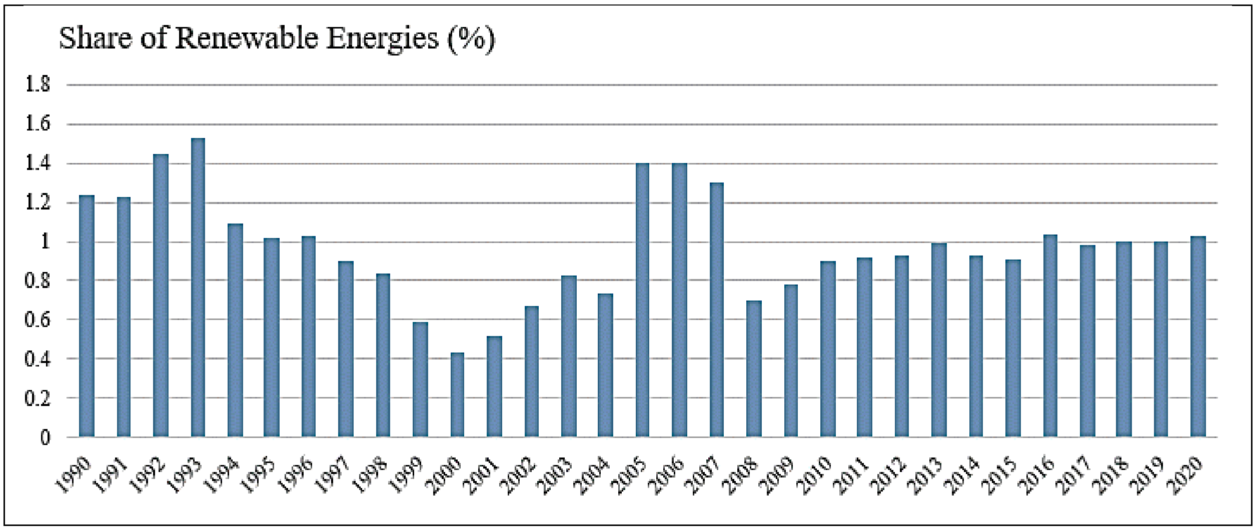

Fig. 1. Share of renewable energies in Iran during 1990 to 2020.

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 (Fig. 1). The world average in 2020 was 19.77 percent (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 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.

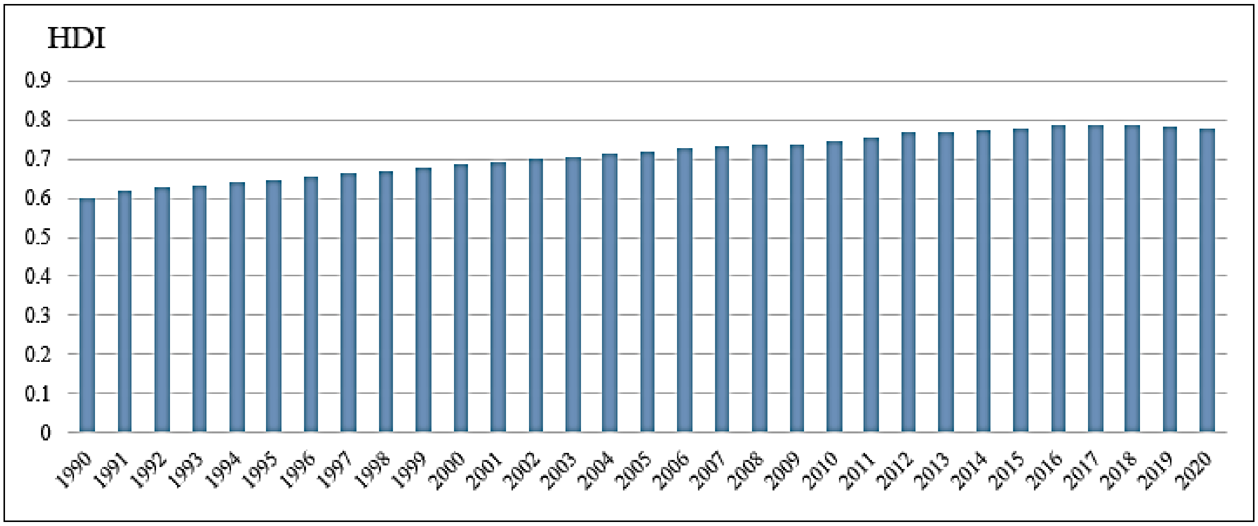

Fig. 2. The trend of HDI in Iran during 1990 to 2020.

Following Kraft and Kraft (1978), this study begins 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 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 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 Human Development Index. 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. (2021) 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 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.

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*. (2021)	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

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 aims 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.

1.3. Data and Methods

1.3.1. 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 WDI[1]. Table 2 introduces the model variables.

Table 2. The model variables.

Variables	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

2. Methology

2.1. Model specification

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

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

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

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

Equation (3) is expressed the natural logarithm specification of the empirical equation:

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

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

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

1. World Development Indicators

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.

2.2. Econometric methodology

The effect of the independent variables on the HDI was examined using the ARDL method. ARDL is a unique cointegration method developed by Pesaran (1997), Pesaran and Shin (1998), and Pesaran et al. (2001). The ARDL method has several advantages over other cointegration methods. Unlike other methods, this method utilizes stationary mixed degrees (I(0) and I (1)) of the variables (Behjat & 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 et al., 2024). The ARDL Formulation is given by Equation (4).

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

The optimal lag lengths of the dependent and independent variables are p, q, r, s, v, and w. The SBC, AIC, and HQC criteria can be applied (Pesaran et al., 2001). However, the SBC method is preferred over HQC and AIC for small sample sizes (Pesaran & Shin, 1998; Fatai et al, 2003). In 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.

3. Empirical Results

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

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

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), the results of breakpoint unit root tests.

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

Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

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.

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 cointegration relationship between the model variables. The cointegration bound test was used to determine whether the econometric model cointegrated. Table 6 shows the analysis results of ARDL cointegration.

Table 5. Results of stationary tests.

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)	-5.144***	-5.262***	I(1)
$Δ(LnCO_2)$	-6.345***	-6.407***	I(1)
Δ(LnGDP)	-4.771***	-4.738***	I(1)
Δ(LnFOS)	-7.620***	-7.620***	I(1)
Δ(LnREN)	-4.458***	-4.438***	I(1)
Δ(LnTO)	-3.946**	-3.986**	I(1)

Note: I(0) denotes that the variable is stationary at level,
Note: I(1) denotes that the variable is stationary after the first difference.
Note: ***, **, and * represent significance at the 1%, 5%, and 10% levels, respectively.

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. As well, the optimal lag length in the ARDL is derived using SBC criteria. Models for the short- and long-terms are shown in Table 7.

Table 6. The results of ARDL cointegration 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

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

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		

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

According to Table 7, the model successfully passed all diagnostic tests, such as the ARCH test[1], Breusche-Godfrey LM test[2], JB test[3], and Ramsey's RESET test[4]. 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.

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 %. 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 EMCCA countries, 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. 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. (2021), 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*. (2024).

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1. Heteroscedasticity
2. Serial correlation
3. Normality test
4. Functional form

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. 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[1] and CUSUMQ[2] tests were used to assess specification stability over time. In Figure 3 and Figure 4 the CUSUM and CUSUMQ statistics are plotted.

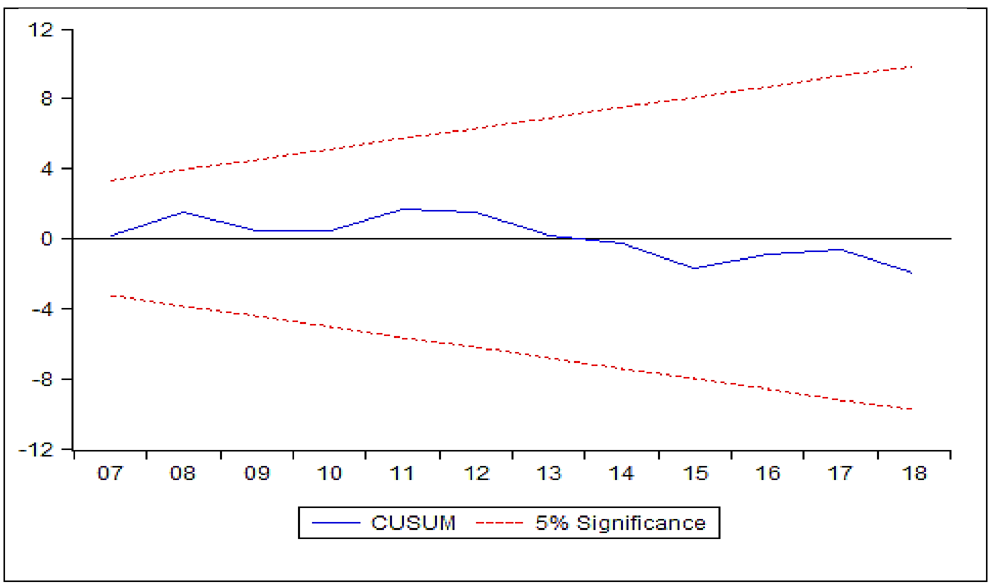

Fig.3. CUSUM.

1. Cumulative sum
2. Cumulative sum of squares

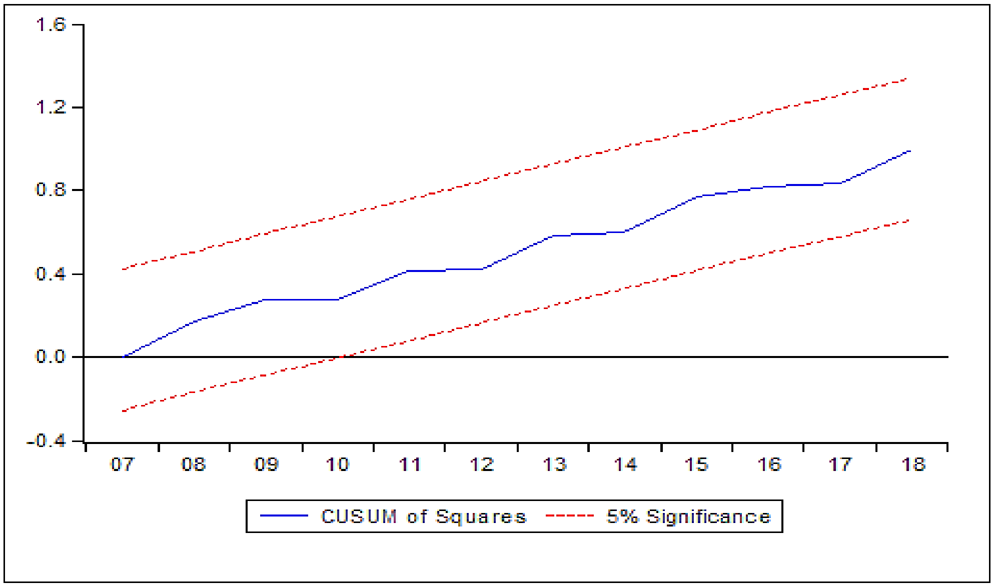

Fig.4. CUSUMQ.

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

4. Conclusions

The main purpose of this study was to compare the effects of renewable and non-renewable energy usage on human development in Iran. The ARDL and ECM methodologies were used to study long-term and short-term relationships, respectively.

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. Considering the positive effects of renewable energy, Iran should continue to pursue incentive policies for long-term clean energy use in the long run. The use of this energy without compromising human development can mitigate the negative effects of nonrenewable energy abuse, such as environmental pollution, worsening climate change, and unstable fossil fuel access. Also, the Iranian government has proactively worked to lessen its reliance on non-renewable energy sources, especially crude oil, to guarantee energy security and alleviate the adverse effects of international sanctions. Sustainable energy can significantly contribute to reaching this objective. Furthermore, Iran ranks among the top 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.

Moreover, the results showed that CO_2 emissions are positively correlated with HDI in Iran. 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, which has a significant positive impact was so great. In Iran, less than one percent of the energy resources produced are renewable or clean. For this reason, Iran's policymakers must consider incentives such as tax exemptions, financing, fee discounts, and technological support to enhance research studies and infrastructure to reach clean energy. As part of their efforts to facilitate sustainable economic development, they should provide incentives and support to this energy group. Iran's unique climate, characterized by sunshine on most days of the year, makes solar energy the preferred energy source in many parts of the country. To raise the level of human development in important areas, it is necessary to use clean and renewable energy as soon as possible. Solar energy is an example of a near-perfect solution for this problem.

Based on the results, Iran's HDI was negatively affected by economic growth. The findings highlight a concerning trend of negative correlation between GDP and HDI in Iran, suggesting that economic growth may not necessarily lead to improved human development outcomes. This is due to the large unproductive expenditure of Iran's budget. Consequently, it is advisable to allocate a greater share of the national budget to education, health, and other aspects of human development to mitigate the negative effects of economic growth on human development. Furthermore, creating adequate jobs in rural areas will increase the income and standard of living for the poor in society, which, in turn, will enhance their life expectancy. Additionally, implement policies to address income inequality, as concentrated wealth may exacerbate the negative effects of economic growth on human development. Finally, fostering collaboration between the government, private sector, and civil society to develop policies that address the intersection of economic growth and human development is recommended.

According to the results, rising trade levels in Iran negatively impact human development. 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. Accordingly, it is recommended that, in conjunction with increased transaction levels, special measures be taken to distribute transaction incomes more fairly so that a wider range of people can benefit.

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 index (LCI) or ecological footprint (EF), is recommended for future studies.

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