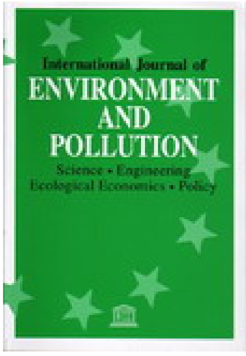

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The dynamic relationship between combined pollution, consumption and production of renewable electricity and sustainable development in Iran

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Abstract: This study investigates the dynamic causal relations between combined pollution, production and consumption of renewable electricity, and sustainable development in Iran. The research has benefited from the autoregressive distributed lag cointegration method during 2010–2018. Based on the results, consumption of renewable electricity has a beneficial impact on combined pollution in the long-run, whereas a detrimental effect in the short-run. Moreover, renewable electricity production and sustainable development statistically affect combined pollution with positive signs whether in the long-run or the short-run. Furthermore, the findings indicate that in the short-run, a unidirectional Granger causality runs negatively from renewable electricity consumption to combined pollution and positively from renewable electricity production to sustainable development, but not vice versa. A positive bidirectional Granger causality is evident between renewable electricity production and combined pollution and also between renewable electricity production and consumption. Finally, it can be concluded that there is a unidirectional Granger causality in the long-run.

Keywords: renewable electricity consumption; renewable electricity production; combined pollution; sustainability.

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1 Introduction

The rates of natural resources degradation and environmental pollution in developing countries have been increasingly accelerated in comparison to developed countries. This matter, on the one hand, leads to reduction of health, increase in disability and mortality rates (Greenstone and Rema, 2014). On the other, the process of development and competitiveness of developing countries whose economies rely on natural resources makes more unsustainable than developed countries. One of the significant ways to reach sustainable development is using renewable energy resources like the solar, geothermal, wind, and so on. Iran has opulent amount of both non-renewable and renewable energy sources. Due to Iran's geographical location very large sources of solar, biogas, hydropower, and wind energy could be reachable. Besides the benefits of reducing greenhouse gas emissions, the increase in supplying energy from renewable based sources reduces the risks of rising fossil fuel prices. Two-thirds of greenhouse gas emissions are as a result of the energy sector. Estimates indicate that by 2030, the cost of climate change in terms of climate adaptation will increase from \$50 billion to \$170 billion, only half of which can be borne by developing countries (Daneshvari et al., 2020). Renewable energy sources have several advantages, including cleanness, abundance, and reliability. As sustainable energy sources, they are capable of achieving the goals of sustainable development of countries in the long-run if properly developed (Kouhi et al., 2015). Accordingly, it can be stated that sustainable energy supply is a necessity for sustainable development. Thus, in recent years, different developed and developing countries have significantly considered renewable energy (solar, wind, geothermal, and so on) with the aims of diversifying energy resources, reducing dependence on an energy carrier and environmental consequences to achieve sustainable energy and development (Shah et al., 2020).

Here, renewable electricity is one of the most widely used energy carriers playing a highly significant role in sustainable development. According to the latest estimates, currently, there are almost 15,000 to 20,000 MW of installable capacity of wind power plants in Iran that are economically viable. Regarding this, according to the latest published statistics, the electricity generation from renewable energy resources in Iran in November 2020 has reached 5568 million kWh (Ministry of Energy Information Database, 2020). Moreover, traditional energy consumption and the burning of fossil fuels in electricity power plants lead to emission of many pollutants like NO_x, SO_x, CO, CO_2, and PM, and resulting in acid rain, ozone depletion, global warming besides producing mercury, arsenic, nickel, and other wastes (Bhattacharyya, 2011).

While the worldwide movement of the countries towards production and use of clean, renewable, and environmentally friendly energy has been started in recent years, it can be seen that by relying heavily on oil and gas resources, Iran has not shown alignment with other countries and new energies have a small portion in electricity generation in Iran. The latest capacity statistics of renewable and clean power plants (governmental and non-governmental) installed in Iran until 20 November, 2020, show that 303.18 MW belongs to wind power plants, 411.60 MW to photovoltaic power plants, 105.65 MW to small hydropower plants, 105.65 MW to biomass power plants, and 13.6 MW to recycled heat loss (Report of the Renewable Energy and Electricity Efficiency Organization of the Ministry of Energy, 2020). According to the report of the World Hydropower Association released in 2018, Iran could be among the leading countries in this field by exploiting 520 MW of new hydropower units and has ranking seventh in the world in terms of increasing the capacity of hydropower plants. Based on the records of the year 2020 released by the Renewable Energy and Electricity Efficiency Organization of the Ministry of Energy 5568 million kWh of electricity generated from new energy in Iran has led to reduction of 1581 million cubic metres of fossil fuel consumption, which is one of the principal reasons for air pollution in the country, and led to saving more than 1225 million litres of water consumption. The performance of renewable power plants has prevented the emission of 3756 thousand tons of CO_2 greenhouse gases and the emission of 23.6 thousand tons of local pollutants.

Given the significance of renewable energy in electricity production and consumption, the present study has aimed to analyse the consumption and production of renewable electricity, environmental pollution and sustainable development in Iran, where traditional electricity sector has been faced a shortage in this year as result of the limitation of generating capacity, and where we witness the consequences of combined environmental pollution in spite of the proper platform for consumption and production of renewable electricity and sustainable development. This is because Iran is among the most polluted countries in terms of air, water, soil, and other pollution. Based on the International Energy Agency Report (2020), the total carbon dioxide emission responsible for approximately 60% of greenhouse gases in Iran is 479.55 tonnes. According to the latest statistics on air pollution deaths, finalised by Iran's Ministry of Health in 2020, more than 4810 people died in 2016 in Tehran because of air pollution. Additionally, according to the World Bank report (2018), air pollution leads to the loss of 2.48% of Iran's GDP and mortality of 33,000 every year.

Furthermore, the capital-intensive nature of the renewable electricity production and the inappropriate valuation of the generated energy because of the supplying energy mainly outside the wholesale electricity market, negative external consequences, excluding costs and social benefits and lower prices for electricity generated from fossil fuels have led to the exacerbation of air pollution and Iran's failure to reach sustainable development goals. In 1992 in the 'Earth Conference', sustainable development was described as satisfying the demands of the existing generation without endangering the demands of later generations. The World Environment Commission describes sustainable development as "The process of changes in using resources, guiding investments, the orientation of technology development, and the institutional variation in line with the demands of today and tomorrow". However, Iran ranked in the medium position regarding the sustainable development index. In 2017, the sustainable development index was prepared for 167 countries, and Iran ranked 89th with a score of 64.7, followed by Lebanon and Egypt. In the 2018 report for 156 countries, Iran ranked 82 with a score of 65.5, and in 2019 for 162 countries ranked 58 with 70.5 points. Sustainable development indices scores range from zero to 100, with zero showing the worst-case scenario and 100 the best for reaching sustainable development goals.

According to the above-mentioned, the current study attempts to answer the following questions: do renewable electricity production and consumption and sustainable development affect short-term and long-term combined air pollution? Is there a unidirectional and bidirectional causal relationship among production and consumption of renewable electricity, combined air pollution and sustainable development? By finding the answers to these questions for Iran for the period 2010–2018 using ARDL bounds testing cointegration strategy and the VCEM Granger causality test method, we make effort to expand the literature related to reducing environmental degradation and achieving sustainable development by highlighting the significance of renewable energy in electricity production and consumption.

2 Research literature

By reviewing the research literature, it can be concluded that no direct investigation has been conducted on the relationship between the variables of production and consumption of renewable electricity, combined pollution, and sustainable development. On the other hand, there are few studies indirectly focused on this issue. We only deal with the results of those studies that are relevant to the subject of our research.

Radmehr et al. (2021) employed panel spatial simultaneous equations model to explore relationship between renewable energy consumption, CO_2 emissions and economic growth for European Union (EU) countries over the period of 1995 to 2014. The empirical results validated a unidirectional link between economic growth and consumption of renewable energy. Moreover, a bidirectional link between economic growth and CO_2 emissions, and between economic growth and renewable energy consumption was confirmed.

Farhani and Shabaz (2020) used the Granger causality analysis for making comparisons between 10 Middle East and North Africa (MENA) countries in terms of the relationship between non-renewable and renewable electricity consumption, CO_2 emissions, and output for a period from 1980 to 2009. Empirical findings revealed an increase in CO_2 emissions by renewable and non-renewable electricity consumption. Moreover, the unidirectional causality from output, non-renewable and renewable electricity consumption to CO_2 emissions was confirmed by the short-term dynamics. Based on the long-run findings, a bidirectional causality was observed between both non-renewable and renewable electricity consumption and CO_2 emissions.

Shah et al. (2020) studied the relationship between renewable energy, institutional stability, environment, and economic growth in D-8 countries over the period of 1990-2016. The results implied that consumption of renewable and non-renewable energy positively affects economic growth and environmental degradation.

Balsalobre-Lorente et al. (2018) examined the contribution of economic growth, renewable electricity, and natural resources towards CO_2 emissions in EU-5 from 1985 to 2015. Empirical results confirmed that natural resources, energy innovation, and renewable electricity consumption decrease environmental degradation. Nevertheless, the interaction between the consumption of renewable electricity and trade openness and economic growth positively affects CO_2 emissions.

Mbarek et al. (2018) performed the Granger causality test and VECM model to explore the dynamic relations between renewable energy consumption, economic growth, CO_2 emissions, and energy consumption in Tunisia during the period 1990–2015. The empirical results validated a bidirectional causal link between CO_2 emissions and the use of energy. Furthermore, a unidirectional relationship from the use of energy to economic growth was evident in the short-run, and the effect of the economic growth on CO_2 emission was also confirmed in the short and long-run.

Fotis and Pekka (2017) explored the impact of economic growth and renewable energy use on pollution in the Eurozone over a period of 2005 to 2013. The findings indicated that environmental pollutants are positively influenced by economic growth.

Moreover, the use of renewable energy sources negatively affects pollution. Meaning that more renewable energy use results in the less air pollution.

Bélaïd and Youssef (2017) applied the autoregressive distributed lag cointegration strategy to test the dynamic causal relationship between non-renewable and renewable electricity consumption, economic growth, and CO_2 emissions in Algeria from 1980 to 2012. The findings indicated that economic growth and non-renewable electricity consumption have negative impacts on the environment quality in the long-run, while renewable energy use has a positive environmental impact. The results also implied that non-renewable and renewable electricity consumption and real GDP have negative long-run unidirectional casualty to the variable CO_2 emissions.

Zeb et al. (2014) examined the long-run and short-run causality relationship among production of renewable electricity, CO_2 emissions, GDP, poverty, and natural resource depletion in some SAARC countries from 1975–2010. The empirical results confirmed that poverty and GDP have a positive impact on energy production. However, for CO_2 emission, a negative influence was observed. CO_2 emissions declines by increasing renewable electricity production, while, natural resource depletion increases CO_2 emissions. Furthermore, GDP increases by increasing energy production leading to an increase in CO_2 emission.

The causal relationship between, renewable and nuclear energy consumption, real GDP, and CO_2 emission for the US from 1960–2007 was assessed by Menyah and Wolde-Rufael (2010). A unidirectional causality was found from nuclear energy consumption to CO_2 emissions, while not vice versa. They also concluded no causality from renewable energy to CO_2 emissions. In fact, renewable electricity consumption has not attained enough level for allowing to reduce CO_2 emission.

Generally, evaluation of all the previous empirical studies indicates that regardless of the bidirectional or unidirectional causal relationship between renewable electricity consumption, the emission of various types of pollutants, and economic growth, in general, the majority of the studies reached a common finding "the positive influence of electricity consumption from renewable sources on pollution reduction". However, no agreement is observed on causality direction. The causality direction of the series differs between countries. The specific nature of different periods, different economic policies of countries, various types of energy resources, and the methodological approach are the main reasons for the heterogeneous feature in the results obtained from causality tests. Moreover, the causal relationship between the production of renewable electricity and pollution has not been addressed in the literature. The present study aimed to fill the gap in the causal relationship between production and consumption of renewable electricity, combined pollution, and sustainable development.

3 Model specification and empirical methodology

This study is conducted according to a functional form of standard log-linear among combined pollution, renewable energy consumption and production and sustainable development. We follow the methodology proposed by Bélaïd and Yussef (2017). However, we adjust the model by replacing a combined pollution index instead of carbon dioxide and a sustainable development index instead of economic growth. Moreover, both renewable electricity production and consumption are included in the model.

$$PI_t = \beta_0 + \beta_1 REC_t + \beta_2 PREC_t + \beta_3 ANS_t + \varepsilon_t \quad (1)$$

where *PI* is combined pollution index based on production and consumption, REC denotes total consumption of renewable electricity specified in billion of Kilowatt hours; PREC is total production of renewable electricity defined in million Kilowatt hours; ANS describes adjusted net savings, includes particulate emission damage (% of GNI), ε_t is the error term. Data associated with REC, PREC, and ANS (independent variables) are collected from the US Energy Information Administration Gs database, Renewable Energy and Energy Efficiency Organization database (SATBA), and World Bank Development Indicators online database (WDI), respectively. Data related to elements of consumption-based pollution index such as CO_2 emissions from transport, residential, manufacturing industries and construction, renewable and fossil fuel energy consumptions, and improved sanitation facilities are obtained from both International Energy Agency and WDI. Data related to elements of production-based pollution index such as production of electricity from natural gas, coal, oil, renewable hydroelectric sources, and nuclear sources are compiled from WDI, Renewable Energy and Energy Efficiency Organization database (SATBA) and Ministry of Energy Statistics and Information database.

The combined pollution index is the sum of consumption and production-based pollution indexes. The consumption-based pollution index (PIc) takes into account the variables responsible for environmental pollution through consumption. This index includes energy consumption variables, CO_2 emission from various sources, and the provision of improved facilities (sanitation). The formula used for this index is as follows:

$$PI_{it}^{C} = \frac{EC_{it}^{X} + CO_{it}^{Y} + IP_{it}^{\text{sanitation}}}{W} \quad (2)$$

$$EC_{it}^{X} = EC_{it}^{\text{fossil fuel}} + EC_{it}^{\text{renewable}} / 2 \quad (3)$$

$$CO_{2it}^{Y} = CO_{2it}^{\text{transport}} + CO_{2it}^{\text{residentid}} + CO_{2it}^{\text{mfg \& cnstr}} / 3 \quad (4)$$

where *i* and *t* demonstrate countries and time period, respectively.

Production based pollution index is calculated using the formula stated below:

$$PI_{it}^{P} = \frac{w_1 EP_{it}^{\text{coal}} + w_2 EP_{it}^{\text{renewable}} + w_3 EP_{it}^{\text{nuclear}} + w_4 EP_{it}^{\text{oil}} + w_5 EP_{it}^{\text{n.gas}}}{W} \quad (5)$$

Combined pollution equals the sum of individual indices obtained from production and consumption processes (see Tables 1 and 2).

$$PI_{it} = PI_{it}^{P} + PI_{it}^{C} \quad (6)$$

In addition, we use the adjusted net savings as an index for sustainable development which is equal to net national savings plus education expenditure and minus mineral depletion, energy depletion, carbon dioxide, particulate emissions damage, and net forest depletion (World Bank, 2020).

Table 1 Elements of formula (1)

$EC_{it}^{\text{fossil fuel}}$	Consumption of fossil fuel energy (% of total)
$EC_{it}^{\text{renewable}}$	Consumption of renewable energy (% of total final energy consumption)
$CO_{2it}^{transport}$	Transport CO_2 emissions (% of total fuel combustion)
$CO_{2it}^{\text{residentid}}$	Residential CO_2 emissions
$CO_{2it}^{\text{mfg\&cnstr}}$	Construction and manufacturing industries CO_2 emissions(% of total fuel combustion)
$IF_{it}^{\text{sanitation}}$	Facilities of improved sanitation (% of population that has access)
w	Total number of variable included in Equation 1

Source: Nazeer et al. (2016)

Table 2 Elements of formula (2)

EP_{it}^{coal}	Production of electricity – coal based sources (% of total)
$EP_{it}^{\text{renewable}}$	Production of electricity – renewable including hydroelectric sources (% of total)
EP_{it}^{nuclear}	Production of electricity –-nuclear based sources (% of total)
EP_{it}^{oil}	Production of electricity – oil based sources (% of total)
$EP_{it}^{\text{n.gas}}$	Production of electricity – natural gas based sources (% of total)
$IF_{it}^{\text{sanitation}}$	Facilities of improved sanitation (% of population that has access)
$w = 1, \ldots, 5$	Individual weights given to variables in equation (4)
W	Sum of all individual weights (*wi*)

Source: Nazeer et al. (2016). Coal has the most weight followed by oil, natural gas, nuclear and renewable sources

In this research the long-run relationship among combined pollution, consumption and production of renewable energy and sustainability is checked by the ARDL model presented in equation (7):

$$\ln PI_t^P = \beta_0 + \sum_{i=1}^{P} \gamma_i \ln PI_{t-i}^P + \sum_{j=1}^{q1} \delta_j REC_{t-j} + \sum_{m=1}^{q2} \varphi_m PREC_{t-m} + \sum_{m=1}^{q3} \mu_r ANS_{t-r} + \varepsilon_{t0} \quad (7)$$

Furthermore, the short-run dynamics of the related variables are examined via estimation of the vector error correction model (VECM) using equation (8):

$$\begin{aligned}\Delta\left(\ln PI_t^P\right) = \beta_0 + \sum_{i=1}^{P} \gamma_i \Delta\left(\ln PI_{t-i}^P\right) + \sum_{j=1}^{q1} \delta_j \Delta(REC_{t-j}) + \sum_{m=1}^{q2} \varphi_m \Delta(PREC_{t-m}) \\ + \sum_{m=1}^{q3} \mu_r \Delta\left(ANS_{t-r}\right) + \vartheta Z_{t-1} + \varepsilon_{t0}\end{aligned} \quad (8)$$

where Z_{t-1} denotes the error correction term (ECT). ECT measures the past disequilibrium magnitude obtained from the cointegration relationship in the long-run. Δ is the first difference operator.

Applying the ARDL approach for evaluation of the statistical link between combined pollution, renewable energy consumption and production and sustainability involves the three following key steps: (1) unit root test, (2) ARDL cointegration test, (3) Granger causality analysis.

4 Empirical results and discussion

4.1 Unit root test

First, the traditional augmented Dicky–Fuller (ADF) and Philips-Perron (PP) analyses are to be performed to establish the order of integration of each variable. Since the measured F statistics suggested by Pesaran et al. (2001) have enough validity in the presence of *I*(1), *I*(0), it is essential to ensure whether none of the variables are *I*(2). Table 3 reports the findings of ADF and PP tests.

Table 3 Unit root analyses

Variables	*ADF* (*test statistics*)	*ADF* (*critical values*)	*PP* (*test statistics*)	*PP* (*critical values*)
Ln PI	–5.107	–6.739***	8.145	9.542**
Ln REC	–8.154	–9.873**	6.129	6.434**
Ln PREC	–8.870	–9.448**	6.7589	9.453***
Ln ANS	–9.156	–8.932*	5.375	8.674**

*, ** and *** demonstrate a 10%, 5% and 1% significance level, respectively.

Based on the ADF analysis findings PI, REC, PREC are non-stationary in term of level and trend, and the integration order is one for the mentioned variables. ANS is stationary *I*(0). The results of the PP test confirm that all variables are non-stationary and *I*(1) in both level and trend. Generally, none of the variables are *I*(2) or beyond.

4.2 Cointegration analysis – ARDL

In this step, the long-run link between variables (cointegration) is assessed utilising the autoregressive distributed lag method suggested by Pesaran et al. (2001). This technique can be adopted with both the explanatory variables of I(0) and I(1). The ARDL is capable of yielding to the error correction model (ECM). In fact, it captures both long and short-run dynamics. The ARDL bound testing is appropriate for small size data, while Johansen cointegration strategy applies for the large sample of data. Even if independent variables are endogenous, the ARDL estimation can be made. Moreover, being free of residual correlation, endogeneity is less debatable in the ARDL (Pesaran and Shin, 1999). The ARDL provides obvious tests for the presence of a unique cointegration vector instead of imagining that it exists.

Generally, the ARDL strategy needs the main following steps:

1 the bounds testing for integration

2 estimating both long and short-term coefficients

3 examining the stability of the model utilising the CUSUMSQ and CUSUM analysis proposed in 1975 by Brown et al.

4.2.1 The ARDL bounds testing strategy

The findings of cointegration using the ARDL bounds testing strategy provide adequate evidence suggesting the presence of a distinctive cointegration in the first model (Table 4). When PI is the dependent variable, the calculated *F*-statistics of 3.48 has higher value than the upper bound of the critical value at the 1% significance. Therefore, the no cointegration null hypothesis is rejected. When REC, PREC, and ANS are dependent variables, the measured *F*-statistics, which are 1.54, 2.48, and 1.36, respectively are below the proper lower bound of the critical value at the 1% significance. According to Table 4, the existence of a long-term relationship among the variables for model 1 is confirmed.

Table 4 ARDL cointegration test results

	Bounds testing to coinegration	
Estimated models	*Optimal lag length*	*F-statistics*
F(PI|GDP, PREC, REC, ANS)	2	3.48*
F(ANS | PI, PREC, REC)	2	1.54
F(PREC | PI, ANS, REC)	2	2.48
F(REC | PI, ANS, PREC)	1	1.36
Significance level	Critical values	
	Lower bounds I(0)	*Upper bounds I(1)*
1% level	3.43	4.56
5% level	2.68	2.48
10% level	2.24	3.2

*Significant at 1% level.

4.2.2 Results of long-term coefficients estimation

The subsequent step needs to examine the long-run marginal impact of consumption and production of renewable electricity and sustainability on combined pollution. The long-run findings are shown in Table 5 indicate that the impact of consumption of renewable electricity on combined pollution is negative and significant, while renewable electricity production positively affects the combined pollution. Moreover, the impact of consumption of renewable electricity (0.005) on combined pollution is negligible in comparison to production of renewable electricity (0.413). Furthermore, we found production of renewable electricity has a greater positive impact (0.413) on the combined pollution than sustainable development (0.139).

Table 5 Long-run analysis

	Dependent variable: ΔPI			
Variables	*Coefficient*	*Std. error*	*t-statistic*	*Prob.*
REC	–0/005	0/045	–2/742	0/0035
PREC	0/413	0/065	7/634	0/001
ANS	0/139	0/078	4/539	0/0054
R^2	0.783			
Adjusted R^2	0.719			

4.2.3 Results of estimation of short-term coefficients

Table 6 demonstrates the short-run findings. As can be seen, renewable electricity consumption has a positive and considerable influence on combined pollution with a greater impact than the long-run (0.041). In fact, renewable electricity consumption increases combined pollution in the short-term, while it decreases combined pollution in the long-term. Hence, renewable electricity consumption is permanently effective to protect the environment in Iran. However, renewable electricity production and sustainable development statistically affect combined pollution with prior signs and smaller coefficients compared to the long-run. Since lower market prices for electricity generated from fossil power plants, significant investment costs in the production of renewable energy, and negative external influences have not been considered by the policy makers. Thus, the electricity production from renewable-based sources is very low and with a detrimental effect on reducing combined pollution in Iran. In fact, renewable electricity production has not reached enough level in order to contribute to the target of reducing the combined pollution. Furthermore, the share of renewable energy in the country's energy consumption basket is less than 0.001%. Moreover, according to theoretical expectations, the more sustainable development means the lower the air pollution. However, the empirical results indicate that sustainable development leads to increasing combined pollution. In fact, sustainable development has not reached a level to control air pollution in Iran. There is a good consistency between our findings and those of Balsalobre-Lorente et al. (2018) and Bélaïd and Youssef (2017) who concluded electricity consumption with renewable sources positively influences environment quality. In fact, renewable-based electricity consumption reduces combined pollution and is capable of contributing to sustainable development in the long-run. It can be considered as the main tool for Iran's sustainable development target in the long-run. Our results contradict with Zeb et al. (2014) which confirmed an inverse impact of production of renewable electricity on environmental degradation.

In addition, by comparing the results obtained in the long-term and short-term, it is clear that the coefficients of all variables (except renewable electricity consumption) in the long-term are greater than the short-term. The coefficient of error correction ECM-1 shows what percentage of the short-term disequilibria of the combined pollution is adjusted in each period to achieve the long-term equilibrium. As we expect, the coefficient of ECM-1 is between zero and negative one and is statistically meaningful at 99% confidence level and its value is 0.474. This matter shows that approximately

0.474 of the combined pollution imbalance caused by the previous year's shock is adjusted to this year's long-term equilibrium. R^2 also offers a relatively good fit.

Table 6 Results of short-run test

Dependent variable: *ΔPI*				
Variables	*Coefficient*	*Std. error*	*t-statistic*	*Prob.*
Δ(REC)	0/041	0/34	–3/27	0/006
Δ(PREC)	0/225	0/44	5/415	0/000
Δ(ANS)	0/062	0/53	5/314	0/025
(ECT_{t-1})	0/474	0/81	3/750	0/000
R^2	0.652			
Adjusted R^2	0.496			

4.2.4 Parameter stability

Finally, the parameters stability is tested by the CUSUM and CUSUMSQ graphs offered by Brown et al. (1975). This test determines the long-run parameters stability in the cointegrating equation, where the dependent variable is PI. Figures 1 and 2 indicate the findings of COSUM and COSUMsq stability test. The mentioned figures suggest the presence of statistics inside the critical bounds, affirming that the ARDL parameters are stable.

4.3 Test of granger causality

In this step, the direction and the sources of causality are determined by the vector error correction model (VECM) with an error-term determined by the long-run cointegration vector developed in the second level. Compared to the previous research in this paper more comprehensive review has been conducted on all aspects of the causal relationship between renewable electricity consumption and production, combined pollution and sustainable development. If there is cointegration between the variables, the long and short-run relationships among the variables are distinguished by the VECM model. In the current research the Granger causality analysis is applied according to error correction model as follows:

$$\Delta Ln\, PI_t = \alpha_{01} + \sum_{i=1}^{1} \alpha_{11} \Delta \ln PI_{t-i} + \sum_{j=1}^{m} \alpha_{22} \Delta Ln\, REC_{t-j} + \sum_{j=1}^{m} \alpha_{33}\, \Delta Ln\, PREC_{t-r} + \sum_{j=1}^{m} \alpha_{44}\, \Delta Ln\, ANS_{t-s} + \eta_1 ECT_{t-1} + u_{1i} \tag{9}$$

$$Ln\, REC_t = \beta_{01} + \sum_{i=1}^{1} \beta_{11} \Delta \ln REC_{t-i} + \sum_{j=1}^{m} \beta_{22}\, \Delta Ln\, PI_{t-j} + \sum_{j=1}^{m} \beta_{33}\, \Delta Ln\, PREC_{t-r} + \sum_{j=1}^{m} \beta_{44}\, \Delta Ln\, ANS_{t-s} + \eta_2 ECT_{t-1} + u_{2i} \tag{10}$$

$$Ln\,PREC_t = \varnothing_{01} + \sum_{i=1}^{1} \varnothing_{11} \Delta \ln PREC_{t-i} + \sum_{j=1}^{m} \varnothing_{22}\, \Delta Ln\,PI_{t-j} + \sum_{j=1}^{m} \varnothing_{33}\, \Delta Ln\,REC_{t-r} + \sum_{j=1}^{m} \varnothing_{44}\, \Delta Ln\,ANS_{t-s} + \eta_3 ECT_{t-1} + u_{3i} \quad (11)$$

$$Ln\,ANS_t = \delta_{01} + \sum_{i=1}^{1} \delta_{11} \Delta \ln ANS_{t-i} + \sum_{j=1}^{m} \delta_{22}\, \Delta Ln\,PI_{t-j} + \sum_{j=1}^{m} \delta_{33}\, \Delta Ln\,REC_{t-r} + \sum_{j=1}^{m} \delta_{44}\, \Delta Ln\,PREC_{t-s} + \eta_2 ECT_{t-1} + u_{2i} \quad (12)$$

In the equations, Δ refers to the first difference operator and u_i stands for the residual terms, which are serially uncorrelated. k is the lag length regarding the test of likelihood ratio. η_i is an adjustment coefficient. ECT_{t-1} shows the cointegration vector.

Figure 1 Plot of cumulative sum of recursive (---CUSUM---5% significance) (see online version for colours)

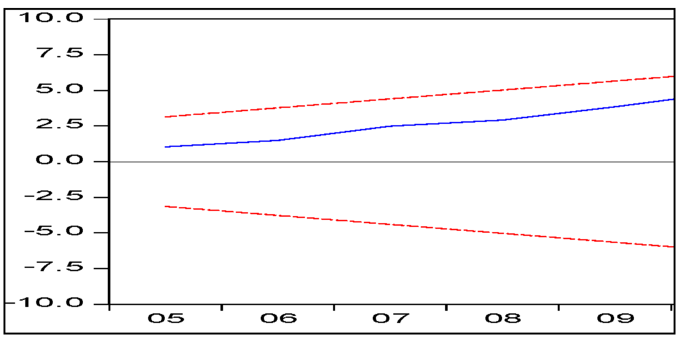

Figure 2 Plot of cumulative sum of squares of recursive residuals (---CUSUM of squares---5% significance) (see online version for colours)

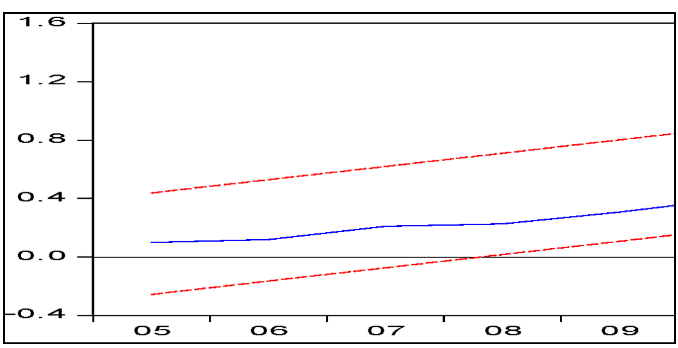

Table 7 indicates the findings of short-term and long-term Granger causality analysis using the vector error correction model. Based on Table 7, a unidirectional short-run Granger causality is evident running negatively from consumption of renewable electricity to combined pollution and positively from production of renewable electricity to sustainable development. Moreover, the positive bidirectional short-run Granger causality between production of renewable electricity and combined pollution and between consumption and production of renewable electricity is confirmed. In the short-run, our results are line with the findings of Farhani and Shahbaz (2020) confirming a unidirectional causality from output, non-renewable and renewable electricity consumption to CO_2 emissions.

Table 7 The VECM Granger causality test results

Short-run					*Long-run*	*SR*	*LR*
Dependent variable	*Δ(PI)*	*Δ(PREC)*	*Δ(REC)*	*Δ(ANS)*	ECT_{t-1}	REC→PI PREC→ANS REC↔PREC RREC↔PI	REC, PREC, ANS→PI
Δ(PI)	–	**1/328****	**–0/349***	0/049	–0/371*		
		(2/702)	**(–3/138)**	(1/553)	(–4/278)		
Δ(PREC)	**0/259*****	–	**0/463****	–0/035	0/232		
	(2/849)		**(2/799)**	(–1/186)	(–1/034)		
Δ(REC)	0/011	**0/059****	–	–0/012	–0/312		
	(1/690)	**(2/368)**		(–1/332)	(–1/361)		
Δ(ANS)	0/213	**2/168****	1/064	–	–0/045		
	(1/698)	**(2/605)**	(1/582)		(–1/121)		

*, ** and *** demonstrate a 10%, 5% and 1% significance level, respectively.

The estimated coefficient on lagged error correction term in equation (9) is indicated by Table 7. According to Table 7, this coefficient is significant at a 1% level. Therefore, the presence of long-run unidirectional causality is confirmed in equation (9) which runs from the variables; consumption and production of renewable electricity, sustainable development to combined pollution. Our findings differ from that of Farhani and Shahbaz (2020) who concluded a bidirectional causality between both renewable and non-renewable based electricity consumption and carbon dioxide emissions. Furthermore, our findings are inconsistent with the results of Menyah and Wolde-Rufael (2010). On the contrary, our findings are compatible with the results of Bélaïd and Youssef (2017) confirming a long-run unidirectional causality from the variables of non-renewable and renewable electricity consumption, and real GDP to the variable of carbon dioxide emissions.

The obtained results also confirm that the principle of sustainability has not been observed in the process of renewable electricity generation. Renewable electricity production is based on non-renewable energy sources and this has led to more emission of the pollutants. Moreover, renewable electricity production has not reached enough level to contribute to reducing combined pollution. One of the main ways to develop renewable electricity production and increase energy efficiency is to make the price of non-renewable electricity more realistic as to include all environmental and social costs. This leads to more economical electricity production from both renewable and non-renewable sources and reduces environmental degradation. Moreover, electricity production from renewable sources has a higher initial investment cost and more difficult access than the fossil fuels in Iran.

In Iran, despite the announcement of the declaration of the Council of Ministers in 2016 to provide 20% of the electricity from renewable sources required by government sectors and agencies, government agencies have not yet implemented this procedure. They stated that the main reason for not implementing the legislation is the lack of funding and incentive mechanisms. However, Iran has much more capacity for renewable energy, which can provide many advantages such as; energy security, affordable electricity, rising natural gas and oil reserves, stabilising electricity prices, reaching sustainable development, green jobs, and a green economy.

Finally, the coefficient of ECT is –0.371, which demonstrates the speed of the adjustment model towards long-term equilibrium. In fact, 34% of deviations in the long-run relationships for PI are adjusted in the current time for bringing the system back to the equilibrium.

5 Conclusion and policy implications

The present paper seeks to examine the dynamic relationship between consumption and production of renewable electricity, sustainable development and combined pollution in Iran over the period from 2010 to 2018. Generally, our results reveal that combined pollution in Iran is dependent on the consumption and production of renewable electricity and sustainable development. Based on the ARDL bounds testing cointegration strategy, the renewable electricity consumption increases the combined pollution in the short-run, although it decreases combined pollution in the long-run. Nevertheless, the production of renewable electricity and sustainable development statistically affect the combined pollution positively whether in the short-run or the long-run. According to the empirical findings, it appears that Iran's energy policymakers and authorities must reform the patterns of electricity production and consumption by swiftly moving from production and consumption of polluting energy to clean and carbon-free ones. They must also design policies to develop electricity generation capacities from renewable energy sources for reducing air pollution and protect the environment based on the principle of sustainability and not harming non-renewable sources. In fact, Iran requires policies and tools to accelerate renewable energy generation to meet the growing domestic energy demands and preserve its domestic oil reservoir for export as much and as fast as possible.

In the next step of the present study, a more general survey of the causal relationship between renewable electricity consumption and production, combined pollution and sustainable development has been conducted using the VCEM Granger causality analysis. According to the empirical findings, a unidirectional short-run Granger causality runs negatively from renewable electricity consumption to combined pollution and positively from renewable electricity production to sustainable development, but not vice versa. The results also confirm the positive bidirectional short-run Granger causality between renewable electricity production and combined pollution, which implies the increasing combined pollution means increasing renewable electricity production, and the opposite action is true too. Moreover, the positive bidirectional short-run Granger causality between renewable electricity consumption and production is concluded.

Furthermore, it can be concluded that consumption and production of renewable electricity and sustainable development Granger result in the combined pollution in the long-run, while the opposite does not occur in Iran. Therefore, an increase in renewable electricity production and sustainable development brings about an increase in combined pollution and an increase in renewable electricity consumption results in a decrease in combined pollution. Hence, it is crucial to decrease combined pollution and protect the environment by increasing renewable electricity consumption in Iran. However, the positive impact of renewable electricity generation on combined pollution is caused by the high price and unsustainable renewable electricity production, and unrealistic price of non-renewable electricity in Iran. Therefore, the government, by strengthening international cooperation, supporting renewable investments of private and non-governmental sectors, gradually eliminating of the fossil fuels subsidies and diverting the revenue from them to provide funding for investment in the renewable energy sector, by increasing the research budget for renewable energy and permitting the guaranteed purchase of renewable electricity by companies affiliated to the Ministry of Energy can pave the way for the widespread share of renewable energy in electricity production and consumption.

Finally, to achieve a green economy and sustainable development at the global level, it is necessary to follow different environmental and energy policies according to the specific economic and institutional characteristics of countries. Iran's electricity sector has been faced a shortage in this year, Iran's environmental and energy policies need to improve further and faster to bring about an energy transition that achieves sustainable development target, reduce environmental degradation, access to climate target, save national capital, provide energy for all and improve energy security. These findings and suggestions are also useful for all international companies consider entering Iran's renewable energy sector after sanctions are lifted.

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Conflict of interest

The corresponding author states that there is no conflict of interest.

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