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Dynamic linkages between renewable energy, carbon emissions and economic growth through nonlinear ARDL approach: Evidence from Iran

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Abstract

This study examines the relationship between economic growth, renewable energy consumption, and carbon emissions in Iran between 1975–2017, and the bounds testing approach to cointegration and the asymmetric method was used in this study. The results reveal that in the long run increase in renewable energy consumption and CO_2 emissions causes an increase in real GDP per capita. Meanwhile, the decrease in renewable energy has the same effect, but GDP per capita reacts more strongly to the rise in renewable energy than the decline. Besides, in the long run, a reduction of CO_2 emissions has an insignificant impact on GDP per capita. Furthermore, the results from asymmetric tests suggest that reducing CO_2 emissions and renewable energy consumption do not have an essential role in decreasing growth in the short run. In contrast, an increase in renewable energy consumption and CO_2 emissions do contribute to boosting the growth. These results may be attributable to the less renewable energy in the energy portfolio of Iran. Additionally, the coefficients on capital and labor are statistically significant, and we discuss the economic implications of the results and propose specific policy recommendations.

1. Introduction

Energy is considered an essential source of any country's socio-economic development and an important key to strengthening all aspects of the country's economy. Recent studies have focused on whether renewable energy sources are a good strategy for reducing carbon emissions. Over the last decades, climate change has become one of the most critical environmental challenges. The challenge is how you shield the environment for coming generations [1]. Due to increasing concerns about the environmental effects of greenhouse gas (GHG) emissions from fossil fuels, renewable energy–same with other efforts to reduce CO2 emissions—has

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emerged as a substitute for energy. According to 2018 data of the International Energy Agency (IEA), fossil fuels constitute over 70% of the demand growth of global energy. Demand for natural power has risen dramatically, reaching a record 22% of total energy demand. Renewables also grew strongly, constitute about a quarter of global energy demand, while nuclear consumption was part of that remaining growth. Despite steady growth in renewables, the equal share of crude oil in global energy demand in 2017 remains at a rate of 81%, which has remained stable for over three decades [2]. Due to the abundance of oil products (Iran has the fourth-largest oil reserves), renewable energy in Iran has been neglected for a long time. Iran has a too high level of energy consumption per capita. This is due to high levels of subsidies on energy and fuel, which does not incentivize efficient energy use. However, during two decades, Iran's policymakers have recognized the renewable energy sector's potential and have taken steps to exploit renewable energy. Energy policies in Iran aimed to substituted oil products with other energy sources (natural gas and electricity) in domestic consumption and try to diversify energy consumptions by improved production and consumption of more clean and renewable energy [3]. By paid subsidies and given the competitiveness of prices [4], Iran is an exciting new market for renewable energy. High demand for electricity and government gives numerous incentives to encourage a switch from hydrocarbons to renewable energy. The biggest challenge faced by developers is the financing of renewable energy projects in Iran.

The economy of Iran is heavily dependent on crude oil and natural gas. It holds the fourth rank in crude oil reserves and the second rank in natural gas reserves globally. In Iran, a large amount of energy is used for industrial purposes. Nearly 97% of the country's overall primary energy consumption depends on oil and gas, which emit more CO_2 into the atmosphere and environment [2]. Meanwhile, since there are high levels of subsidies on energy and fuel for consumers and the manufacturing sector, Iran has a too high energy consumption level per capita, which does not incentivize efficient energy use. Therefore, energy consumption can be considered a significant cause of pollution in Iran. The change in energy consumption from renewable and non-renewable sources in Iran has followed an exciting trend over the past few decades. This continually addresses the rise in air pollution and inadequate future energy sources. Renewable energy sources are now believed to be the future of providing Iran's energy demand.

Since decreasing fossil fuel consumption and reducing CO_2 emissions affect economic development, it is crucial for Iran. Many studies have recently explored the existence of a dynamic long-term relationship between energy consumption and economic growth in many countries and regions [5–7]. One of the aims of studying energy consumption may be to determine whether the causality pattern between economic growth and renewable energy differs from economic growth and non-renewable energy. This kind of diversity is needed among research work on energy growth. Policymakers are encouraged to develop different strategies and policies for each energy source to achieve sustainable growth levels [8].

This study empirically investigates the link between CO_2 emissions, economic growth, and renewable energy consumption in Iran. Different from previous studies in the literature, we employ nonlinear and asymmetric techniques. The relationship between renewable energy consumption, CO2 emissions, and Iran's economic growth has not been previously studied to the best of our knowledge. Moreover, our paper differs from existing studies. We utilize a nonlinear asymmetric method in which there has been no study that tried to estimate these variables by asymmetric approach.

This paper's remainder is structured as follows: Section 2 reviews the literature and other relevant previous study initiatives. Section 3 includes the analytical model, evidence overview, and methodology. Section 4 discusses and describes the empirical findings. The last section concludes the research with policy implementations.

2. Literature review

The link between energy consumption and economic growth is one that can be contemplated without much difficulty using the growth theory such as Cobb–Douglas production function and energy as a factor in the production function that could constrain or enable economic growth and energy consumption plays a crucial role for the economic growth process. Energy and renewable energy are fundamental drivers of output growth in the world economy, as fusil energy is more harmless, so countries try to substitute it with renewable energy. For instance, both labor and capital can use renewable energy to produce goods and services that are the main source of growth. Recent literature concerning economic growth indicates that capital, labor, technological progress, and energy are the basic economic growth elements in developed and developing countries. The recent literature pays attention to the role of energy, particularly renewable energy in growth. In this section, studies examining the short and long-term relationship between energy consumption and economic growth in the literature are included. Most studies on energy consumption and economic growth generally focus on energy consumption, electricity consumption, and oil consumption variables [9–11]. However, renewable energy-based studies are still scarce. In the literature, we discern the various relationships between renewable energy consumption, economic growth, CO_2 emissions, and other variables. This body of research has used several approaches to demonstrate capabilities, such as the Autoregressive Distributed Lag (ARDL) model, Vector Error Correction Model (VECM), Vector Autoregressive (VAR) model, cointegration, and Granger causality tests for developing and developed countries. There are mostly studies explaining a causal relationship between renewable energy and economic growth when the literature is examined.

Some of these studies are as follows. Soytas and Sari [12] examine the causality relationship between energy consumption and GDP. As a result of this study, a two-way causality relationship was determined in Argentina, while a causality from GDP to energy consumption was found in Italy and Korea. Turkey, France, Germany, and Japan, extending causality from energy consumption to GDP, has been determined. Therefore, it has been stated that energy saving can harm economic growth in the last four countries. Arbex and Perobelli [13] explored the relationship between renewable energy and production for six Central American countries from 1980 to 2006. Their findings confirmed the presence of bidirectional causality in both the short-run and long-run between renewable energy and economic growth.

Mahmoodi et al. [14] examined the existing relationship between renewable energy consumption and income growth for seven Asian countries from 1985 to 2007. Their findings showed the presence of unidirectional causality in Pakistan, India, Iran, and Syria. Unlike the earlier development, a bidirectional causality concerning Jordan and Bangladesh was discovered, and no causality was identified in Sri Lanka. Joyeux and Ripple [15] examined the causality relationship between renewable energy and GDP in China from 1980 to 2010. Estimation of a multivariate labor and capital model showed that renewable energy has a positive effect on GDP.

Marjanović et al. [16] tried to demonstrate a causal relationship between renewable energy and economic growth using certain regional economies in Italy between 1997–2007. This study's findings revealed that renewable energy generation in the regions studied has significant effects in reducing the existing balance of payments constraints. Payne [17] used VECM to check the relationship between renewable and non-renewable energy consumption and economic growth; findings suggest a feedback hypothesis for the relationship between GDP and renewable energy use and a conservation hypothesis GDP-energy relationship. Apergise and Danuletiu [18] used the Fully Modified Ordinary Least Square (FMOLS) method to test the long-run bidirectional relationship between high-income renewable energy consumption in upper-middle-income, lower-middle-income countries and GDP growth during the period 1980–2009. The findings reflect a direct link for most countries.

Keyns [19] studied how renewable electricity production could aid economic development rather than economic growth in 154 countries. The outcome of this research showed that renewable energy production exists in long-term economic growth, and bidirectional relationships were found to exist only in the short run. Apergis and Danuletiu [18] examined the relationship between renewable energy and economic growth in the long run by applying the ARDL panel and Granger causality over 80 countries in four different regions of the world. In the long run, they found bidirectional causality between renewable energy and GDP across all areas. Ouedraogo [20] reviewed the nexus for the period 1990–2011 in 15 European countries between 1990–2011 using panel cointegration and the panel causality process and found evidence of growth hypothesis. Fang [21] investigated the link for 19 OECD countries during the period between 1980–2008 using a panel causality model and found evidence of the conservation hypothesis. Salim et al. [22] examined the unidirectional relationship between GDP and renewable energy consumption in OECD economies. As a result, a unidirectional causality relationship from renewable energy to GDP was determined.

Inglesi-Lotz [23], the relationship between renewable energy consumption and economic growth in all OECD countries by panel cointegration methods investigated, and the growth hypothesis was found to be valid. Lee [24] examined the relationship between energy consumption, economic growth in OECD countries, and the Middle East and North Africa (MENA) region between 1975–2011. They found that economic growth positively impacts energy consumption in the MENA region, and no significant relationship is found in OECD countries. Özdevecioğlu [25] studied the link between renewable energy consumption and economic growth in newly developed countries between 1971 and 2011. Findings indicated that adverse shocks in renewable energy consumption caused positive shocks in South Africa and Mexico's real GDP. For India, the negative shocks in renewable energy consumption cause negative shocks in real GDP.

Destek and Aslan [26] used the causality bootstrap panel to evaluate renewable and non-renewable energy consumption's relative economic growth performance in 17 developing economies. In the case of renewable energy consumption, the findings revealed that the growth hypothesis has only been confirmed for Peru; the conservation hypothesis was endorsed for Thailand and Colombia; the feedback hypothesis for South Korea and Greece was identified, and the neutrality hypothesis was relevant for the other 12 emerging economies. The growth hypothesis for Colombia, Mexico, Philippines, and China was found in the case of non-renewable energy consumption; the conservation hypothesis was supported for Peru, Egypt, and Portugal; the feedback hypothesis was only accepted for Turkey, and the neutrality hypothesis was true for the other nine developing economies.

Apergis and Tang [27] indicated different ties between economic growth and energy consumption for renewables and non-renewables for income panels in 89 countries between 1971 and 2011, while renewable energies were considered to boost economic growth in low and lower middle income countries. Empirical results have shown that renewable energy does not increase the social development situation in Pakistan. It was concluded that CO_2 emission is necessary to raise the human development index. Causality analysis supports the feedback hypothesis between the environmental factor in Pakistan and the long-term human development cycle. Atems and Belaid and Youssef [24, 28], using the Generalized Moments Method (GMM), analyzed panel data for 174 countries from 1980–2012. In their studies, they examined the effect of electricity generation on economic growth. Study results showed that there is a link between electricity loss and economic growth. Besides, the findings show that there is a statistically significant and positive relationship between renewable and non-renewable electricity generation and economic growth.

Dogan [29] examine the causal relationship between renewable energy sources (RESs), CO_2 emissions, and GDP. The findings of the study confirm the relationship between RESs, CO_2 emissions, and GDP. Saidi and Omri [30] examined the relationship between growth, renewable energy, and carbon emissions in the case of 15 major renewable energy-consuming countries. As a result of the study, it was determined that there is bidirectional causality between economic growth and renewable energy in the short and long run. In the long run, a causal link between CO_2 emissions and renewable energy has not been identified. However, a bidirectional causality has been detected between the two variables in the short term.

Studies in which no causality relationship could be obtained between renewable energy and economic growth are also included in the literature. Pirlogea and Cicea [31] used Toda–Yamamoto causality test to investigate the correlation between renewable and non-renewable energy consumption and economic growth for 1949–2006. The findings indicate no causatives between renewable energy consumption and economic growth during that period. Bilan et al. [32] analyzed the causal sectoral relationship between renewable and non-renewable energy consumption and economic growth in the US economy. Their findings were identified in the US. There were no causatives between renewable energy and real GDP in the commercial and industrial sectors.

As shown above, many studies have investigated the connection between energy consumption and economic growth. Yet, it seems that there is no consensus on the findings. Among the reasons for this situation, it can be stated that the studies are based on different national groups, times, or methods. Another reason is to use the data weekly, annually, or quarterly. From the perspective of the literature, this article is expected to contribute in two ways. First, it measures whether the impact of Iran's renewable energy and CO_2 emissions are symmetrical or asymmetrical. Second, this study is one of the first empirical studies on the effects of renewable energy and CO_2 emissions in Iran. Using seasonal data in our research makes it possible to define and analyze these long-term and short-term effects. Because of the lack of econometric studies in relevance to the link between renewable energy, CO2 emissions, and economic growth in Iran, this study aims to remedy this lack and explore the causal relationships.

3. Methodological framework and data

3.1. Theoretical framework

The analytical method used here developed and justified by Arbex and Perobelli [13] and Mahmoodi and Mahmoodi [33]. Therefore, this study increases the neoclassical output role of Cobb–Douglas by integrating renewable and non-renewable energy consumption and capital and labor in estimating the long-term relationship between variables.

Let the role of output be in the form of this production function:

$$Y_t = AK_t^{\mu} L_t^{\pi} E_t^{\gamma} \tag{1}$$

Y_t: Aggregate output at time t
Kt: Capital
Lt: Labor
Et: Renewable energy
A: The parameter of technology

According to Mahmoodi and Mahmoodi [33] and Atems and Hotaliang [34], the logarithmic type of production function gives log-linear form and yields:

$$LnY_t = LnA + \mu LnK_t + \pi LnL_t + \gamma LnE_t + e_t \tag{2}$$

In the above model, Y denotes economic growth calculated by the per capita real gross domestic product (GDP). As independent variables, K, L, and E stand for capital, labor, and renewable energy consumption. Here μ, π and γ: measure the elasticity of output concerning capital, labor, and energy, respectively.

There is a direct link between CO_2 emission and economic activity—the CO_2 emission changing with an increase or decrease of production and consumption. Therefore the undeniable relationship between CO_2 emissions and economic growth acts as an important bridge between economic and environmental policy Destek [35].

To further examine the dynamic effects of renewable energy and CO_2 emissions in Iran, this study extends Eq (2) after [36] by adding CO_2 emissions as an explanatory variable, and the extended equations can be specified as follows:

$$\ln GDPP_t = \alpha_0 + \alpha_1 lnK_t + \alpha_2 lnL_t + \alpha_3 lnE_t + \alpha_4 lnCO2_t + \varepsilon_t \tag{3}$$

3.2 Model specification

The autoregressive distributed lag (ARDL) model has various advantages compared to other time-series cointegration models used to check the long-run relationship between two variables. In contrast, Johansen's cointegration test is applied to study the long-run relationship for multiple variables. The Johansen and Juselius method is appropriate for specific situations, i.e., it does not deal with small sample size. All variables should be integrated in the same order, such as the first difference. At the same time, ARDL can be used for a small sample. The advantage of the ARDL model is the ability to estimate short-run and long-run parameters simultaneously. ARDL can be applied if the series is I(0) and I(1) or a combination of both Liao [37].

In a famous remark, Khan et al. [38] noted that "the substitution of a downward for an upward tendency often takes place suddenly and violently, whereas there is, as a rule, no such sharp turning point when an upward is substituted for a downward tendency". After Shin et al. [39], we can assume that "the nonlinearity of many macroeconomic variables and processes has long been recognized and nonlinearity is endemic within the social sciences and that asymmetry is fundamental to the human condition". Furthermore, Khan et al.[40] and Shiller [41] and Shin et al. [39] suggested nonlinear approaches for economic models. Hence, we have to check nonlinearity in the model to avoid neglecting fundamental economic relationships.

Following the existing empirical and theoretical literature in this area, the relationship between the GDP per capita, capital, labor, renewable energy consumption, and CO_2 emissions are taken by Eq (3). All the variables are transmuted into a natural logarithm to enable the slope coefficients to be interpreted as a measure of the regress's elasticity and concerning the independent variables. Eq (3) is our long-run model to incorporate the possibility of asymmetric nonlinear adjustments to equilibrium; any short-run shock in long-run equilibrium is presented in error term in Eq (4).

$$\begin{aligned}\Delta \mathrm{LGDPP}_t = \beta_0 + \sum_{j=1}^{p}\beta_{1j}\Delta \mathrm{LGDPP}_{t-j} + \sum_{j=0}^{q}\beta_{2j}\Delta \mathrm{LK}_{t-j} + \sum_{j=0}^{m}\beta_{3j}\Delta \mathrm{LL}_{t-j} + \sum_{j=0}^{n}\beta_{4j}\Delta \mathrm{LE}_{t-j} \\ + \sum_{j=0}^{v}\beta_{5j}\Delta \mathrm{LCO2}_{t-j} + \theta\epsilon_{t-1} + e_t\end{aligned} \tag{4}$$

Eq (4) is the Error Correction Model (ECM) that could be modified in the short run for any shock in a long-run relationship. The correction parameter is displayed with θ, which corrects the shock over time, and the short-run errors can be shown with e in this model. Changes in variables are expressed with Δ and all β parameters belonging to short-run variables. With a mishmash of Eqs (3) and (4), both long and short-run formulas can be revised into one Eq (5) is a basic ARDL model, including simultaneous long and short-run dynamics. This model is a complete symmetric model that consists of both short and long-run symmetric behavior.

$$\begin{aligned}\Delta \mathrm{LGDPP}_t = \psi + \eta_0 \mathrm{LGDPP}_{t-1} + \eta_1 \mathrm{LK}_{t-1} + \eta_2 \mathrm{LL}_{t-1} + \eta_3 \mathrm{LE}_{t-1} + \eta_4 \mathrm{LCO2}_{t-1} \\ + \sum_{j=1}^{p} \beta_{1j} \Delta \mathrm{LGDPP}_{t-j} + \sum_{j=0}^{q} \beta_{2j} \Delta \mathrm{LK}_{t-j} + \sum_{j=0}^{m} \beta_{3j} \Delta \mathrm{LL}_{t-j} + \sum_{j=0}^{n} \beta_{4j} \Delta \mathrm{LE}_{t-j} \\ + \sum_{j=0}^{v} \beta_{5j} \Delta \mathrm{LCO2}_{t-j} + e_t\end{aligned} \tag{5}$$

In Eq (5), The parameters are explained as:

$$\psi = \beta_0 - \theta\alpha_0,\ \eta_0 = \theta,\ \eta_1 = -\theta\alpha_1,\ \eta_2 = -\theta\alpha_2,\ \eta_3 = -\theta\alpha_3\ and\ \eta_4 = -\theta\alpha_4$$

Besides, the long-run parameters could be recalculated by $\theta = \eta_0,\ \alpha_1 = -\frac{\eta_1}{\theta},\ \alpha_2 = -\frac{\eta_2}{\theta},\ \alpha_3 = -\frac{\eta_3}{\theta}\ and\ \alpha_4 = -\frac{\eta_4}{\theta}$ relations. Eq (5) is used for entirely symmetric estimation assumes that all variables have a linear relationship with CO_2 emissions. Nonetheless, if there are any nonlinear relationships among variables, we may be deceived by such a linear assumption. So checking nonlinearities in the model is essential. In that case, the function should be calculated using the nonlinear autoregressive distributed lag (NARDL) model. We should assume that the value of capital, labor, renewable energy consumption, and CO_2 emissions is not linear, so we should model the asymmetric relationship between GDP per capita and the value of renewable energy consumption and CO_2 emissions. Eqs (6) and (7) will produce the nonlinear variables for renewable energy consumption and CO_2 emissions.

$$\begin{aligned}\mathrm{LE}_t^{+} = \sum_{i=1}^{t} \Delta \mathrm{LE}_i^{+} = \sum_{i=1}^{t} max(\Delta \mathrm{LE}_i, 0);\ \mathrm{LE}_t^{-} = \sum_{i=1}^{t} \Delta \mathrm{LE}_i^{-} = \sum_{i=1}^{t} min(\Delta \mathrm{LE}_i, 0) \\ \mathrm{LCO2}_t^{+} = \sum_{i=1}^{t} \Delta \mathrm{LCO2}_i^{+} = \sum_{i=1}^{t} max(\Delta \mathrm{LCO2}_i, 0);\ \mathrm{LCO2}_t^{-} = \sum_{i=1}^{t} \Delta \mathrm{LCO2}_i^{-} = \sum_{i=1}^{t} min(\Delta \mathrm{LCO2}_i, 0)\end{aligned} \tag{7}$$

The new model long-run model could be rephrased because of the asymmetric character of LE and LCO2 variables in Eq (8).

$$\begin{aligned}\mathrm{LGDPP}_t = \alpha_0 + \alpha_1 \mathrm{LK}_t + \alpha_2 \mathrm{LL}_t + \alpha_3^{+} \mathrm{LE}_t^{+} + \alpha_3^{-} \mathrm{LE}_t^{-} + \alpha_4^{+} \mathrm{LCO2}_t^{+} + \alpha_4^{-} \mathrm{LCO2}_t^{-} \\ + \epsilon_t\end{aligned} \tag{8}$$

Consistent with Shin et al. [39], the model in the case of asymmetry in both long-run and short-run is offered in Eq (9). This model is a full asymmetric model that consists of asymmetric behavior in both the short and long-run, and the following asymmetric ARDL model can represent the equation:

$$\begin{aligned}\Delta \mathrm{LGDPP}_t &= \psi + \eta_0 \mathrm{LGDPP}_{t-1} + \eta_1 \mathrm{LK}_{t-1} + \eta_2 \mathrm{LL}_{t-1} + \eta_3^{+} \mathrm{LE}_{t-1}^{+} + \eta_3^{-} \mathrm{LE}_{t-1}^{-} \\ &+ \eta_4^{+} \mathrm{LCO2}_{t-1}^{+} + \eta_4^{-} \mathrm{LCO2}_{t-1}^{-} + \sum_{j=1}^{p} \beta_{1j} \Delta \mathrm{LGDPP}_{t-j} + \sum_{j=0}^{q} \beta_{2j} \Delta \mathrm{LK}_{t-j} \\ &+ \sum_{j=0}^{m} \beta_{3j} \Delta \mathrm{LL}_{t-j} + \sum_{j=0}^{n} \beta_{4j}^{+} \Delta \mathrm{LE}_{t-j}^{+} + \sum_{j=0}^{n} \beta_{4j}^{-} \Delta \mathrm{LE}_{t-j}^{-} + \sum_{j=0}^{v} \beta_{5j}^{+} \Delta \mathrm{LCO2}_{t-j}^{+} \\ &+ \sum_{j=0}^{v} \beta_{5j}^{-} \Delta \mathrm{LCO2}_{t-j}^{-} + e_t \end{aligned} \tag{9}$$

By checking the symmetry hypotheses, the correct model should be determined. If the symmetry hypotheses of LCO_2 cannot be rejected, the model can be written as follow:

$$\begin{aligned}\Delta \mathrm{LGDPP}_t &= \psi + \eta_0 \mathrm{LGDPP}_{t-1} + \eta_1 \mathrm{LK}_{t-1} + \eta_2 \mathrm{LL}_{t-1} + \eta_3^{+} \mathrm{LE}_{t-1}^{+} + \eta_3^{-} \mathrm{LE}_{t-1}^{-} \\ &+ \eta_4 \mathrm{LCO2}_{t-1} + \sum_{j=1}^{p} \beta_{1j} \Delta \mathrm{LGDPP}_{t-j} + \sum_{j=0}^{q} \beta_{2j} \Delta \mathrm{LK}_{t-j} + \sum_{j=0}^{m} \beta_{3j} \Delta \mathrm{LL}_{t-j} \\ &+ \sum_{j=0}^{n} \beta_{4j}^{+} \Delta \mathrm{LE}_{t-j}^{+} + \sum_{j=0}^{n} \beta_{4j}^{-} \Delta \mathrm{LE}_{t-j}^{-} + \sum_{j=0}^{v} \beta_{5j} \Delta \mathrm{LCO2}_{t-j} \\ &+ e_t \end{aligned} \tag{10}$$

On the other hand, by rejecting the symmetry hypotheses only for $LCO_{2,}$ the model changes as follow:

$$\begin{aligned}\Delta \mathrm{LGDPP}_t &= \psi + \eta_0 \mathrm{LGDPP}_{t-1} + \eta_1 \mathrm{LK}_{t-1} + \eta_2 \mathrm{LL}_{t-1} + \eta_3 \mathrm{LE}_{t-1} + \eta_4^{+} \mathrm{LCO2}_{t-1}^{+} \\ &+ \eta_4^{-} \mathrm{LCO2}_{t-1}^{-} + \sum_{j=1}^{p} \beta_{1j} \Delta \mathrm{LGDPP}_{t-j} + \sum_{j=0}^{q} \beta_{2j} \Delta \mathrm{LK}_{t-j} + \sum_{j=0}^{m} \beta_{3j} \Delta \mathrm{LL}_{t-j} \\ &+ \sum_{j=0}^{n} \beta_{4j} \Delta \mathrm{LE}_{t-j} + \sum_{j=0}^{v} \beta_{5j}^{+} \Delta \mathrm{LCO2}_{t-j}^{+} + \sum_{j=0}^{v} \beta_{5j}^{-} \Delta \mathrm{LCO2}_{t-j}^{-} \\ &+ e_t \end{aligned} \tag{11}$$

LGDPP, LK, LL and LCO2 represent the logarithmic transformation of aggregate output per capita, capital, labor and renewable energy, respectively. Increase/decrease in CO2 emission represented by $LCO2^{+}/LCO2^{-}$. Also, the positive/negative decomposition of renewable energy were demonstrated by LE^{+}/LE^{-}.

3.3 Data

This study used annual frequency data to cover the period 1975–2017. Annual data on real GDP per capita in constant 2005 US dollars (Y) as a proxy of economic growth, CO_2 per capita (CO_2) is measured in metric tons per capita, real fixed capital (K) and labor (L) are taken from the World Bank, World Development Indicator (2018) and Renewable energy (E) include hydropower, solar energy, wind energy, nuclear energy, wave energy, ocean energy, etc. measured in kilowatt-hours collected from IEA (2018).

Table 1 contains descriptive statistics for each variable included in this study. The mean value, the median, range of each variable, standard deviation, skewness, kurtosis, and Jarque-Bera test stats for normality of the data.

Table 1. Descriptive analysis of data.

	LCO2	LCO2_N	LCO2_P	LE	LE_N	LE_P	LGDPP	LK	LL
Mean	1.60	-0.63	1.07	-0.25	-0.78	2.23	8.65	24.93	16.61
Median	1.51	-0.75	1.06	-0.09	-0.38	2.10	8.64	24.86	16.57
Maximum	2.17	0.00	1.84	0.42	0.00	3.76	9.24	25.66	17.14
Minimum	1.03	-0.83	0.08	-1.67	-2.17	0.06	8.20	23.98	13.98
Std. Dev.	0.36	0.30	0.55	0.49	0.88	1.06	0.27	0.42	0.48
Skewness	0.22	1.36	-0.09	-1.23	-0.53	0.04	0.43	-0.11	-3.35
Kurtosis	1.65	3.16	1.62	4.25	1.59	2.03	2.34	2.17	19.86
Jarque-Bera	4.11	14.75	3.84	15.57	6.18	1.90	2.43	1.51	671.78
Probability	0.13	0.00	0.15	0.00	0.05	0.39	0.30	0.47	0.00

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4. Empirical results and discussion

4.1 Unit root tests

To implement the ARDL model, the variables used in the model must be a single or zero-degree integer. For this reason, it must be checked first that the variables are not integers of two degrees or more. Additionally, the unit root test by Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) was applied. The findings presented in Table 2 show that some of the variables examined are not stationary at levels. However, it is seen that these variables become stationary in the first differences. For this reason, the cointegration test can be continued in the ARDL framework.

In Table 3, normalized versions of long-run estimation results of linear and nonlinear models are given. Here, the Iran-Iraq war is included in the model as a dummy variable.

According to Table 3, it is seen that the estimated coefficients related to real fixed capital formation, workforce, and war puppet are insignificant according to the 5% significance level. These results indicate that these variables are not important in determining the GDP level in Iran. The main reason for this is that Iran's leading source of growth is related to the oil sector and income from oil. By looking at the coefficients of the LCO_2 variable, it is seen that the nonlinear Eq (9) model has an insignificant coefficient in all models except negative long-run

Table 2. Results of unit root test.

	Constant				Constant + Trend			
	ADF		PP		ADF		PP	
	Lev	Dif	Lev	Dif	Lev	Dif	Lev	Dif
LGDPP	-1.18	-4.35*	-1.46	-4.72*	-1.64	-4.66*	-1.18	-4.67*
LK	-2.21	-5.58*	-2.21	-5.52*	-2.23	-5.57*	-2.38	-5.50*
LL	-6.65*	-24.70*	-4.55*	-19.91*	-18.96*	-25.65*	-9.26*	-20.61*
LE	-3.18**	-5.99*	-3.21**	-5.96*	-2.60	-6.26**	-2.58	-6.25*
LE_N	0.48	-5.66*	0.48	-5.64*	-1.92	-5.76*	-1.95	-5.71*
LE_P	-1.77	-6.67*	-1.76	-6.67*	-2.45	-6.78*	-2.62	-6.78*
LCO2	-0.42	-5.11*	-0.42	-5.71*	-1.55	-5.10*	-1.68	-5.67*
LCO2_N	-5.39*	-1.60	-2.27	-5.26*	-4.33*	-2.79	-1.19	-5.61*
LCO2_P	-1.46	-6.18*	-1.64	-6.16*	-1.82	-6.37*	-1.82	-6.39*

*- stationary at 1%

**-stationary at 5%

***-stationary at 10%. LE_P, LE_N, CO2_P and CO2_N indicate the positive and negative long-run coefficients for renewable energy and Co_2 emissions, respectively.

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Table 3. Long-run coefficient estimates of linear and nonlinear ARDL models.

	Linear	Nonlinear	Nonlinear only for LE	Nonlinear only for LCO2
	Eq 5	Eq 9	Eq 10	Eq 11
LK	-1.49 (-0.97)	-0.31 (-1.74)	1.17 (-1.33)	-0.14 (-0.55)
LL	-1.25 (-0.24)	-0.66 (-1.36)	-0.97 (0.31)	0.67 (0.87)
LCO2	4.56 (0.85)		2.28 (-0.61)	
LCO2_P		-0.48 (-1.61)		0.58 (0.96)
LCO2_N		1.18 (2.02) ***		1.87 (1.70)
LE	2.07 (1.87) ***			0.42 (2.89) *
LE_P		0.36 (2.86) **	-1.34 (1.91) ***	
LE_N		-0.46 (-2.51) **	-0.12 (0.15)	
Constant	2.29 (0.58)	32.92 (2.38) **	0.40 (0.08)	0.45 (0.13)
WAR	0.0004 (0.01)	-0.04 (-0.53)	-0.05 (-0.95)	0.03 (0.88)

Notes

***, ** and * Denotes %10, %5 and 1% level of significant respectively.

LE_P, LE_N, CO2_P, and CO2_N indicate the positive and negative long-run coefficients for renewable energy and CO_2 emissions, respectively.

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coefficients for CO_2 emissions coefficient. It is understood that all LE coefficients in Eq (10) are significant except for negative long-run coefficients for renewable energy. Here, all models' short-term coefficients are displayed in Table 4 to distinguish between long-term and short-term effects.

The short-run coefficients reveal conflicting results for different models. The estimation results in Table 4 display that the real output as economic growth in the short run is positively correlated with renewable energy consumption, CO_2 emissions, real fixed capital, and labor. It also displays that Eq (5) and Eq (10) involve the symmetrical dynamics of LCO_2 in the short-run. The meaningful and positive sign of the coefficients of the relevant variables expresses this situation. However, asymmetric dynamics have adverse consequences for positive and negative changes. The relationship between positive and negative shocks on GDPP with the analyzed asymmetric test results is also shown in Table 4. In Eq (9), the reduction of LCO_2 in the short-run has a positive and significant effect. Positive changes have a negative and significant coefficient. Eq (11) results reveal that only negative changes have meaningful predictions in the short-run. The LE has a variety of signs and significance on models. The short-run LK coefficients are positive and significant in all models. The LL variable has more inconsistent results compared to LK. These results show the importance of these two variables in determining the real GDP level in Iran. The results found in this study are consistent with existing studies. A statistically significant and positive coefficient for renewable energy is compatible with deviant studies [8, 11, 13].

In this study, the Wald test (W_{LR}) and (W_{SR}) symmetries were used for both the long and short term, respectively, to test an asymmetric model's suitability. Concerning the diagnostic statistics, the findings are reported in Table 5. The results suggest a rejection of the null hypotheses of the symmetry of CO_2 for both long-run and short-run time horizons. These findings further support that a linear model for the GDP and CO_2 emissions in Iran would be unspecified. Wald test (W_{LR}) and (W_{SR}) symmetries for renewable energy could not be rejected. Therefore, only the model results associated with Eq 11 can be interpreted as valid estimation results. We apply the Cumulative Sum (CUSUM) and Cumulative Sum Squares (CUSUMQ) of The Cumulative Sum (CUSUM) and Cumulative Total Squares (CUSUMQ) of the recursive residual tests were applied to check the robustness of the analysis. These tests

Table 4. Short-run coefficient estimates of linear and nonlinear ARDL models.

	Linear	Nonlinear	Nonlinear only for LE	Nonlinear only for LCO2
	Eq 5	Eq 9	Eq 10	Eq 11
Δ LGDPP$_{t-1}$	-0.25 t-2.10) **	0.31 (0.82)	-0.46 (-2.44) **	-0.27 (-2.25) **
Δ LGDPP $_{t-2}$	-0.21 (-2.02) ***	0.07 (0.26)	-0.35 (-2.72) **	-0.44 (-3.92) *
Δ LGDPP $_{t-3}$		0.22 (0.92)		
Δ LCO2 $_{t}$	0.76 (4.85) *		0.54 (2.76) *	
Δ LCO2 $_{t-1}$			0.24 (1.34)	
Δ LCO2_N $_{t}$		1.18 (4.28) *		1.35 (7.32) *
Δ LCO2_N $_{t-1}$		-0.38 (-1.06)		
Δ LCO2_N $_{t-2}$		-0.28 (-0.98)		
Δ LCO2_N $_{t-3}$		0.04 (0.17)		
Δ LCO2_P $_{t}$		-0.76 (-2.40) **		-0.08 (-0.38)
Δ LCO2_P $_{t-1}$		0.06 (0.20)		
Δ LCO2_P $_{t-2}$		-0.38 (-1.27)		
Δ LCO2_P $_{t-3}$		-0.18 (-0.87)		
Δ LE $_{t}$	0.12 (2.38) **			0.04 (1.07)
Δ LE_N $_{t}$		-0.43 (-2.02) ***	0.11 (1.35)	
Δ LE_N $_{t-1}$		-0.06 (-0.66)		
Δ LE_N $_{t-2}$		-0.07 (-0.66)		
Δ LE_N $_{t-3}$		0.07 (0.81)		
Δ LE_P $_{t}$		0.24 (1.94) ***	0.08 (0.94)	
Δ LE_P $_{t-1}$		0.14 (1.05)		
Δ LE_P $_{t-2}$		0.35 (2.51) **		
Δ LE_P $_{t-3}$		0.08 (1.10)		
Δ LK $_{t}$	0.27 (4.26) *	0.21 (2.29) ***	0.27 (4.04) *	0.32 (5.59) *
Δ LK $_{t-1}$	0.19 (2.52) **	0.44 (3.00) **	0.27 (3.05) *	0.20 (3.08) *
Δ LK $_{t-2}$		0.41 (2.65) **	0.10 (1.35)	0.14 (2.40) **
Δ LK $_{t-3}$		0.08 (0.78)		
Δ LL $_{t}$	0.26 (0.42)	-1.19 (-1.13)	0.37 (0.51)	0.73 (1.30)
Δ LL $_{t-1}$		1.51 (1.48)		0.11 (2.06) **
Δ LL $_{t-2}$		2.16 (1.23)		0.03 (1.25)
Δ LL $_{t-3}$		-0.16 (-3.05) **		

Notes

***, ** and * Denotes %10, %5 and 1% level of significant respectively.

LE_P, LE_N, CO2_P, and CO2_N indicate the positive and negative long-run coefficients for renewable energy and Co2 emissions, respectively.

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show no serial correlation in the model under consideration, and there is no Heteroscedasticity problem. Looking back at the long-term dynamic studies shown here in Table 3, based on the long-term prediction coefficients of the asymmetric ARDL model, we can state that LE Long-term coefficients justify their significance in renewable energy. This result supports other studies in the literature. The estimated long-term coefficients on LE are 0.42 and are significant (Table 3). These results mean that not all variables other than renewable energy consumption will be a significant driver of economic growth in the long-run in the case of Iran. However, there are different models of short-run dynamics. While negative changes in LCO_2 have a positive and significant effect on LGDPP, positive changes have a negative and insignificant effect. We can also observe that LE has a negligible impact in the short-run, despite its

Table 5. Diagnostic statistics associated with linear and nonlinear ARDL models.

	Linear	Nonlinear	Nonlinear only for LE	Nonlinear only for LCO2
	Eq 5	Eq 9	Eq 10	Eq 11
Bound F	3.69 ***	3.1	3.34	4.17 **
LM Test	2.06	10.54 **	0.27	0.13
RESET Test	10.34 *	0.58	5.02 **	0.08
Cusum	S	S	S	S
CusumQ	S	S	S	S
Adjusted R2	0.72	0.89	0.73	0.84
Wald-S (LCO2)		2.74		25.91 *
Wald-L (LCO2)		47.67 *		13.64 *
Wald-S (LE)		5.48 **	0.06	
Wald-L (LE)		8.51 **	0.64	
Jarque—Bera	5.44 ***	5.44 ***	3.45	1.45
ARCH	2.66	10.82 *	3.25 ***	0.15

Note

***, ** and * Denotes %10, %5 and 1% level of significant respectively.

W_{LR} Refers to the Wald test for the null of long-run symmetry.

W_{SR} Refers to the Wald test for the null of the additive short-run symmetry.

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significant long-run impact. The most remarkable results are about the short-run coefficients of LK and LL. In the short-run, both variables have a positive and vital impact.

Energy use also has been on the increase, as well as the population in Iran. The primary sources of energy in Iran belong to fossil fuels. A significant proportion of Iran's CO_2 emissions is related to the consumption of vehicle fuels in the transportation sector and natural gas in this country's building sector (Hosseini et al. 2019). Because of the unproductive source of CO_2 emission in Iran, the long-run effect on economic activities is meaningless. We found the positive impact of renewable energy on economic activities. Technological advances mostly accompany renewable energy production; thus, it can be interpreted as the country's technological progress. By looking at labor and capital impact on aggregate production, the long-run coefficients are insignificant, while their short-run effects are positively related to the economic activities. Because of fundamental problems about the economic environment, such as trade and political sanctions and the high unemployment rate, the increase of capital and labor force can not increase production capacity in the long run.

5. Conclusion and policy implications

Despite the improvement in literature over the last few years on renewable energy, carbon emissions, and economic growth, no study has examined these relationships by using a nonlinear ARDL approach for Iran.

Renewable energy also plays an important role not only in energy security but also in reducing emissions. Since its cleanliness and less harmful environmental impact, it has gained significant importance in today's world. Iran is considered among the world's rich in fossil fuel production, and In Iran, fossil fuels such as natural gas and oil are mostly used for electricity. However, these are not renewable resources and can be exhausted one day. Manufacturing such fuels is also more environmentally harmful than renewable sources, minimizing carbon dioxide emissions and protecting the environment. This paper explores the relationship between renewable energy consumption and CO_2 emissions, and economic growth for Iran using the Cobb–Douglas production mechanism through the nonlinear ARDL modeling process. A small number of studies in the literature on energy -growth have studied the linkage between economic growth and energy consumption and CO_2 emissions by asymmetric approach.

The results obtained with the analyzes performed in this study support similar studies in the literature. The empirical evidence reveals that renewable energy, CO_2 emissions, and economic growth have a short-term relationship. On the other hand, results indicate no significant relationship in the long-run between economic growth and renewable energy use. This means that the renewable energy sector is in an immature stage in Iran. Suggesting that the expansion of renewable energy—stand-alone- cannot reduce fossil energy sources' dependence, and Iran has an extremely high level of fossil energy consumption globally. The renewable energy share is too small in the total energy consumption. This is due to high levels of subsidies on energy and fuel for consumers. It is also important to remember that fossil fuels' energy subsidies are seen as critical restrictions against renewable energy production in Iran. And the elimination of energy subsidies for fossil fuels in Iran is politically tricky for the government, which may entail increased social and educational spending. The government of Iran should undertake alternative ways to foster renewable energy industries' deployment and expand the renewable energy market by fossil fuel tax and incentives and developing and improving the most promising technologies for renewable energies. As always, with Iran's serious commitment to reducing CO_2 emissions, there is still a long way to go. There was also no evidence of causality between renewable energy and economic growth in the long-run. Such results support the neutrality hypothesis, which implies that renewable energy is a relatively minor component of real GDP, and thus it should have no significant impact on economic growth.

The use of renewable energy as a solution continues to be hampered by increasing investment costs for new technologies. It is well known that the initial investment in the renewable energy sector is expensive for this country. However, Iran's geography, climate potential, reliability, and stability of policies Iran are key areas of interest for renewable energy investors. Increasing investments by the government in the renewable energy sector and obtaining financial aid and technological assistance from developed countries should be a fundamental goal as policy implementation.

The econometric findings obtained from this study show that appropriate alternative energy and environmental policies can provide information in terms of implementation. Policymakers should adopt a strategic approach to solving environmental pollution problems caused by rapid industrialization. From this perspective, multilateral negotiations involving the public sector, business world, academia, and non-governmental organizations are necessary to solve environmental problems. Besides, prioritizing increasing energy efficiency in terms of technology, developing clean production resources, and using common action plans in environmentally friendly policies can be among other policy suggestions that can be presented. Understanding sustainable development, which emerges from the necessity of taking the environment into account in ensuring economic development, can only be possible by evaluating renewable energy policies, which is one of the clean energy resources.

However, this study provides only preliminary empirical evidence on the effect of renewable and renewable energy and CO_2 emissions on economic growth in Iran, and during this study some limitations exist. The main was the lack of availability on the source of all kinds of renewable energy over the study period. Therefore, it would be interesting to investigate further the role of including hydropower, solar, wind, bioenergy, and geothermal on economic growth in future research.

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