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MODELING THE CAUSAL RELATIONSHIP BETWEEN NUCLEAR POWER, RENEWABLE ENERGY, AND IRAQI ECONOMIC GROWTH

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Abstract

Researchers are now concentrating on the connection between economic growth and environmental pollution as a result of growing worries about climate change and global warming (Ahmad et al., 2018). In fact, the argument over energy consumption has entered a new phase among scholars and decision-makers. This problem has grown more important in light of recent developments in climate agreements like COP-22. The International Energy Agency (IEA) has noted that the environment, society, and economy are all unstable under the current situation of energy usage. Unique energy actions are required in this circumstance. If not, oil demand will rise along with energy-related CO2 emissions, which will more than double until 2050 (IEA, 2017). The usage of fossil fuels like coal, gas, and oil in the majority of emerging nations, including Iraq, is another issue. These energy resources will eventually run out because they are non-renewable and non-nuclear in nature. As opposed to fossil fuels, renewable and nuclear energy sources have less of an impact on the environment. It's also crucial to remember that nuclear and renewable energy sources help safeguard the environment, cut down on CO2 emissions, and lessen reliance on imports. As a result, nuclear and renewable energy sources appear to be crucial for addressing issues with energy security and environmental deterioration (Saidi & Mbarek, 2016).

Introduction

High concerns about global warming, fluctuating fossil fuel energy prices, and environmental effects of CO_2 emissions have made nuclear and renewable energy sources an essential part of the world's energy consumption. The IEA (2009) states that "nuclear renewable energy is the fastest growing source of energy in the world and their share will increase from 10% to 14% in reference case in 2035." Numerous studies have looked into the connection between the use of nuclear and renewable energy sources and economic expansion. The relationship between nuclear, renewable energy, and economic growth should be highlighted while considering the primary tenet of a sustainable energy future.

Iraq is one of the nations with a power crisis, and the use of nuclear and renewable energy has a negligible impact on growth. Furthermore, less than half of the rural population has no access to power or has extremely limited access, making access to electricity a crucial issue for both rural and urban populations. Iraq relies on fossil fuels to meet its energy needs (73% of the nation's total energy consumption in 2021 came from oil; the remaining 24% came from gas; and the lowest percentage came from hydropower (3%); Iraq Energy Information, 2022).

However, access to these fuels is constrained, and they also produce pollution, which is a worrying problem. According to Baloch and Kaloi (2016), only 1.0% and 3% of Iraq's energy consumption comes from nuclear and renewable sources, respectively, while 73% of the country's energy demands are met by oil. According to Sheikh (2010), 99% of Iraq's energy supply comes from traditional sources like oil, gas, and electricity, with only 3% coming from renewable sources. Although renewable energy was used 46.5% of the time in 2015, the production capacity of renewable energy appears to be limited (Fig. 1(A)). A declining trend in the utilization of renewable energy is depicted in Fig. 1(B). Additionally, it is seen that CO_2 emissions have increased over time as measured in million tons (Fig. 1 (C)).

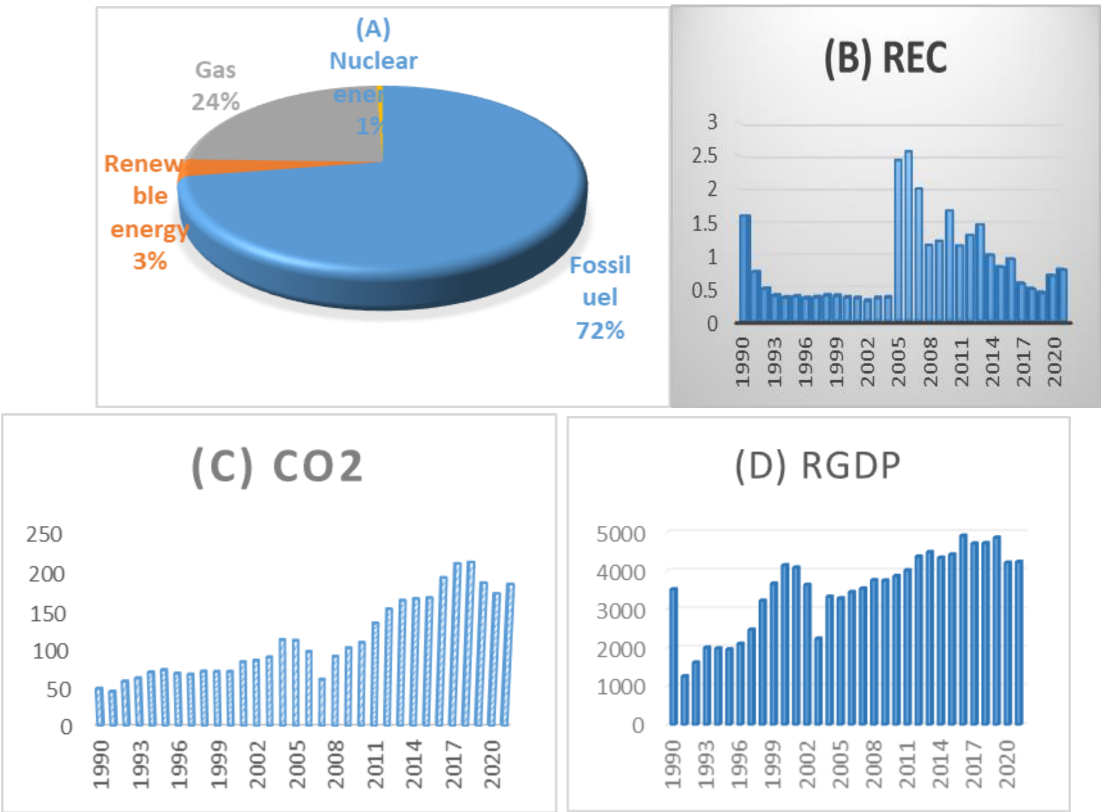

Figure 1: The production capacity of per energy source is shown in (A), Usage of renewable energy in % term is shown in (B), development of CO_2 emissions in million tones is shown in (C) and economic growth shown in (D).

Iraq is experiencing an electrical shortage of 6–8 hours in urban regions and 9–12 hours in rural areas due to recent energy crises. The IEA (2017) estimates that Iraq produced over 70 million tons of oil equivalent in total energy in 2017. Furthermore, research has shown that energy is the lifeblood of an economy (Ahmad & Du, 2017); nevertheless, in this context, nuclear and renewable energy can offer a bright future for sustainable growth and development, as well as help Iraq resolve its electricity shortage problem. First, it is a novel study that combines nuclear energy and renewable energy in the production function with labor and capital to test their impact on Iraq's economic growth given the significance of both energies in the discussion of climate change and sustainable development. This study also contributes to literature in three other ways. In order to determine the most affordable methods of energy efficiency for Iraq, this research also takes into account clean energies, such as nuclear and renewable energy, as a dependent variable. Third, to extract trustworthy information, this research applies the recently developed linear autoregressive distributed lag (ARDL) approach by Shin & Yu (2014). According to Shin and Yu (2014), the traditional autoregressive distributed lag model (ARDL) developed by Pesaran et al. (2001) can produce accurate findings when there is a symmetric relationship. Additionally, ARDL will provide research on the effects of nuclear and renewable energy usage on economic growth. Section 2 provides a brief review of the literature, and Section 3 presents the econometric model, data, and estimation technique. The short- and long-term findings are shown in Section 4. Section 5 is for discussion, while section 6 offers policy recommendations to wrap up the report.

2. Review of the literature

Energy economics literature from the past has looked at the short- and long-term relationships between energy use and economic growth. Ahmad & Du (2017); Cong et al. (2008); Cong & Shen (2013); Ahmad et al. (2017); Ozturl et al. (2010); Apergis & Payne (2009); Payne et al. (2017); Luqman et al. (2019); however, in earlier literature, much emphasis is placed on the relationship between energy consumption and growth, and literature pertaining to Iraq appears to be lacking. The purpose of this article is to further the conversation by examining how nuclear power, renewable energy, and economic growth in Iraq are related. According to Apergis & Payne (2011), the relationship between energy and economic growth raises four hypotheses: "feedback, growth, conservation, and neutral hypothesis." The feedback hypothesis contends that there is a causal link between energy consumption and economic growth. It indicates that two variables are complementing one another. Studies on the relationship between growth and energy, however, also reveal a one-way causal link from energy to economic growth, indicating that energy consumption plays a crucial role in the expansion and development of the economy. According to the conservation theory, energy consumption began as a result of growth.

There is no causal link between energy use and economic growth, according to the neutrality hypothesis. In the literature, researchers have found support for the previously mentioned hypothesis that the use of renewable energy contributes to economic growth (Ahmad et al., 2017; Apergis & Payne, 2011; Apergis & Payne, 2010; Menegaki, 2010; Pao & Fu, 2013; salim & rafiq, 2012; Sari et al., 2008; Soyates & Sari, 2009; Soyates et al. According to research (Ang et al., 2010; Go & Ang, 2018), implementing efficient technology can help reduce CO_2 emissions. Therefore, it would appear that calculating CO_2 emissions directly would be difficult without taking nuclear and renewable energy use into account.

The two-way causal relationship between nuclear energy consumption and economic growth has been the subject of a few recent empirical investigations. Yoo and Jung's (2006) research examined the relationship between Korea's nuclear energy use and economic growth. Results support the growth concept. Menyah and Wolde-Rufael (2010) expanded the research on single-country time series and supported the neutrality hypothesis for the USA. The study by Payne and Taylor (Payne & Taylor, 2010) supported the conclusion. Shahbaz et al. (2017) conducted an additional single-country research for India utilizing financial development and capital as supplementary factors. Yoo & Jung's (2006) analysis of the evidence supports the growth concept. Energy productivity and energy intensity are convergent, according to recent literature (Shahbaz et al., 2017; Miketa & Mulder, 2005; Markandya, 2006). Electricity can replace the usage of coal in Chinese urban areas, claim Herrerias et al. (2017). Their findings show some steady state convergence in energy usage across urban and rural locations. Following their discovery of the existence of regional cluster convergence, they have proposed a local policy instrument. In recent research, the LM and RASL-LM tests have been employed to examine whether energy consumption and economic development are convergent (Payne, Vizek & Lee, 2017; Payne et al., 2017; Meng et al., 2013).

The relationship between energy use and economic growth in Pakistan has received little research. According to Bakhsh et al. (2017), Pakistan's industrial sector is the main driver of economic growth. They've come to the conclusion that as Pakistan's economy grows, so do its environmental emissions. Satti et al. (2014), on the other hand, investigated the link between coal consumption and economic growth in Pakistan, confirmed the feedback hypothesis, and discovered bi-direction causality between coal consumption and economic growth using a vector error correction model. However, there is no literature on the link between Iraq's economic growth and nuclear or renewable energy. As a result, this report fills in the gaps, emphasizes the relevance of nuclear and renewable energy, and offers practical solutions for the Iraqi energy market. To the best of our knowledge, this study is the first to examine how nuclear energy, renewable energy, and economic growth in Iraq relate to one another. The study's originality is also its usage of ARDL.

3. Data, model and econometric estimation technique

3.1. Econometric modeling

The relationship between economic growth, renewable energy, and nuclear energy is investigated using a comprehensive system of production model. The traditional Cobb-Douglas production function includes extra factors like labor and capital in order to address the biasness caused by variables omission. The first equation is specified to examine the impact of energy consumption from renewable and nuclear sources, respectively, on economic growth of the Iraqi economy in line with recent studies such as Apergis & Payne (2010), Apergis & Payne (2010b), Wolde-Rufael & Menyah (2010), Marques & Fuinhas (2012), and Luqman et al. (2019). The Cobb Douglas production function is specified in an abbreviated form as follows:

$$Y = AK^{\beta_1} L^{\beta_2} E^{\beta_3} \varepsilon^{\upsilon} \quad \text{..........(1)}$$

After the logarithm of both sides, equation (1) can be expressed as:

$$\ln Y_t = \beta_0 + \beta_1 \ln K_t + \beta_2 \ln L_t + \beta_3 \ln E_t + \upsilon_t \quad \text{..........(2)}$$

The abridged version of equation (2) is as follows:

$$\ln RGDP_t = \beta_0 + \beta_1 \ln GCF_t + \beta_2 \ln TLF_t + \beta_3 \ln ENE_t + \upsilon_t \text{.................................}(3)$$

Where β_0 = lnA_0,, t stands for time intervals, Y = real GDP, E = ENE stands for energy consumption indicator for nuclear and renewable energy consumption, K = GCF stands for stock of capital, and L = labor stands for total labor force. A is the technological level, and is a phrase for white noise mistake. Energy consumption, capital, and labor output elasticities are denoted as β_1, β_2, and β_3, respectively. Cobb Douglas' production function is constrained to ($\beta_1 + \beta_2 + \beta_3 = 1$), which results in a constant return to scale. Moving on, equation (4) is applied, which assumes that the consumption of two types of energies (nuclear and renewable) can be influenced by economic development (RGDP), environmental degradation (CO_2), oil consumption (OIL), and actual oil price (ROP). Equation (4) was inspired by Sadorsky (2009) and Lee and Chiu (2011). In order to study the determinants of nuclear energy and renewable energy, this paper builds two more models based on equation (4). Variables are expressed in log form to be understood as elastic. This is how the energy equation is expressed:

$$ENE_t = \lambda_0 + \lambda_1 RGDP_t + \lambda_2 CO_{2t} + \lambda_3 OIL_t + \lambda_4 ROP_t + \mu_t \text{...............................}(4)$$

3.2 Data

In the analysis, annual statistics on the Iraqi economy from 1990 to 2021 were used. Nuclear energy consumption (NUC) is measured in Terawatt-hours and is expressed as real GDP (RGDP) in constant 2015 US dollars. Combustible renewables and waste percentage of total energy are used to determine renewable energy consumption (REC), which is stated in thousands of metric tons. Gross fixed capital formation (K), which was constant in 2005, is measured in billions of US dollars, while the total labor force (TLF) is expressed in millions. Million tons of carbon dioxide emissions are used to measure CO2 emissions. Oil consumption is expressed in thousand barrels of day oil consumption (OIL), and the real oil price (ROP) is roughly based on the spot price on "West Texas Intermediate" (WTI). The information on nuclear energy use, CO2 emissions, oil price, and oil consumption is taken from the British Petroleum Statistical Review of World Energy, whereas the information on real GDP, combustible renewable and waste energy's share of total energy, gross fixed capital formation, and labor force is taken from the World Development Indicators published by the World Bank in 2022. To translate coefficients into elasticities, all variables are translated into log form.

3.3. Technique of estimation

The ARDL model utilized in this work is a symmetric system of Pesaran et al. (2001)'s linear autoregressive distributed lag model (ARDL). A dynamic error correction model used in the ARDL technique enables the capturing of both short- and long-run symmetries.

In comparison to existing co-integration methods, this methodological framework performs better in both small and large samples (Ahmad et al., 2017; Romilly et al, 2001). It also permits co-integration and symmetric -linearity in a single equation. When variables are I(0), I(1), or a combination of the two, conventional ARDL and Non-ARDL are more flexible and produce accurate and precise findings (Ahmad & Du, 2017; Nusair, 2016). The Johansen methodology (Johansen, 1991; Johanse, 1988) and Engle and Granger (1987) are acceptable approaches based on standardized methodologies. In order to use the Johansen approach, all variables must be integrated to the first order, i.e. The only application of the I(1) and Engle and Granger approach is to determine causation. First, the co-integration relationship will be evaluated using the ordinary least squares (OLS) approach, and the proper lag order will be selected. Second, the ARDL approach is still useful regardless of the order of integration (I(0), I(1), or both). Third, it's important to note that this technique (ARDL) is excellent for small samples (Ahmand & Du, 2017). Fourth, ARDL will offer objective long run approximations and test statistics when some of the regressors are endogenous. Fifth, the ARDL test documents the data production process from a general to a specialized framework using a variety of lags (Apergis & Payne, 2009). These traits allow ARDL to incorporate short-run adjustment to long-run equilibrium without sacrificing long-term knowledge (Shin & Yu, 2014).

3.4. Check for stationarity with structural breaks

We perform a unit root test prior to the estimate of the ARDL model using the recently established unit root test with structural breaks by Lee and Strazicich (2013) to assess the stationarity characteristics of the variables. The Lee and Strazicich (L&S) test is a structurally broken minimum Lagrange multiplier (LM) unit root test. By providing details on the unidentified break dates, the L-S test mitigates the drawbacks of the traditional unit root tests like the augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS). Comparing the L'S test to other structural break tests such the Zivot Andrews (1992), Lumsdaine and Papell (1997), and Clemente, Montaés, and Reyes (1998) tests, it has also been shown that the L'S test has better size and power qualities and can estimate the break dates with greater accuracy. Because of this, difficulties with erroneous estimates and incorrect break date estimation are avoided when using the L-S test.

3.5. Analysis of co-integration

The study employs the ARDL model's limits testing approach to cointegration. As a result, it is appropriate for the model's cointegration properties. The following describes the general form of the ARDL approach's unrestricted error correcting model:

$$\Delta Y_t = \partial + \rho Y_{t-1} + \psi X_{t-1} + \sum_{j-1}^{p-1} \beta_j \Delta Y_{t-1} + \sum_{j=0}^{q-1} \lambda_j \Delta X_{t-1} + \xi_t \qquad (5)$$

where Δ stands for the first difference operator, Y_t represents the dependent variable, is an intercept, X_t stands for a k - 1 vector of regressors, ρ and ψ stand for the long-run coefficients, βj and λ_j for the short-run coefficients, p and q for the lags order of the individual variables, and ε_t stands for the white noise error component. The ARDL model procedure entails contrasting the co-integration option, ρ = ψ = 0 against the null hypothesis of no co-integration, ρ ≠ ψ ≠ 0. Pesaran et al. (2001) have developed a non-standard F-test, denoted as FPS, which incorporates the stationarity characteristics of the variables to test this hypothesis. They have determined boundaries with critical values to be more exact. All variables are assumed to be I(0) for lower bounds and I(1) for higher bounds, respectively. If the test statistic is above the upper bounds critical value, the null hypothesis of no co-integration is rejected; conversely, if the test statistic is below the lower bounds, the null hypothesis is accepted. Finally, if test statistics fall inside the top and lower boundaries, the results are still unclear. In this case, the presence of co-integration will be confirmed by a negative and considerable error correction term (Ahmad et al., 2018; Ahmad etal., 2017). We test nonlinear co-integration after determining the order of variable integration by using a general ARDL (p, q) model, as illustrated below:

$$\Delta RGDP_t = \chi_0 + \chi_1 \ln RGDP_{t-1} + \chi_2 \ln ENE_{t-1} + \chi_3 \ln Controls_{t-1} + \sum_{i=0}^{p} \varphi_1 \Delta \ln RGDP_{t-i} + \sum_{i=0}^{q} \varphi_2 \Delta \ln ENE_{t-i} + \sum_{i=0}^{q} \varphi_3 \Delta \ln Controls_{t-i} + \eta ECM_{t-1} + \varepsilon_t \quad (6)$$

$$\Delta ENE_t = \theta_0 + \theta_1 \ln ENE_{t-1} + \theta_2 \ln RDP_{t-1} + \theta_3 \ln Controls + \sum_{i=0}^{p} \pi_1 \Delta \ln ENE_{t-i} + \sum_{i=0}^{q} \pi_2 \Delta \ln RGDP_{t-i} + \sum_{i=0}^{q} \pi_3 \Delta \ln Controls_{t-i} + \varpi ECM_{t-1} + \upsilon_t \quad (7)$$

where ln is the natural logarithm of the variables, χ_1-χ_3 are the long–run parameters for the RGDP model, ϕ_1-ϕ_3 are the short–run parameters, χ_0, and ε are the intercept term and the white noise stochastic term, respectively, is the parameter of the error correction mechanism (ECM), and is the difference operator. Similar to this, the energy (renewable and nuclear) model's long run parameters are θ_1-θ_3; the short run parameters are π_1-π_3; the intercept and error term are θ_0 and ν, respectively; controls are the control variables such as the total labor force (TLF), gross fixed capital formation (GCF), and carbon emissions (CO_2); and is the parameter of the error correction mechanism with respect to the energy equation. There may be delays in the long-run effects of shocks to any of the regressors on RGDP and ENE, causing the system to be out of equilibrium and necessitating the use of the error correction mechanism (ECM_{t-1}). The ECM_{t-1} is a one lag error correction term that takes into account how quickly the long-run equilibrium is reached. Furthermore, we use the block exogeneity/VECM Granger causality test to look into the direction of causality among the variables. Shahbaz, Khan, Ali, and Bhattacharya (2017) contend that as this test permits estimate of both short-run and long-run causal links, it is preferable to pairwise Granger causality. The VECM Granger causality model for this investigation is described in Equations (8) and (9), which follows the framework of Ozatac et al. (2017).

$$\begin{bmatrix} \Delta \ln RGDP_t \\ \Delta \ln ENE_t \\ \Delta \ln Control_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} + \begin{bmatrix} \rho_{11i}\rho_{12i}\rho_{13i} \\ \rho_{21i}\rho_{22i}\rho_{23i} \\ \rho_{31i}\rho_{32i}\rho_{33i} \end{bmatrix} X \begin{bmatrix} \Delta \ln RGDP_{t-1} \\ \Delta \ln ENE_{t-1} \\ \Delta \ln Control_{t-1} \end{bmatrix} + \ldots +$$

$$\begin{bmatrix} \rho_{11i}\rho_{12i}\rho_{13i} \\ \rho_{21i}\rho_{22i}\rho_{23i} \\ \rho_{31i}\rho_{32i}\rho_{33i} \end{bmatrix} X \begin{bmatrix} \Delta \ln RGDP_{t-i} \\ \Delta \ln ENE_{t-i} \\ \Delta \ln Control_{t-i} \end{bmatrix} + \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} ECM_{t-1} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} \text{..........(8)}$$

$$\begin{bmatrix} \Delta \ln ENE_t \\ \Delta \ln RGDP_t \\ \Delta \ln Control_t \end{bmatrix} = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \end{bmatrix} + \begin{bmatrix} \rho_{11i}\rho_{12i}\rho_{13i} \\ \rho_{21i}\rho_{22i}\rho_{23i} \\ \rho_{31i}\rho_{32i}\rho_{33i} \end{bmatrix} X \begin{bmatrix} \Delta \ln ENE_{t-1} \\ \Delta \ln RGDP_{t-1} \\ \Delta \ln Control_{t-1} \end{bmatrix} + \ldots +$$

$$\begin{bmatrix} \rho_{11i}\rho_{12i}\rho_{13i} \\ \rho_{21i}\rho_{22i}\rho_{23i} \\ \rho_{31i}\rho_{32i}\rho_{33i} \end{bmatrix} X \begin{bmatrix} \Delta \ln ENE_{t-i} \\ \Delta \ln RGDP_{t-i} \\ \Delta \ln Control_{t-i} \end{bmatrix} + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix} ECM_{t-1} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix} \text{..........(9)}$$

ECM_{t-1} is the lag of error correction term derived from the long-run equation, and ε_1, ε_2, and ε_3 are the white noise error terms. Here, stands for the first difference operator. If the value of ECMt1 is statistically significant, there is a long-term causal relationship between the variables; nevertheless, if the F-statistic for the first differenced variables is statistically significant, there is a short-term causal relationship between the variables.

4.0. Analysis of the data and results of findings

4.1 The outcome of descriptive statistics

The mean, standard deviation, Jarque Bera, and related probability for normalcy are shown in Table 1's descriptive statistics, along with the total number of observations.

Table 1: Descriptive statistics result

	RGDP	GCF	NUC	REC	OIL	ROP	TLF	CO_2
Mean	3496.782	2.16E+10	0.539	0.869	543.062	61.173	7162058.	113.144
Std Dev.	1249.068	5.84E+09	0.120	0.310	217.000	20.190	4147362.	45.185
J-B	2.878812	1.805418	6.091	9.035	0.153	3.723	2.309	3.275
P-Value	0.237068	0.405470	0.047	0.010	0.926	0.155	0.315	0.194
Obs.	32	32	32	32	32	32	32	32

Source: Author’s compilation

The data in Table 2 demonstrates that, aside from nuclear and renewable energy, all variables pass the Jarque-Bera (JB) test of normality. With the exception of the total labor force, which shows a considerable variance, the standard deviations of the variables suggest small deviations from the mean.

4.2 Correlation matrix results

A correlation analysis is carried out to look at the relationships between independent factors and the dependent variable as well as between independent variables. The outcome is displayed in Table 2.

Table 2: Correlation analysis result

	RGDP	GCF	NUC	REC	OIL	ROP	TLF	CO_2
RGDP	1							
GCF	0.203	1						
NUC	0.001	0.395	1					
REC	0.214	-0.284	-0.124	1				
OIL	0.658	0.281	0.392	-0.111	1			
ROP	0.508	-0.074	0.129	0.613	0.309	1		
TLF	0.823	0.186	0.134	0.131	0.806	0.479	1	
CO_2	0.775	0.210	0.253	0.044	0.851	0.428	0.956	1

Source: Author's computation

4.3 Unit root test outcome

All the variables are integrated of order one [(I(1)] according to the findings of the L-S unit root test in Table 3, with the exception of gross fixed capital formation (GCF) and oil consumption (OIL), which are at level and show signs of structural fractures.

Table 3: Unit root results

	L-S test at levels		L-S test at first difference	
Variable	LM statistics	Break date	LM statistics	Break date
$\ln CO_2$	-3.8892(0)	2007	-9.9519(0)***	2007
lnGCF	-5.9734(0)***	2000	-14.0453(0)***	2001
lnNUC	-3.9843(1)	2011	-6.1261(1)***	2012
lnOIL	-5.9627(0)***	2012	-8.1606(0)***	2007
lnREC	-3.8267(1)	2004	-9.1989(0)***	2005
lnRGDP	-3.5649(0)	1997	-15.8863(0)***	2003
lnROP	-4.4452(2)	2014	-5.9204(1)***	2013
lnTLF	-4.1679(5)	2005	-5.4969(5)***	2005

Note: Values in parenthesis are the lag length of variables.
** denotes rejection of null hypothesis at the 5% level.

4.4 The ARDL bounds test's conclusion

We implement the ARDL limits test cointegration test to verify the cointegrating relationship among the variables since the results show a combination of I(0) and I(1) processes for all of the series. The findings are shown in Table 4. The Fisher statistics for the three models (lnRGDP, lnREC, and lnNUC) tests are higher than the upper limits critical bounds at 5% for all the models, as is seen from the findings. This implies that the null hypothesis—that there is no cointegration among the variables—is rejected and that cointegration occurs among the variables regardless of which one is endogenized.

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Table 4: ARDL bounds test to cointegration result

Estimated model	F-statistic	Critical values of Pesaran etal		Outcome
		I(0)	I(1)	
lnRGDP (3,1,3,3,4)	4.7677**	2.56	3.49	Cointegration exists
lnREC (1,2,4,4,4)	5.9286**	2.947	4.088	Cointegration exists
lnNUC (4,4,2,4,4)	4.5091**	2.947	4.088	Cointegration exists

** denotes significance at the 5% level.

4.5 Results of short- and long-run elasticities

The next stage after symmetric co-integration has been established is to determine the three models' short- and long-term elasticities. This discussion comes after the short-term outcomes in Table 5.

Table 5: Short run coefficients' results

Model 1 (Dep. Var: lnRDGP)		Model 2 (Dep. Var: lnREC)		Model 3 (Dep. Var: lnNUC)	
Variable	Coef. (std error)	Variable	Coef. (std error)	Variable	Coef. (std error)
$\Delta lnRGDP_{(-1)}$	-0.6159***(0.1749)	$\Delta lnREC_{(-1)}$	0.8265***(0.1224)	$\Delta lnNUC_{(-1)}$	-0.3535(0.1713)
ΔlnREC	0.1542**(0.0532)	ΔlnRGDP	1.1810***(0.2796)	ΔlnRGDP	-3.2328(7.2245)
ΔlnNUC	0.0574**(0.0268)	ΔlnOIL	-1.5478***(4.0612)	ΔlnOIL	3.1675(2.7913)
ΔlnGCF	0.0501(0.0317)	ΔlnROP	0.1819(0.2050)	ΔlnROP	1.3655(0.5930)
ΔlnTLF	0.9769(0.9614)	ΔCO_2	1.7587(0.7148)	ΔCO_2	0.6659(0.7491)
$ECM_{(t-1)}$	-0.5528(0.0828)	$ECM_{(t-1)}$	-0.3993***(0.0624)	$ECM_{(t-1)}$	-0.5226***(0.0868)

***,** denote significance at the 1% and 5% level respectively.

The data in Table 5 show that real GDP inertia significantly and negatively affects the real GDP as of the current year. This suggests that the present real GDP is less than the previous real GDP. Furthermore, when economic growth is the dependent variable, the shock to renewable energy is found to be significant and has a positive correlation with economic growth, with a coefficient of 0.1542. It implies that any effort to increase the use of renewable energy won't have an immediate negative impact on Iraq's economic expansion. With a coefficient of 0.0574, the usage of nuclear energy is revealed to have a shock that positively affects economic growth. The introduction of nuclear and renewable energy technology as a potential means of reducing Iraq's energy shortage depends on policymakers having access to this information. The total labor force and gross fixed capital formation are determined to be inconsequential in explaining economic growth in the Iraqi economy.

When renewable energy is the dependent variable, the shock to economic development has a positive contribution in the short run with a 1% significance level. The economic justification for these findings suggests investing in renewable energy technologies as a reliable insurance policy against Iranian energy emergencies. The short-term, 1% substantial impact of the negative shock to oil consumption is bad for renewable energy. The findings imply that Iraq's use of renewable energy is being hampered by investments in oil consumption. These findings seem to imply that any short-term effort to cut oil use may have an impact on the use of renewable energy sources. Additionally, for the time period under consideration, the consumption of renewable energy in Iran is not significantly impacted by the price of oil or CO_2 emissions. It emphasizes that reducing CO_2 emissions is a long-term issue.

When nuclear energy is the dependent variable, positive shocks to economic development have negative effects. It implies that using nuclear energy in the short term won't help Iraq's economy grow or resolve its energy challenges. Other shocks are also determined to be inconsequential for the related equations since growth and development are long-term phenomena with visible positive results.

The three models' rates of adjustment (Real GDP, renewable energy use, and nuclear energy consumption) are all statistically significant and in the negative. The findings show that, in the case of short run distortions, it takes real GDP, renewable energy consumption, and nuclear energy consumption, respectively, 55.28%, 39.93%, and 52.265 to adjust to long run equilibrium pathways.

Table 6: Long run coefficients' results

Model 1 (Dep. Var: lnRDGP)		Model 2 (Dep. Var: lnREC)		Model 3 (Dep. Var: lnNUC)	
Variable	Coef (std. error)	Variable	Coef (std. error)	Variable	Coef (std. error)
lnREC	0.4402**(0.2014)	lnRGDP	1.3316**(0.6149)	lnRGDP	0.4241***(1.3020)
lnNUC	0.1001**(0.0222)	lnROP	-0.7958(2.7200)	lnROP	0.7726(0.5058)
lnGCF	1.0971***(0.0441)	lnOIL	-8.5893(10.3006)	lnOIL	2.3764(1.4399)
lnTLF	-0.0797(0.7150)	$lnCO_2$	4.6223(6.1208)	$lnCO_2$	0.2182**(0.0107)

***,** denote significance at the 1% and 5% level respectively.

The analyses of long-run dynamics that follow, with economic growth as the dependent variable, are presented in Table 6. Based on the symmetric ARDL model's calculated long-run coefficient, the results show that renewable energy is important for positive shocks. It implies that long-term economic growth in Iraq will benefit from the use of renewable energy. The projected long-run coefficients are 7.24, which means that a 1% increase in renewable energy will increase economic growth by 7.24%.

Results pertaining to nuclear energy indicate that it is significant for positive with favorable indicators. Nuclear energy's predicted long-run coefficients were reported to be 0.1001. Therefore, we get the conclusion that a 1% increase in nuclear energy causes an economic growth of 0.1001%. Positive shocks to gross fixed capital creation over the long term have a big effect on economic growth. It is consistent with recent research that have discovered a beneficial relationship between capital formation and economic growth, including Sahoo et al. (2010) for China, Sahoo and Dash (2009) for India, and Lugman et al. (2019) for the Pakistani economy. It has little bearing on the relationship between an increase in the labor force and economic growth.

When renewable energy is considered a dependent variable, the results show that the long-run coefficients of economic growth are substantial for positive shocks. With a value of 1.3316, a positive shock to economic growth has a positive and large impact on the use of renewable energy. It suggests that every boost to economic growth results in higher utilization of renewable energy. Renewable energy and a positive shock to oil consumption have no real connection. It has no bearing on the connections between the cost of oil and the utilization of renewable energy. Positive shocks to CO_2 emissions show that renewable energy usage is actively accelerated by any positive shock to CO_2 emissions. It is significant to highlight that over time, CO_2 emissions and the consumption of renewable energy are related.

The analysis of long-run dynamics is presented in the final stage when nuclear energy consumption is used as the dependent variable. Economic growth has a strong, positive long-term coefficient. According to the projected long-run coefficients, a 1% increase in economic growth results in an increase of 0.4241% in nuclear energy consumption. The relationship between the price of oil and the use of nuclear energy, as well as the relationship between the two, is negligible. Finally, CO_2 emissions (a positive shock) have a 0.2182 coefficient influence on renewable energy usage. It means that any reduction in CO_2 emissions has a significant impact on speeding up Iraq's use of nuclear energy. It is significant to highlight that CO_2 emissions and nuclear energy usage have a history of being linked. Table 7's diagnostic test statistics show that none of the three models had serial correlation or heteroscedasticity issues.

Table 7: Diagnostic test results

Model 1 (Dep. Var: lnRDGP)		Model 2 (Dep. Var: lnREC)		Model 3 (Dep. Var: lnNUC)	
χ^2_{SC}	3.16(0.24)	χ^2_{SC}	3.36(0.17)	χ^2_{SC}	0.73(0.49)
χ^2_{ARCH}	0.01(0.91)	χ^2_{ARCH}	3.57(0.12)	χ^2_{ARCH}	0.06(0.80)
R^2	0.59	R^2	0.23	R^2	0.28
Adj. R^2	0.55	Adj. R^2	0.20	Adj. R^2	0.15
D-W statistic	2.36	D-W statistic	1.62	D-W statistic	2.20

Note: χ^2_{SC} and χ^2_{HS} denote Lagragian Multiplier tests for serial correlation and heteroscedasticity respectively.

4.6 Granger causality result for the Vector Error Correction Mechanism (VECM)

Long-run and short-run causality are both evident in the economic growth (lnRGDP) model's VECM Granger causality results in Table 8. Given that the error correction term (ECM) is negative, statistically significant, and has an annual speed of adjustment of 55.2%, the results suggest that there is long-term unidirectional causality between the independent variables (renewable energy consumption, nuclear energy consumption, gross fixed capital formation, and total labor force) and real GDP. At a 5% level of significance, the data point to a unidirectional causal relationship between real GDP and renewable energy consumption in the short run. Similar to this, we discover unidirectional causality connecting total labor force to renewable energy consumption, nuclear energy to gross fixed capital formation, and total labor force to nuclear energy. Additionally, the findings show a two-way causal relationship between a number of variables in the real GDP model.

Table 8: VECM Granger causality results

Direction of Granger causality: Model 1 (lnRGDP as the dependent variable)						
Short run				Long run		
Variable	ΔlnRGDP	ΔlnREC	ΔlnNUC	ΔlnGCF	ΔlnTLF	$ECM_{(t-1)}$
ΔlnRGDP	-	0.154**(0.017)	0.057*(0.061)	0.050(0.148)	0.961(0.336)	-0.552***[-6.670]
ΔlnREC	0.406(0.171)	-	0.127**(0.039)	0.173**(0.018)	3.287***(0.000)	-
ΔlnNUC	1.834**(0.043)	0.658*(0.065)	-	0.198(0.284)	0.613(0.390)	-
ΔlnGCF	0.138(0.853)	0.322(0.170)	0.307**(0.035)	-	0.924(0.344)	-
ΔlnTLF	0.011**(0.044)	0.295***(0.003)	0.385(0.251)	0.768*(0.078)	-	-
Direction of Granger causality: Model 2 (lnREC as the dependent variable)						
Variable	ΔlnREC	ΔlnRGDP	ΔlnOIL	ΔlnROP	$\Delta lnCO_2$	$ECM_{(t-1)}$
ΔlnREC	-	1.181***(0.001)	0.108(0.680)	0.567**(0.018)	2.300***(0.002)	-0.399***[-6.398]
ΔlnRGDP	0.145(0.117)	-	0.254*(0.067)	0.085(0.194)	0.018(0.896)	-
ΔlnOIL	0.126(0.818)	0.015(0.907)	-	0.230(0.204)	0.169(0.193)	-
ΔlnROP	0.427**(0.050)	0.821**(0.034)	0.241(0.350)	-	2.791***(0.003)	-
$\Delta lnCO_2$	0.089**(0.021)	0.076(0.219)	0.081(0.185)	0.229***(0.000)	-	-
Direction of Granger causality: Model 3 (lnNUC as the dependent variable)						
Variable	ΔlnNUC	ΔlnRGDP	ΔlnOIL	ΔlnROP	$\Delta lnCO_2$	$ECM_{(t-1)}$
ΔlnNUC	-	0.896*(0.097)	0.023(0.876)	0.128(0.647)	0.038(0.923)	-0.522***[-6.020]
ΔlnRGDP	0.130(0.954)	-	0.847***(0.001)	0.508***(0.002)	0.399***(0.005)	-
ΔlnOIL	0.034(0.111)	0.658***(0.000)	-	0.499***(0.002)	0.371***(0.002)	-
ΔlnROP	0.043(0.271)	0.970***(0.000)	1.511***(0.000)	-	0.421**(0.021)	-
$\Delta lnCO_2$	0.018(0.610)	1.007***(0.002)	1.051***(0.003)	0.401**(0.030)	-	-

***,**,* denote significance at the 1%, 5% and 10% level respectively.

Additionally, the VECM Granger causality for the consumption of renewable energy (lnREC) model in Table 8 indicates both long- and short-term causality. First, the ECM's negative sign and statistical significance demonstrate the long-term results. In other words, a single line of causality connects the independent variables (real GDP, oil consumption, real oil price, and carbon emissions) to the consumption of renewable energy. In terms of short-term causality, real GDP and renewable energy are related in a single direction, whereas real oil prices, carbon emissions, and renewable energy consumption are related in two directions.

Additionally, the significance of the ECM for the VECM Granger causality for nuclear energy consumption (lnNUC) model in Table 8 demonstrates that there is a unidirectional causality from the independent variables (real GDP, oil consumption, real price of oil, and carbon emissions) to nuclear energy consumption. The rate of nuclear energy consumption adjustment to the run path is typically 52.2%. There are several short-term bidirectional causal relationships between the factors affecting nuclear energy usage.

5. Conclusion and implication for policy

Using annual data from 1990 to 2021, this study examines the relationship between the consumption of nuclear energy, renewable energy, and economic growth in Iraq. We use annual time series data from 1990 to 2016 to accomplish these goals. We use second-generation econometric approaches such as the Lee and Strazicich test with structural break to examine the stationarity properties of the variables and the bounds test to combined cointegration test to determine whether or not there is a long-run relationship among the variables. Finally, we apply ARDL and the VECM Granger causality test to investigate the effect and causal relationships. The findings show that consumption of nuclear energy, renewable energy, and gross fixed capital formation all contribute to better economic growth in both the long and short terms, however the total labor force did not significantly affect economic growth in Iraq over the study period. Results imply that economic growth occurs without a significant investment in the labor force. The model of renewable energy consumption also shows that only economic growth leads to rising renewable energy consumption, with no discernible effects from oil usage, oil price, or carbon emissions. According to the nuclear energy consumption model, oil consumption and the actual price of oil do not affect the level of nuclear energy consumption; only economic growth and carbon emissions do. Accordingly, increasing investment in the industry may help the economy in the long run by increasing the use of nuclear energy, renewable energy, and gross domestic product. Given that the error correction term (ECM) is negative and statistically significant, the results of the VECM Granger causality test suggest that independent variables in each of the models have a long-term effect on economic growth, the use of renewable energy sources, and the consumption of nuclear energy. The short-run causation demonstrates a one-way relationship between the use of renewable energy and economic growth.

Last but not least, the findings show numerous feedback relationships between the variables, indicating that one influences the other. The CO_2 emissions' beneficial effects on nuclear and renewable energy provide plausible evidence that the industrial sector is where the CO_2 emissions problem originates. This industry is regarded as the foundation of the economy. Therefore, reducing CO_2 emissions is a long-term phenomenon. Furthermore, nuclear energy plays a crucial role in the expansion of the economy. Findings imply that any policy intended to promote the use of renewable (nuclear) energy will benefit Iran's economic development. Utilizing creative energy-saving solutions in the production process that might increase working intensity will result in more stable energy consumption. For sustained growth, the government may invest more money in infrastructure development. Collaboration between the fiscal government and decision-makers will provide favorable results and increase the likelihood of growth. With the use of nuclear or renewable energy technology, CO_2 emissions can be completely eliminated while using less oil and coal. Additionally, the development of the nuclear and renewable energy sectors might encourage the improvement of the energy industry.

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