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The Toda–Yamamoto Causality Analysis of the Relationship Between Natural Gas Production and Electricity Consumption in Iraq (2000–2023)

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ABSTRACT

Objective: *This study sought to uncover the nature of the bidirectional causal relationship between natural gas production and electricity consumption in Iraq during 2000–2023 by employing the Toda–Yamamoto causality test, a key method for revealing relationships between economic time series with varying degrees of integration.* ***Method:*** *This study sought to uncover the nature of the bidirectional causal relationship between natural gas production and electricity consumption in Iraq during 2000–2023 by employing the Toda–Yamamoto causality test, a key method for revealing relationships between economic time series with varying degrees of integration.* ***Results:*** *The results of the Toda–Yamamoto causality test revealed a bidirectional relationship: an increase in natural gas production contributes to an increase in electricity consumption in Iraq, and an increase in electricity production and consumption contributes to an increase in natural gas production. These results confirm the importance of interdependence between the two sectors and that neither can grow without the other.* ***Novelty:*** *One of the most important recommendations from the research is the need for optimal utilisation of associated gas, which is automatically extracted with crude oil. The proportion of gas flared without being utilised amounts to approximately 20% of the gas produced in Iraq by 2025. This is a significant figure; associated gas must be optimally utilised for electricity production, thereby reducing reliance on gas imported from neighbouring countries.*

INTRODUCTION

Natural gas is one of the most important and in-demand energy sources on the global market, owing to its numerous applications and its low carbon emissions and high thermal efficiency compared to other energy sources. Iraqi natural gas is characterised by its ease of extraction and low costs, as it is extracted alongside crude oil. Despite these advantages, a considerable proportion of it is flared off and wasted due to the lack of the necessary infrastructure for natural gas production and its utilisation in the electric power sector – the lifeblood of any economy – on which various productive, service, industrial and agricultural activities depend. The oil industry in Iraq has expanded in recent decades and has witnessed major transformations in the natural gas and electricity sectors [1], [2], [3], [4], [5].

Significance of the Study

The study highlights the importance of examining the long-term causal relationship between natural gas production and electricity consumption, and in determining the direction of this relationship: whether an increase in natural gas production leads to an increase in electricity consumption, or whether it is the growth in electricity demand that drives an increase in natural gas production. The formulation of a comprehensive policy based on the optimal use of natural gas in electricity generation can be described as a

necessary relationship that reflects the extent to which natural gas to electricity consumption and meeting domestic electricity demand, rather than importing natural gas, through the use of new technologies, particularly in the field of natural gas production [6], [7].

Problem Statement

Although Iraq possesses vast reserves of natural gas, a considerable proportion of it is flared off or wasted due to a lack of investment, whilst the electricity sector has for years suffered from a chronic shortfall in production and has had to rely on imports to meet domestic demand .

This raises the following key issues:

- Is there a causal relationship between natural gas production and electricity consumption in Iraq?
- Does natural gas production drive electricity consumption, or is it electricity consumption that drives an increase in natural gas production?

Research Hypotheses

In order to achieve the research objective, the researcher adopted an analytical approach to examine the current state of natural gas production and electricity consumption in Iraq, and to ascertain the nature and direction of the relationship between the target variables (natural gas production and electricity consumption), using the Toda–Yamamoto causality method

RESEARCH METHOD

2. The conceptual framework of the Toda–Yamamoto model and natural gas production and electricity consumption in Iraq.

a. The 1995 model (Toda–Yamamoto)

The study by Toda and Yamamoto (1995) employed an improved method, known as the Mwald test, to test the Wald test under the constraints of a VAR(k) model, where k represents the lag length, and utilised the Wald criterion based on the F-statistic and the chi-squared statistic to assess the null hypothesis [8]. The adjusted Wald test for Granger causality is then estimated using a method of seemingly unrelated regression models (this method is characterised by the fact that it does not require knowledge of the properties of cointegration; that is, the test can be conducted even in the absence of a cointegration relationship [9]. It is also considered a model for use in long-run testing; the effectiveness of the Granger causality test diminishes if the integration process of the time series is different and unclear. As an alternative, the Toda–Yamamoto causality test is used [10]. The causality test represents a standalone empirical approach, and this approach forms the basis for studying the causal relationship between variables [11].

Before commencing the estimation process, the stationarity of the time series must be tested to determine whether they are stationary at the level or stationary after taking first differences; that is, whether the time series are integrated of order zero (I(0)) or integrated of order one (I(1)) using the Augmented Dickey–Fuller (ADF) test (ADF) and the Phillips–Perron unit root test (PP) [12].

b. Determining the optimal lag order for the VAR model (lag periods)

Empirical studies suggest that the number of lags, denoted by (K), can be set at one-quarter of the time series length. The optimal number of lags can also be determined using various criteria, the most common of which are the Akaike Information Criterion (AIC) or the Schwarz (Schwarz Bayesian Criterion (SBC)) or the Q-statistic, whereby a relatively large number of lags can be identified and gradually reduced until the lowest value of (AIC) or SBC [13]. To measure the direction of the causal relationship, four lag periods were selected and calculated based on the criteria of LR, FPE, AIC, SC, and HQ. The number of lags for estimating the VAR model is determined based on a number of criteria, and Table 5 illustrates the results of the criteria for the lags.

3. The Reality of Natural Gas Production in Iraq

Natural gas is considered one of the world's most important modern energy sources, owing to its high combustion efficiency and lower levels of polluting emissions compared to other petroleum derivatives. Natural gas is also used to power electricity generation plants and petrochemical industries, as well as being a significant source of financial resources for oil-producing nations. Iraq is blessed with vast quantities of natural gas, making it one of the world's leading nations in this regard, bearing in mind that there is a vast area of Iraq that has not yet been explored, as well as numerous gas fields that have not been fully discovered [14]. Iraq possesses one of the largest natural gas reserves in the Middle East and the world, estimated at approximately 132 trillion standard cubic feet (TCF), equivalent to around 1.7% of global reserves, according to the BP Statistical Review of World Energy (2023). Despite successive Iraqi governments' policies on natural gas production, oil policy may reflect a delicate balance between the exploitation of oil resources and natural gas production, and the achievement of economic independence, whilst facing the ongoing challenges that have hindered development in production, which has been unstable due to the security, political and economic conditions the country has experienced since 2003

The Development of Gas Production in Iraq (2000–2023)

The development of gas production in Iraq can be divided into three main phases:

I. Phase 1 (2008–2000)

Production was characterised by a decline due to economic sanctions and the economic blockade during the 1990s and the early 2000s, which prevented the development of the natural gas industry, as well as the weakness of the infrastructure in the oil and gas sector up until 2003. Most of the gas produced during this period was associated gas, which was flared or wasted rather than utilised to its full potential, due to a lack of adequate technology [15].

II. Phase Two(2014–2009)

This phase saw a gradual increase in gas production following the launch of the Oil Licensing Rounds, which encouraged the oil sector to boost oil production and, consequently, associated gas production, as well as increasing proven natural gas reserves, as well as the potential to invest in gas to meet the needs of the domestic market,

with agreements being signed with international companies such as Shell and Mitsubishi, the most notable of which was the Basra Gas Company 2013 project.

c. Phase Three(2023–2015)

This period saw an expansion in gas production as a result of investment projects in the south (Rumaila, Zubair, West Qurna); however, the rate of gas flaring remains high, estimated at over 50% of the gas produced, Data from the Iraqi Ministry of Oil indicates that total gas production has reached around 10–12 billion cubic metres per annum in recent years, with plans to increase this to over 20 billion m^3/year by 2030.

Table 1. Natural gas production from 2000 to 2023 (billion cubic metres).

Year	Gas Production Annually (bcm)	Annual Growth Rate (%)	Year	Gas Production Annually (bcm)	Annual Growth Rate (%)
2000	3150.03	–	2012	5954.02	0.7
2001	2760.03	-12.4	2013	6684.02	12.3
2002	2360.02	-14.5	2014	7144.02	6.9
2003	1552.59	-34.2	2015	6914.02	-3.2
2004	995.25	-35.9	2016	9514.02	37.6
2005	1450.01	45.7	2017	9734.02	2.3
2006	1800.02	24.1	2018	10194.02	4.7
2007	4015.27	123.1	2019	10710.80	5.1
2008	6030.72	50.2	2020	7370.01	-31.2
2009	6446.62	6.9	2021	9590.01	30.1
2010	6744.02	4.6	2022	9860.01	2.8
2011	5914.02	-12.3	2023	10536.78	6.9

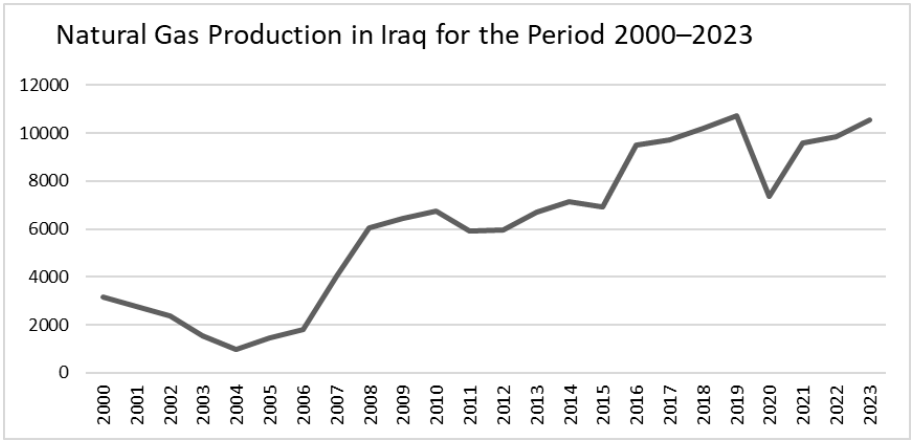

Figure 1. Natural gas production in Iraq for the period 2000–2023 (billion cubic metres).

Source: Compiled by the researcher based on Table 1.

Table (1) and Figure (1) show sharp fluctuations in natural gas production: whilst production in 2000 stood at just over 3 billion cubic metres, it rose to more than 10 billion cubic metres in 2023. Growth rates also show clear fluctuations: the highest negative growth rate was recorded between 2003 and 2004 at -35.9%, whilst the highest positive growth rate was recorded between 2006 and 2007, reaching 123.1%.

The State of Electricity Consumption in Iraq (Electric Power Consumption in Iraq)

Electricity is the cornerstone of economic and social development, serving as a key indicator of economic well-being and the efficiency of infrastructure. The electricity sector in Iraq is one of the sectors most affected by economic and political changes, suffering from a chronic production deficit coupled with continuous growth in demand due to population growth and urban and industrial expansion. The stages of development in electricity consumption in Iraq can be summarised as follows:

Phase 1: Fluctuations in electricity consumption

2000to 2005: Consumption fluctuated, with the highest peak recorded in 2002 at 33,863 MW, whilst consumption fell to 28,812 MW.

Phase 2: A steady rise in electricity consumption

From 2006 to 2021, electricity consumption continued to rise during this period, reaching its first peak in 2012 at 74,062 megawatt-hours. Consumption then fell in 2013 to 58,422 MWh, with a negative growth rate of -21.1% between 2012 and 2013, before gradually rising again to reach 86,106 MWh in 2021.

Stage Three: The Rapid Rise Stage:

Electricity consumption reached... The growth rate of electricity consumption for 2022 and 2023 stood at approximately 85.09%, which is the highest growth rate recorded between 200 and 2023. Electricity consumption also reached 176,640 megawatt-hours.

Table 2. Electricity consumption from 2000 to 2023.

Year	Electricity Consumption (MWh)	Annual Growth Rate (%)	Year	Electricity Consumption (MWh)	Annual Growth Rate (%)
2000	31900	–	2012	74062	21.14
2001	32251	1.10	2013	58422	-21.12
2002	33863	5.00	2014	67768	16.00
2003	28340	-16.31	2015	68688	1.36
2004	30266	6.80	2016	80030	16.51
2005	28812	-4.80	2017	85508	6.84
2006	32138	11.54	2018	82130	-3.95
2007	33283	3.56	2019	87900	7.03
2008	36779	10.50	2020	85376	-2.87
2009	46065	25.25	2021	86106	0.86
2010	48908	6.17	2022	159370	85.09
2011	61136	25.00	2023	179460	12.61

Source: www.iea.org

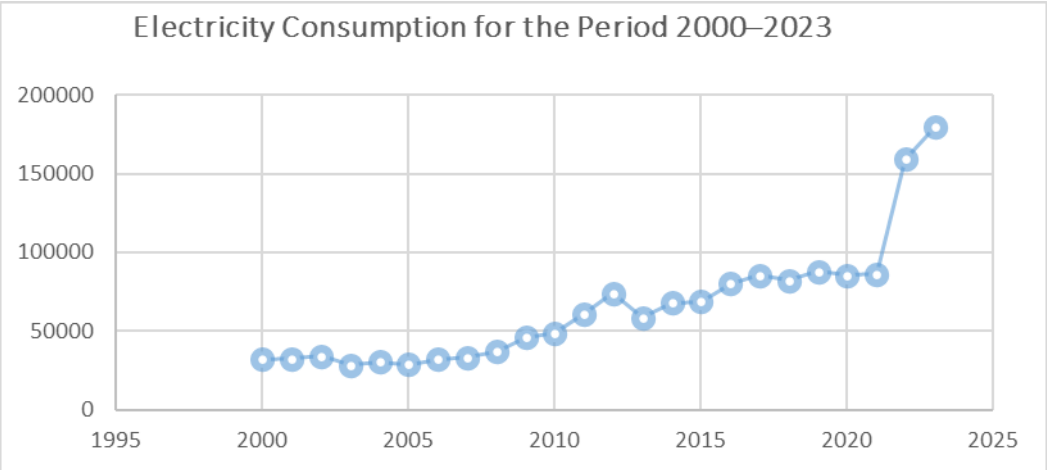

Figure 2. Shows electricity consumption for the period 2000–2023 (MWh).
Source: Compiled by the researcher based on Table 2.

4. The relationship between natural gas production and electricity consumption in Iraq

Natural gas is the primary fuel source for power stations in Iraq. However, the limited supply of gas from the Ministry of Oil and the lack of availability in the required quantities lead to a decline in electricity generation. This highlights the interactive relationship between the two sectors:

- On the one hand, increased gas production leads to improved electricity generation.
- On the other hand, rising demand for electricity may drive the development of gas investment projects.

It is therefore necessary to evaluate the temporal causality between the two variables to determine the direction of the relationship and interpret it.

Table 3. Natural gas production and electricity consumption for the period from 2000 to 2023.

Year	Gas Production Annually (bcm)	Annual Growth Rate (%)	Electricity Consumption (MWh)	Annual Growth Rate (%)
2000	3150.03	–	31900	–
2001	2760.03	-12.4	32251	1.10
2002	2360.02	-14.5	33863	5.00
2003	1552.59	-34.2	28340	-16.31
2004	995.25	-35.9	30266	6.80
2005	1450.01	45.7	28812	-4.80
2006	1800.02	24.1	32138	11.54
2007	4015.27	123.1	33283	3.56
2008	6030.72	50.2	36779	10.50
2009	6446.62	6.9	46065	25.25
2010	6744.02	4.6	48908	6.17
2011	5914.02	-12.3	61136	25.00
2012	5954.02	0.7	74062	21.14
2013	6684.02	12.3	58422	-21.12

2014	7144.02	6.9	67768	16.00
2015	6914.02	-3.2	68688	1.36
2016	9514.02	37.6	80030	16.51
2017	9734.02	2.3	85508	6.84
2018	10194.02	4.7	82130	-3.95
2019	10710.80	5.1	87900	7.03
2020	7370.01	-31.2	85376	-2.87
2021	9590.01	30.1	86106	0.86
2022	9860.01	2.8	159370	85.09
2023	10536.78	6.9	179460	12.61

Source: www.energyinst.org/statistical

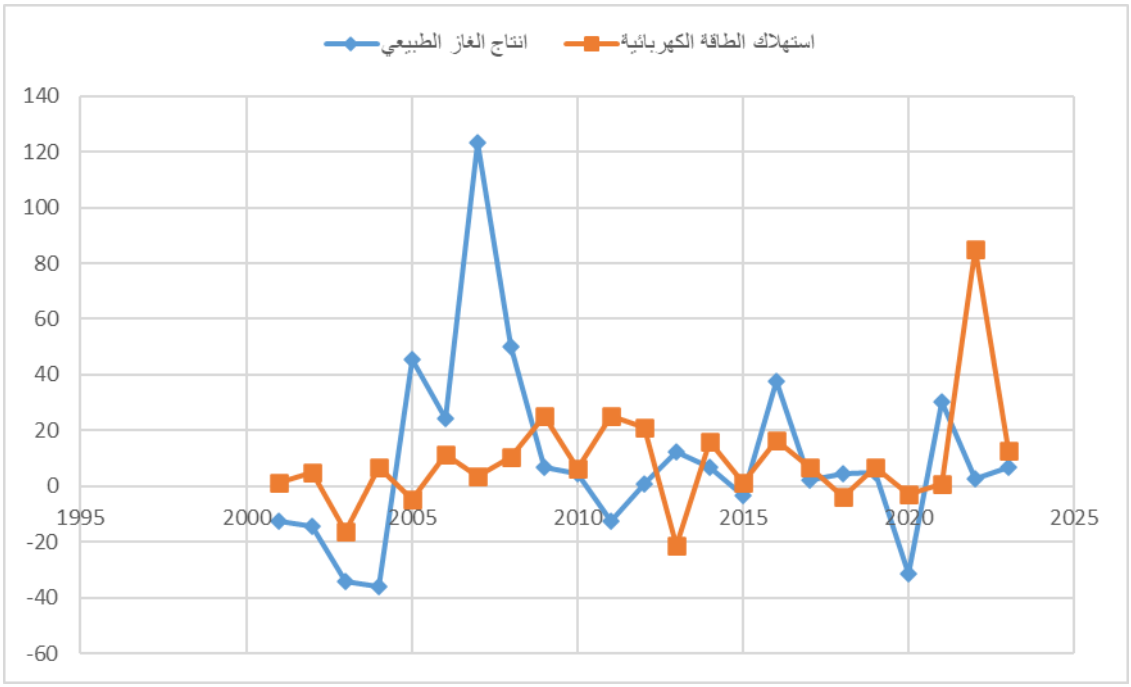

Figure 3. Annual growth rate of natural gas production and electricity consumption for the period 2000–2023.

Source: Compiled by the researcher based on Table 3, columns 2 and 4.

We observe from the relationship between gas production and electricity consumption that there is a general upward trend in the long term for both variables; gas production rose from just over 3 billion cubic metres in 2000 to just over 10 billion in 2023, representing a 3.3-fold increase from its 2000 value. Furthermore, both variables peaked simultaneously at the end of the time series in 2023, reinforcing the hypothesis of a causal relationship between them. We also note the correlation of the shocks in 2020, as we observe a decline in the growth rate of natural gas production by -31.2 per cent, whilst the negative growth rate of electricity consumption stood at -2.87 per cent.

RESULTS AND DISCUSSION

a) Evaluating the stationarity of time series:

In the first stage, we evaluate the stationarity of the time series; unit root tests are among the most important methods for determining the stationarity of time series in terms of their order of integration. The Dickey–Fuller (ADF) test was used, and the results obtained (Table 1) show that when testing the stationarity of the target variables (PNG) and (EC) using the augmented Dickey-Fuller (ADF) test, it is evident that natural gas production (PNG) and electricity consumption (EC) are stationary with a stationarity level of one.

Table 4. ADF stability test results (PNG) and (EC).

Null Hypothesis: the variable has a unit root			
	At Level	EC	PNG
With Constant	t-Statistic	1.2511	-0.6204
	Prob.	0.9975	0.8475
		no	no
With Constant & Trend	t-Statistic	-0.8547	-5.1527
	Prob.	0.9446	0.0027
		no	***
Without Constant & Trend	t-Statistic	2.1182	0.7978
	Prob.	0.9893	0.8781
		no	no
	At First Difference	d(EC)	d(PNG)
With Constant	t-Statistic	-3.3393	-5.1816
	Prob.	0.0252	0.0006
		**	***
With Constant & Trend	t-Statistic	-4.0425	-4.9913
	Prob.	0.0225	0.0042
		**	***
Without Constant & Trend	t-Statistic	-3.0559	-4.6967
	Prob.	0.004	0.0001

a: (*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%, and (no) Not Significant

Source: Compiled by the researcher using Eviews version 13.

The results of the stationarity test for the research variables, based on the ADF method, show that the EC variable is non-stationary in all equations at the original level; however, after taking the first difference of the EC variable, we find that the variable becomes stationary for all equations at a significance level of less than 5%. Furthermore, the PNG variable is non-stationary in the equation without an intercept and the equation without an intercept and a general trend; all equations become stationary after taking the first difference, as shown in the figure above.

b) **The Toda–Yamamoto causality test**

Before applying the Toda–Yamamoto test, it is necessary to determine the optimal lag period for the relationship between electricity consumption and natural gas production [16]. The following table shows the results of applying the optimal lag period, as follows:

Table 5. Testing for optimal lag lengths in the VAR model.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-322.6374	NA	2.14E+14	38.66323	38.9573	38.69246
1	-308.1135	20.50435	6.37E+13	37.42512	37.91525	37.47384
2	-307.2429	1.024296	9.85E+13	37.79328	38.47946	37.86149
3	-304.6645	2.426742	1.33E+14	37.96052	38.84275	38.04822
4	-292.0595	8.8976	6.24E+13	36.94818	38.02646	37.05536
5	-271.688	9.586597	1.47E+13	35.02212	36.29645	35.14879
6	-228.9819	10.04849*	4.39e+11*	30.46846*	31.93884*	30.61462*

Source: researchers based on using the output from Eviews version 13.

The table above shows that the best lag order between the variables EC and PNG is the sixth lag, as most of the criteria achieved their lowest values at the sixth lag. According to the Toda–Yamamoto methodology, a one-year lag should be added; that is, the number of lags when determining Toda–Yamamoto causality, bringing the total to seven lags: 227, 1995 Yamamoto and Toda. The following table shows the results of the Toda–Yamamoto causality estimation as follows:

Table 6. Toda–Yamamoto Causality Matrix.

Dependent variable: EC			
Excluded	Chi-sq	df	Prob.
PNG	69.86088	7	0
All	69.86088	7	0
Dependent variable: PNG			
Excluded	Chi-sq	df	Prob.
EC	17.73727	7	0.0132
All	17.73727	7	0.0132

Source :based on the researcher's work, using output from Eviews 13.

From the results in the table above, we can see the following:

1. From the EC equation for electricity consumption, we find a causal relationship running from natural gas (PNG) production to electricity consumption in Iraq during the period 2000–2023, at a significance level of less than 5% according to the

chi-square test; this means that past natural gas production contributes to the prediction of current electricity consumption.

2. From the PNG equation for natural gas production, we find a causal relationship running from electricity consumption to natural gas production (PNG) in Iraq during the period 2000–2023, at a significance level of less than 5% according to the chi-square test, which means that past electricity consumption contributes to the prediction of current natural gas production.

Based on these results, we find a bidirectional causal relationship between electricity consumption and natural gas production in Iraq during the study period 2000–2023, according to the Toda–Yamamoto causality test.

Key findings of the research

1. The existence of bi-directional causality, as defined by the Toda–Yamamoto methodology, between electricity consumption and natural gas production in Iraq during the period 2000–2023, thereby confirming the research hypotheses.
2. An increase in natural gas production contributes to an increase in electricity production and consumption in Iraq, as increased gas production boosts the capacity of power stations that rely on natural gas for electricity generation, thereby increasing electricity output, particularly during periods of high or low temperatures.
3. An increase in electricity production and consumption contributes to an increase in the extraction and production of natural gas, as gas production processes vitally depend on a continuous supply of electrical energy; without a continuous supply of electricity, natural gas extraction and production could be disrupted.

The key conclusion for economic policy in Iraq is that increasing electricity generation capacity is only possible through increased natural gas production, meaning that the relationship between the two sectors is one of mutual dependence, and the reverse is also true.

CONCLUSION

Fundamental Finding : The study examined the bidirectional causal relationship between natural gas production and electricity consumption in Iraq over the period 2000-2023 using the Toda–Yamamoto causality test. The results confirm a significant mutual dependency between these two sectors, where an increase in natural gas production boosts electricity consumption, and conversely, increased electricity consumption drives higher natural gas production. This mutual dependency highlights the interconnected nature of the two sectors, suggesting that economic and infrastructure development in one sector necessitates growth in the other. **Implication :** The findings underscore the importance of addressing the interdependence between natural gas production and electricity consumption in Iraq. A key implication is the need to optimize the use of associated gas, which is currently wasted through flaring, to improve energy utilization efficiency. By utilizing this gas for electricity production, Iraq could reduce its reliance on imported gas, thus improving its energy security and sustainability. Additionally,

fostering investments in both sectors and enhancing the infrastructure will be crucial in meeting the growing demand for both natural gas and electricity, contributing to economic growth and stability. **Limitation :** One limitation of the study is that it focuses primarily on the period from 2000 to 2023, which may not account for future developments in the energy sector or the potential impact of emerging technologies. The reliance on historical data may also overlook the influence of other external factors, such as political instability or global energy market shifts, that could affect the relationship between natural gas production and electricity consumption. **Future Research :** Future research should explore further advancements in technology and infrastructure that could maximize the utilization of natural gas in electricity generation and reduce wastage. It would also be beneficial to examine the role of renewable energy sources in diversifying Iraq's energy portfolio, as well as the potential for integrating energy-efficient technologies in both sectors. Additionally, studies could expand beyond the 2000-2023 period to incorporate longer-term projections and consider the effects of political, economic, and global energy trends on Iraq's energy strategy.

RECOMMENDATIONS

1. Given that the findings have shown a mutual dependency between natural gas production and electricity consumption, stakeholders should develop both sectors in parallel and avoid isolated plans, as increased natural gas production will inevitably contribute to increased electricity production and consumption.
2. It is essential to make optimal use of associated gas, which is extracted automatically alongside crude oil. The proportion of gas flared without being utilised is estimated to be approximately 20% of the gas produced in Iraq by 2025; this is a significant figure. Associated gas must be utilised to the fullest extent in electricity generation, thereby helping to reduce reliance on gas imported from neighbouring countries.
3. Licensing rounds should be launched for foreign companies to invest in the natural gas sector. This will help increase financial returns, thereby contributing to the development of infrastructure for power stations or supporting renewable energy projects.

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