ITJ | The International Tax Journal

# The causative relationship among energy efficiency, renewable energy consumption, and carbon dioxide emissions utilizing the VAR model: A case study of Tunisia from 1991 to 2022

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**Abstract---**This study investigates the causal relationship among energy efficiency, renewable energy consumption, and carbon dioxide emissions in Algeria from 1991 to 2022, employing the Variable Autoregressive Regression (VAR) model. The findings indicated a causal association between energy efficiency and carbon dioxide emissions, although no causal relationship exists among the other factors. Consequently, energy efficiency pertains to the mitigation or augmentation of carbon dioxide emissions, indicating that fewer natural resources are utilized to produce equivalent energy, resulting in a decrease in carbon dioxide emissions.

**Keywords---**Energy intensity, consumption of renewable energy, renewable energy sources, carbon dioxide emissions.
**Jel Classification Codes:** Q49، Q43،Q42،Q53

## 1. Introduction

The economic and environmental issues confronting Tunisia have made the relationship between energy efficiency, dependence on renewable energy sources, and carbon emissions a crucial element of national policies designed to attain sustainable development objectives. The transition to renewable energy sources, including solar and wind power, presents a substantial opportunity to diminish reliance on conventional fossil fuels, the primary source of carbon dioxide emissions in Tunisia. Energy efficiency is crucial in this context, as its enhancement can yield two advantages : diminishing the need

**How to Cite**:
Saouli, Y. (2025). The causative relationship among energy efficiency, renewable energy consumption, and carbon dioxide emissions utilizing the VAR model: A case study of Tunisia from 1991 to 2022. *The International Tax Journal*, *52*(4), 1386–1396. Retrieved from https://internationaltaxjournal.online/index.php/itj/article/view/154

The International tax journal ISSN: 0097-7314 E-ISSN: 3066-2370 © 2025

Submitted: 27 June 2025 | Revised: 18 July 2025 | Accepted: 03 August 2025

for fossil fuels and promptly lowering carbon emissions by decreasing reliance on ecologically detrimental energy sources. Examining the causal relationship between these aspects in Tunisia can elucidate the intricate connections between economic development and environmental conservation, aiding in the formulation of essential actions. This paper examines effective strategies for tackling environmental challenges and fostering sustainable economic growth, alongside an analysis of the interconnections among energy efficiency, renewable energy consumption, and carbon dioxide emissions utilizing econometric, economic, and statistical models. This study will analyze the effect of energy efficiency on the reduction of carbon dioxide emissions. This study will analyze the causal relationship between the dependent variable, energy intensity, and the two independent variables, renewable energy utilization and carbon dioxide emissions. This will offer explicit insights into improving renewable energy efficiency in Tunisia as a tool for attaining sustainable development objectives and reducing carbon emissions.

Consequently, the issue addressed by the study can be articulated as follows: What is the magnitude of the causal association between energy efficiency and its effects on renewable energy consumption and carbon dioxide emissions in Tunisia from 1991 to 2022?

**Study hypotheses:**

- ✓ A causal relationship exists between energy efficiency and the use of renewable energy or carbon dioxide emissions.
- ✓ There is a unilateral causal relationship between energy efficiency and other independent variables.

**Importance of the study :**

- ✓ Renewable energy is a subject of significant interest in numerous research studies due to its capacity to diminish carbon dioxide emissions and promote the utilization of renewable energy at reduced costs.
- ✓ This aims to enhance energy efficiency, in contrast to fossil fuels, which contribute to environmental damage and elevate carbon dioxide emissions.
- ✓ Tunisia aims to diminish reliance on conventional energy sources and prioritize new and renewable energy sources to achieve energy sustainability.

**Research objectives**

The research seeks to elucidate evidence of causal interconnections by demonstrating the connections between energy efficiency, renewable energy use, and carbon dioxide emissions in Tunisia. The study seeks to analyze the effects of alterations in energy efficiency and renewable energy utilization on carbon dioxide emissions and the reciprocal relationship.

**The methodology used in the research**

This study will employ the following methodologies: The descriptive approach examines the theoretical dimensions of energy efficiency. The quantitative technique uses the dynamic VAR model to examine the interrelationships among the three study objectives: energy efficiency, renewable energy consumption, and carbon dioxide emissions, and to ascertain the causal linkages among them.

**Previous studies**

*Hakan Altin's study (2024)* analyzed the influence of energy efficiency and renewable energy utilization on carbon dioxide emissions in G7 nations. The research extended across multiple years. We determined that there are two primary outcomes: The initial aspect is the complementary relationship among the variables. Consequently, a sustained complimentary relationship exists among energy efficiency, renewable energy utilization, and carbon dioxide emissions. The second aspect is the direction and persistence of this enduring link, wherein a gain in energy efficiency correlates with a reduction in carbon dioxide emissions. This outcome aligns with prevailing predictions. Conversely, a positive correlation exists between renewable energy consumption and carbon dioxide emissions. This outcome fails to satisfy general expectations. The existence of a positive correlation between renewable energy usage and carbon dioxide emissions is yet to be established. *Research (C.L.M. Faiza, 2019)* This study seeks to examine and quantify the causal relationship among renewable energy consumption, carbon dioxide emissions, and economic growth in European nations, while assessing the influence of renewable energy consumption and carbon dioxide emissions on economic growth through the static effects method. The VECM determined a bidirectional causative association among long-term economic growth, renewable energy consumption, and carbon dioxide emissions, as well as a bidirectional causal relationship between renewable energy and economic growth. Unipartite causal link between energy consumption and economic growth, together with renewable energy usage and carbon dioxide emissions.

**1.1 Energy Efficiency Concept :**

Energy efficiency denotes the capacity to attain optimal outcomes in a specific activity while utilizing minimal energy resources. This diminishes the consumption of all energy forms, along with their environmental repercussions. This pertains to both energy generation and utilization. Consequently, energy efficiency is crucial for minimizing energy use while maintaining performance and comfort. The outcome is a more sustainable and cleaner residence achieved by diminishing emissions of carbon dioxide and other greenhouse gases from the environment (Roufechaei, Abu Hassan , & Amin , 2014).

**1 .1 .1 The importance of energy efficiency :**

The significance of comprehending the energy of critical variables in contemporary society, along with the density and consequences of their predecessors, can be assessed as follows (Bridge, et al., 2018) :

**1 .1 .1 .1 Environmental perspective :**

From an environmental perspective, energy efficiency plays a significant role in reducing carbon emissions. (Knight, 2017) Reducing energy use reduces the amount of fossil fuels burned for electricity generation and transportation, thereby reducing greenhouse gas emissions. For example, replacing traditional light bulbs with energy-efficient LED bulbs can significantly reduce electricity consumption and carbon emissions**.** (World, 2025)

**1 .1 .1 .2 Economic Perspective :**

Energy efficiency possesses significant economic potential. Investments in energy-efficient technologies and practices can yield substantial cost savings for people, enterprises, and organizations (Kamal, Sami , & Muammer , 2019). Pre-insulated roofs can diminish heating and cooling expenses by minimizing heat transfer via walls and ceilings. This not only benefits households but also alleviates pressure on the electrical grid during peak periods. (He, 2023)

**1 .1 .1 .3 Aspects of energy security :**

Energy efficiency aims to bolster energy security by diminishing reliance on fossil fuels and augmenting self-sufficiency. By emphasizing energy efficiency initiatives, nations can mitigate their vulnerability to price volatility in international fuel markets and geopolitical conflicts that may interrupt supply chains (Bocca & Muqsit , 2022). By diversifying conventional energy sources and enhancing their utilization, nations can bolster energy resilience and guarantee a stable and dependable energy supply for their populace**.** (Agency, 2023)

**1.1.1.4 Development of energy density during the period (1991-2022) :**

From Figure 1, it is clear that Tunisia witnessed a slight increase in energy intensity during the period from 1991 to 2000, due to the reliance on heavy industries and fossil fuels at that time. After 2000, it witnessed a slight decline due to the intensification of efforts and the advancement of energy intensity improvement until 2022.

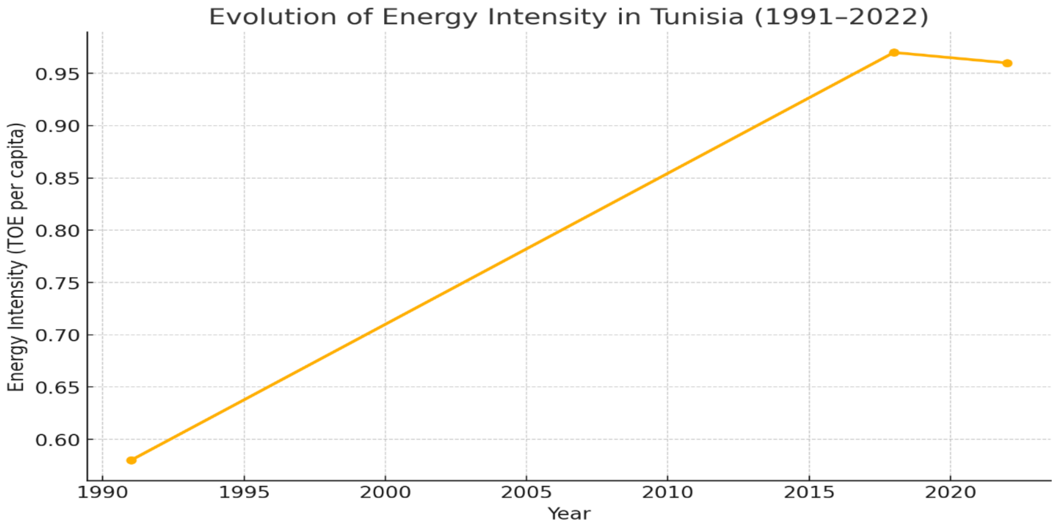


Figure 1: Development of energy density during the period (1991-2022)
Source: https://ourworldindata.org/grapher/per-capita-renewables?utm_source

**1.1.1.5 Per capita share of renewable energy consumption the period (1991-2022) :**

Figure 2 illustrates that from 1991 to 2010, per capita renewable energy use was virtually negligible. This results from Tunisia's dependence on conventional energy sources (oil and gas) and insufficient investment in the renewable energy sector. Between 2015 and 2022, there was a modest rise in per capita renewable energy usage. This results from the implementation of governmental plans to advance renewable energy, including the initiation of renewable energy projects, albeit on a limited and small scale.

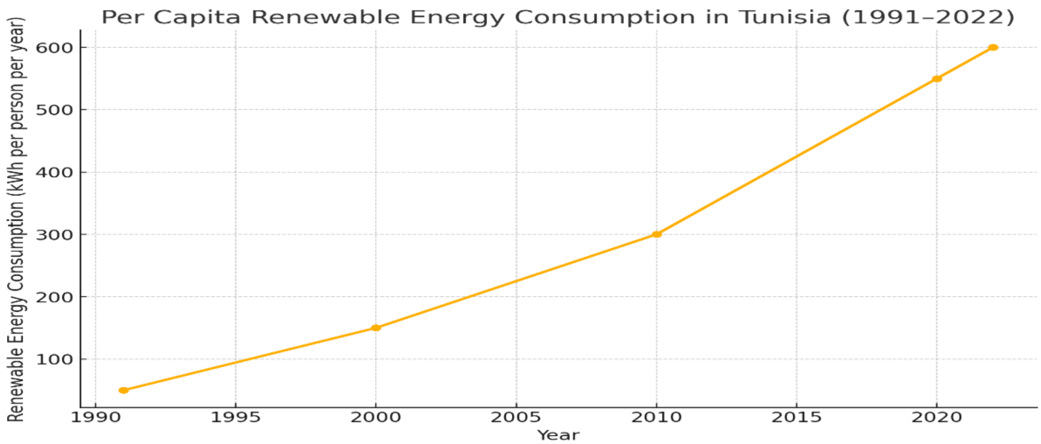


Figure 2: Per capita share of renewable energy consumption the period (1991-2022)
Source: https://ourworldindata.org/grapher/per-capita-renewables?utm_source

**1.1.1.6 Carbon dioxide emissions in Tunisia the period (1991-2022)**
From Figure 03, There was a steady increase between 1991 and 2010, attributed to population and industrial expansion, along with heavy reliance on traditional sources. After 2010, growth began to slow, attributed to the implementation of renewable energy initiatives and improvements in energy efficiency.

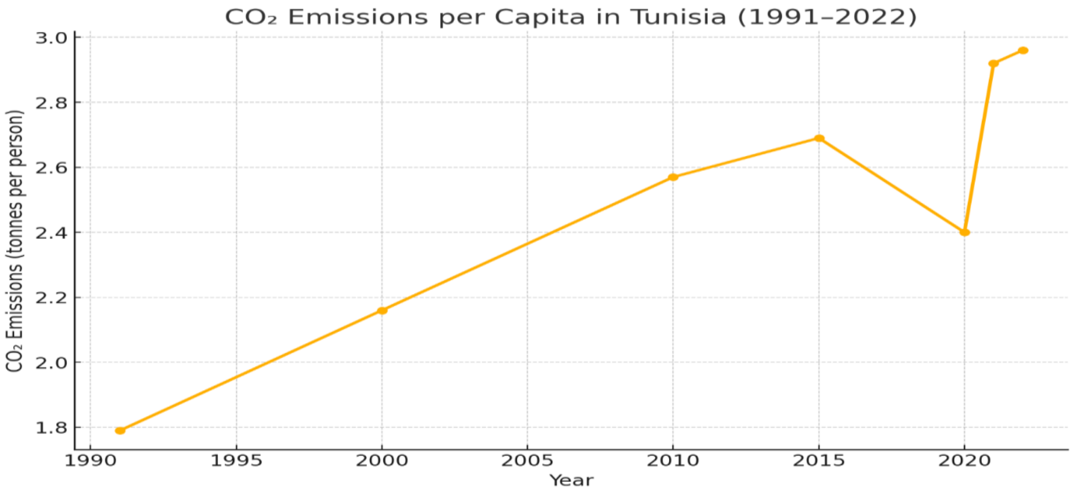


Figure 3: Carbon dioxide emissions in Tunisia the period (1991-2022)
Source: https://www.worldometers.info/co2-emissions/tunisia-co2 emissions/ ? utm source

## 2. Method and Tools :

### 2.1 Study Method :

The study variables—energy efficiency, renewable energy consumption, and carbon dioxide emissions—were sourced for Tunisia from the World Bank website from 1991 to 2022, including a sample of 32 observations.

### 2. 2 Tools used :

#### 2.2.1 Definition of the VAR model :

The general equation for the generalized vector model (Victor autorégressive) can be written as follows (Naqqar & Munther , 2012):

$$\Phi(\mathrm{B})Y_t = e_t \dots\dots\dots\dots (1) The\ equation$$

*It can be detailed as follows :*

*($Y_t$) : A random variable of **n** dimension, stable at degree **2***

*Φ(B) : A matrix density of degree **p** with a time delay factor **B**, which is separated as follows :*

$$\Phi(\mathrm{B}) = \mathrm{f}_0 - B\mathrm{f}_1 - B^2\mathrm{f}_2 - \dots\dots B^p\mathrm{f}_p \dots (2) The\ equation$$

Hence :

$\mathrm{f}_0$: A single matrix of rank n

$e_t$: The white noise of dimension n

The VAR model can also be written with the general equation as follows :

$$y_{nt} = \mathrm{f}_{n1}^{(1)} y_{1.t-1} + \dots + \mathrm{f}_{n1}^{(1)} y_{1.t-p} + \dots + \mathrm{f}_{nn}^{(1)} y_{n.t-1} + \dots + \mathrm{f}_{nn}^{(p)} y_{n.1-p} + e_{n.t} \dots\dots (3) The\ equation$$

The last equation shows that each equation represents the relationship between a component of the vector $\boldsymbol{y_t}$ and its historical values, as well as the priors of the other components within it. These equations exhibit statistical regularity in the input variables. Besides taking into account the dynamic interactions between these variables, the aforementioned model can be estimated using the least squares method applied to each equation. All asymptotic properties of the estimators can be derived from the standard properties. If a random variable $\boldsymbol{y_t}$exhibits quadratic stationarity, then the coefficient of variation of the variable**VAR** is stationary only if the following conditions are met (Chaired, 2006):

$$E(Y_t) = \mu, \gamma_t$$
$$var(Y_t) < \infty$$
$$cov(Y_t, Y_{1,+K}) = E[(Y_t - \mu)(Y_{1+t} - \mu)] = \Gamma_{(k)}, \nabla_1$$

**2.2. 2 Description of the Standard Model Variables :**

- ✓ **Energy efficiency (intensity)** : Energy intensity is quantified as primary energy use per unit of GDP, expressed in kilowatt-hours per dollar.
- ✓ **Renewable Energy Consumption (REC)** : The consumption of renewable energy during period **t**.
- ✓ **Carbon dioxide emissions ($\mathbf{CO_2}$)** : Emissions of carbon dioxide during time **t**.

The general formula of the model can be formulated as follows :

$$\log \text{intensity} = \beta_0 + \text{REC} + \text{CO}^2 + \varepsilon \ldots (6)\text{The equation}$$

**2. 2 .3 Extended Dickey Fuller String Stasis Test ADF** :

The extended Dickey-Fuller model was employed to assess the stability of the variables, serving as a unit root test that revealed the instability of any model variable at its level. Assessing the stability of the series necessitates the application of the unit root test, utilizing a number of evaluations, including the augmented Dickey-Fuller test (ADF) (Al-Tuwairi & Muhammad Ali, 2023).

**2.2.4 Determine the degree of lag of the model VAR :**

The quantity of time lags is established according to the following criteria : the **AIC** criterion, the Schwarz criterion, the **FPE** criterion, and the **HQ** Hannan-Quinn criterion. The interval with the minimal observation values for these criteria is selected, namely the fundamental time lag period that aligns with these requirements, ensuring optimal performance at the lowest of these standards (Khadidja & Brahimi, 2020،).

**3 Results and Discussion**

**3.1 Testing the stationarity of the time series :**

**3.1.1 Testing the stationarity of the original time series during the period (1991-2022) :**

Table No.01 indicates that both renewable energy consumption series exhibit stability at the first level with a trend and constant, as well as stability at the first difference level. The logarithm of the energy density series remains stable at its original level with the constant, devoid of trend and constant, and is similarly stable at the first difference. The series of carbon dioxide emissions is stable solely at the initial difference. This signifie that the series for renewable energy consumption and the logarithm of energy density are integrated of orders zero and one. The series of carbon dioxide emissions is integrated to the first degree. This enables the utilization of the vector autoregressive (VAR) model.

**Table No. 01 :** Testing the chain using the expanded Dickey-Fuller (ADF) test

| Variables | Level | | | First difference | | | Decision |
|---|---|---|---|---|---|---|---|
| | Fixed | Constant and directional | Without | Fixed | Constant and directional | Without | |
| Rec | -2,71 (0,08) | -3.56 (0,04) | -1,00 (0,27) | -8,04 (0,00) | -8,00 (0,00) | -8,15 (0.00) | I (1) and I (0) in the direction and constant |
| Log intensity | -3.63 (0.01) | -0,54 (0,97) | -0,25 (0,00) | -3,23 (0,02) | -4, 88 (0,002) | -2,72 (0,00) | At the constant level, without, I (1) |
| Co2 | -1,49 (0,52) | -2,68 (0,24) | 0,52 (0,82) | -8,29 (0,00) | -8,13 (0,00) | -8,17 (0,00) | I(1) |

**Source:** Eviews 10 outputs

**3.1.2 Determine the degree of delay of the studied model :**

Table No.02 reveals that all criteria (HQ, SC, AIC, FPE) need the inclusion of a single temporal gap, corresponding to model (VAR).

**Table No. 02 :** VAR model delay degree table

| Lag | LagL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -131.466 | NA | 1.569 | 8.964 | 9.104 | 9.009 |
| 1 | -48.012 | 144.65* | 0.011* | 4.000* | 4.561* | 4.180* |
| 2 | -43.700 | 6.612 | 0.15 | 4.313 | 5.294 | 4.627 |

**Source :** Eviews 10 outputs

**3.1.3 Model estimation :**

The estimation equation is in the following form :

LOG INTENSITY=0.951388×LOG INTENSITY(-1)+0.000479×REC(-1)+0.044252×CO2(-1)

From Table No. 03, we can see that the coefficient of determination $R^2 = 99\%$ This proves the strong correlation between the two variables: renewable energy consumption and carbon dioxide emissions, which are explained by the logarithm of energy intensity. As for the correction factor : $\bar{R}^2 = 0{,}98$ this indicates that the explanatory power of the independent variables reached 98% The rest is due to other variables that were not included in the study model, and the value of F-STATISTIC and the power of 631.37 is greater than the tabulated value estimated at 3.34, which indicates the significance of the model, VAR (1), completely and acceptable for statistical and economic estimation.

**Table No. 03 :** Model estimation results (1) VAR

| **R-squared** | 0.985946 |
|---|---|
| Adj. R-squared | 0.984384 |
| F-statistic | 631.3720 |

**Source :** Eviews 10 outputs

**3.1.4 Model Quality Test :**

**3.1.4.1 Unit Root Test :**

Figure No. 01 illustrates that the aggregate of the unit roots is inferior to one, indicating that the model is devoid of linear correlation issues between the two variables. This affirms that the examined model (VAR), which delineates the causal relationship among energy efficiency, renewable energy consumption, and carbon dioxide emissions, is entirely static and stable.

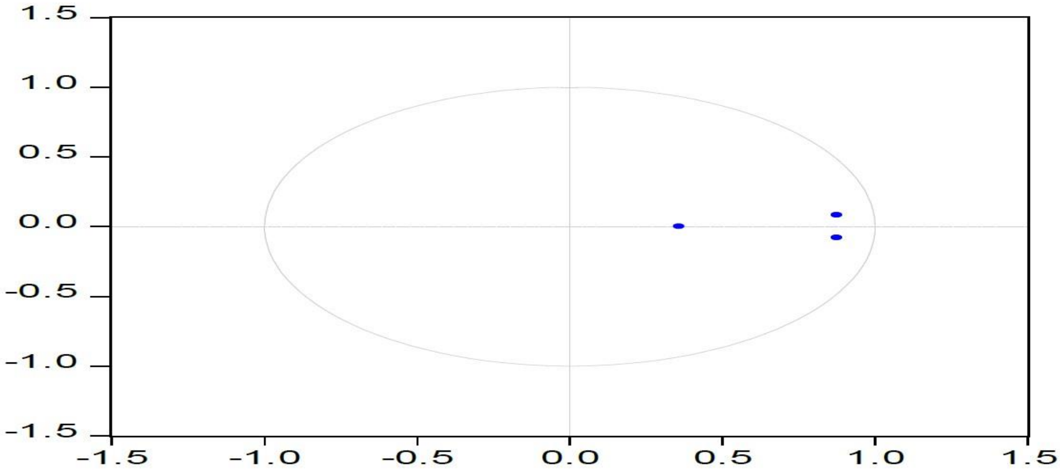


Figure 4 : Inverse roots of the characteristic polynomial (AR)
Source : Eviews 10 outputs

**3.1.4.2 Residuals Test :**
Figure 02 illustrates that the autocorrelation of the residuals is paired, indicating that the majority fall within the confidence interval. This implies the absence of statistical significance, elucidating the memoryless nature of the residuals.

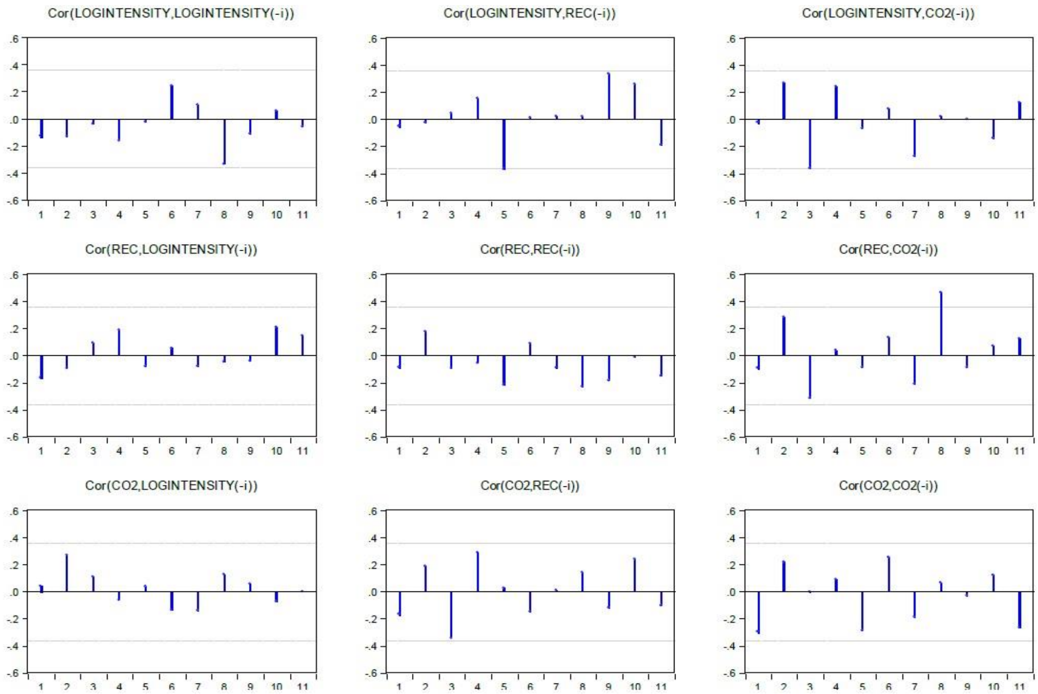


Figure 5 : Shows the residual test. ( Autocorrelations with Approximate 2 Std.Err. Bounds)
Source : Eviews 10 outputs

**3.1.4. 3 Normal Distribution Test :**

From Table 4, we can see that the calculated value of the jarque-bera statistic is 0.8044, which is greater than the theoretical value of 0.05. Therefore, we accept the null hypothesis, which states that the series of residuals follows a normal distribution.

**Table No. 04** : Jarque-Berra Normal Distribution Test

| Null Hypothesis : Residuals are multivariate normal | | | |
|---|---|---|---|
| Date : 21/06/25 Time : 21 :33 | | | |
| Sample : 1991 2022 | | | |
| Included observations : 31 | | | |
| Component | Jarque-Bera | Df | Prob. |
| 1 | 1.527564 | 2 | 0.4659 |
| 2 | 1.297938 | 2 | 0.5226 |
| 3 | 0.209715 | 2 | 0.9005 |
| Joint | 3.035217 | 6 | 0.8044 |

**Source :** Eviews 10 outputs

**3.1.4.4 Granger causality test :**

From Table 5, we note the following :

The vector relationship from the independent variable CO2 to the dependent variable LOG INTENSITY, according to the probability value of the F-STATISTIC, is less than 0.05 and has a value of 0.0157. This means that the variable CO2 causes LOG INTENSITY, while the variable REC does not cause LOG INTENSITY, because the probability value is greater than 0.05 and is estimated at 0.3862. This means that the variable REC does not cause LOG INTENSITY. Therefore, we conclude that there is a unidirectional causality from the variable CO2 to the variable LOG.

Table No. 05 : Granger causality test for the model (1) VAR

| NULL HYPOTHESIS | F- STATISTIC | PROB |
|---|---|---|
| REC does not granger causes LOGINTENSITY | 0.750874 | 0.3862 |
| CO2 does not granger causes LOGINTENSITY | 5.833528 | 0.0157 |
| LOGINTENSITY does not granger causes REC | 0.013830 | 0.9064 |
| CO2 does not granger causes REC | 3.156783 | 0.0756 |
| LOGINTENSITY does not granger causes CO2 | 2.155463 | 0.1421 |
| REC does not granger causes RCO2 | 0.296372 | 0.5862 |

**Source :** Eviews 10 outputs

**5 Conclusion**

Through the study, which highlighted the causal relationship between energy efficiency, renewable energy consumption, and carbon dioxide emissions in Tunisia during the period 1991-2022, using the autoregressive model (VAR), we reached the following :

**5.1 Results :**

- ✓ The results of the unit root test indicated that renewable energy consumption and the logarithm of energy intensity are stationary at degrees zero and one, respectively, whereas carbon dioxide emissions are integrated at degree one, permitting the application of the vector autoregressive (VAR) model.
- ✓ By testing the degree of lag of the VAR model, we found that all the criteria : (HQ, SC, AIC, FPE) indicate the necessity of taking one time lag, which is the (VAR) model.
- ✓ When testing Granger causality, we found a directional relationship from the independent variable CO2 to the dependent variable LOG INTENSITY. This was based on a probability value of less than 0.05 for the F-STATISTIC, with a value of 0.0157. This indicates that the CO2 variable causes the LOG INTENSITY variable, while the REC variable does not cause LOG INTENSITY, and vice versa. Therefore, we conclude that there is a unidirectional causality from the CO2 variable to the LOG INTENSITY variable.

**5.2 Suggestions and recommendations :**

- ✓ Enhancing and enhancing efficiency through the promotion of well-established and accessible energy technology, the encouragement of innovations and innovation in this area, and the expansion of reliance on renewable energy through the financing and support of wind and solar energy projects as well as the offering of incentives to investors.
- ✓ Sharing knowledge, participating in international environmental projects, and enhancing regional and worldwide collaboration**.**

**Références**


1. Agency, I. R. (2023). *World Energy Transitions Outlook 2023.* the EU: International Renewable Energy Agency.
2. Al-Tuwairi, N. S., & Muhammad Ali, a.-H. (2023). Using the VAR model to measure the impact of public investment on private investment in Libya during the period (1990-2020). *Academic Research Journal, 26*, 44-35. Récupéré sur https://lam-journal.ly/index.php/jar/article/view/507/396
3. Bocca, R., & Muqsit , A. (2022). *Fostering Effective Energy Transition 2022.* the World Economic Forum.
4. Bridge, G., Stewart , B., Stefan , B., Michael , B., Ed , B., Harriet , B., & Gordon , W. (2018). *Energy and Society A Critical Perspective* (éd. 1st Edition). London: Routledge. doi:https://doi.org/10.4324/9781351019026
5. Chaired, R. R. (2006, 03 30). Vector Autoregressive Models for. washington. Récupéré sur https://faculty.washington.edu/ezivot/econ584/notes/varModels.pdf
6. He, P. (2023, November ). Energy-saving, economic and environmental benefits analysis of cool roofs and green roofs for retail buildings in America. *Applied and Computational Engineering, 25*(1), 242-253. doi:10.54254/2755-2721/25/20230771
7. Kamal, A., Sami , G.-G., & Muammer , K. (2019, August ). Revaluing the costs and benefits of energy efficiency: A systematic review. *Energy Research & Social Science, 54*, 68-84. doi:https://doi.org/10.1016/j.erss.2019.03.012
8. Khadidja, B., & Brahimi, B. (2020،, 10 18). The relationship between Energy consumption and the CO2 emission and Economic growth in Germany by using the vector auto regression during (1979-2017). *Journal of Strategy and Development, 10*(5), 132-152. Récupéré sur https://asjp.cerist.dz/en/downArticle/276/10/5/130469
9. Knight, S. (2017). *LED bulbs reduced carbon dioxide emissions by more than half a billion tons in 2017.* USA: TECHSPOT. Récupéré sur https://www.techspot.com/news/72489-led-bulbs-reduced-carbon-dioxide-emissions-more-than.html?
10. Naqqar, O., & Munther , A. (2012). Using VAR models in forecasting and studying the causal relationship between GDP and gross capital formation in Syria. *Damascus University Faculty of*

*Economics and Law., 28*(2), 339-360. Récupéré sur chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.damascusuniversity.edu.sy/mag/law/images/stories/2-2012/a/337-360.pdf

11. Roufechaei, K. M., Abu Hassan , A., & Amin , A. (2014). Energy-efficient design for sustainable housing development. *Journal of Cleaner Production*, 380-388.
12. World, A. (2025). *Energy Efficiency Redefined: The Environmental Benefits of LED Lighting*. Houston. USA: APLED World. Récupéré sur https://www.apledworld.com/energy-efficiency-redefined-the-environmental-benefits-of-led-lighting]/