

Dynamic Effects of Temperature Anomalies on Energy Consumption shock in Egypt: Assessing the Economic Burden of Climate Change Using VAR

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Abstract

This study analyzes the dynamic influence of temperature anomalies on energy consumption trends in Egypt from 1990 to 2023. Employing Vector Autoregression (VAR) methodology, we examined the impact of climate variability on electricity consumption, natural gas utilization, and the adoption of renewable energy. Results demonstrate strong correlations between temperature variations and energy consumption (electricity: 0.8294; natural gas: 0.7804), with intricate temporal dynamics corroborating our hypotheses that temperature anomalies substantially influence energy consumption and that these effects exhibit seasonal variability. The economic ramifications entail fluctuations in energy prices, where a 1% rise in temperature anomalies correlates with a 0.89% increase in energy costs. Urban expansion intensifies consumption trends, elevating electricity and natural gas demand by 4.02% and 39.04%, respectively, for each 1% increase in urbanization. Granger causality tests demonstrate that temperature anomalies significantly affect both electricity ($p = 0.0257$) and natural gas consumption ($p = 0.0222$). These findings validate the necessity for climate-resilient energy infrastructure, diversified supply chains, expedited renewable transition, and cohesive urban energy planning. This research quantifies the economic impact of climate change on Egypt's energy sector, offering evidence-based recommendations to bolster energy resilience in the face of escalating climate uncertainty, thereby advancing Egypt's sustainable development goals.

Keywords: Temperature Anomalies, Energy Consumption Shocks, Economic Burden, Climate Change and VAR Methodology.

المستخلص

تحلل هذه الدراسة التأثير الديناميكي للاضطرابات في درجات الحرارة على اتجاهات استهلاك الطاقة في مصر خلال الفترة من ١٩٩٠ إلى ٢٠٢٣. من خلال منهجية الانحدار الذاتي الموجه (VAR)، قمنا بدراسة تأثير التغيرات المناخية على استهلاك الكهرباء، واستخدام الغاز الطبيعي، واعتماد مصادر الطاقة المتجددة. أظهرت النتائج وجود ارتباطات قوية بين التغيرات في درجات الحرارة واستهلاك الطاقة (الكهرباء: ٠.٨٢٩٤؛ الغاز الطبيعي: ٠.٧٨٠٤)، حيث أكدت الديناميكيات الزمنية المعقدة صحة فرضياتنا بشأن التأثير الكبير لاضطرابات درجات الحرارة على استهلاك الطاقة، بالإضافة إلى التباين الموسمي لهذه التأثيرات.

تتجلى التداعيات الاقتصادية لهذه الظاهرة في تقلبات أسعار الطاقة، حيث يرتبط ارتفاع درجات الحرارة بنسبة ١% بزيادة تكاليف الطاقة بنسبة ٠.٨٩%. كما يؤدي التوسع الحضري إلى تفاقم اتجاهات الاستهلاك، مما يرفع الطلب على الكهرباء والغاز الطبيعي بنسبة ٤.٠٢% و ٣٩.٠٤% على التوالي، لكل زيادة بنسبة ١% في معدل التوسع العمراني. وتُظهر اختبارات سببية غرانجر أن اضطرابات درجات الحرارة تؤثر بشكل ملحوظ على كل من استهلاك الكهرباء ($P = 0.0257$) واستهلاك الغاز الطبيعي ($P = 0.0222$).

تؤكد هذه النتائج على ضرورة بناء بنية تحتية للطاقة قادرة على التكيف مع التغيرات المناخية، وتنويع سلاسل التوريد، وتسريع التحول نحو مصادر الطاقة المتجددة، وتحقيق تكامل فعال بين التخطيط العمراني واحتياجات الطاقة. تسهم هذه الدراسة في قياس التأثير الاقتصادي لتغير المناخ على قطاع الطاقة في مصر، وتقدم توصيات قائمة على الأدلة لتعزيز مرونة الطاقة في ظل تزايد حالة عدم اليقين المناخي، مما يدعم تحقيق أهداف التنمية المستدامة في مصر.

الكلمات المفتاحية: تقلبات درجات الحرارة، صدمات استهلاك الطاقة، العبء الاقتصادي، تغير المناخ، منهجية الانحدار الذاتي المتجه

1. Introduction

Egypt faces significant energy challenges as climate change drives more frequent temperature fluctuations. With a rapidly growing economy dependent on diverse energy sources, understanding these shifts is crucial for sustainable planning. Using a Vector Autoregression (VAR) model, we analyzed how temperature variations influenced energy consumption from 1990 to 2023. Our study explores the relationship between climate trends and energy demand, offering insights that could inform smarter policies and investment strategies. Ultimately, this research contributes to building resilient energy systems and adaptive climate responses, supporting Egypt's transition toward a sustainable future. These findings align with recent studies by [Tembin Hé et al. \(2024\)](#).

1-1. Background and Motivation

Climate change is pressuring Egypt to adapt its energy infrastructure. Erratic temperature fluctuations affect energy consumption and electricity demand. Studies show that meteorological conditions affect energy use, making these trends important for energy planning ([Ogunsola et al., 2022](#)). Researchers increasingly use Vector Autoregression (VAR) models to study seasonal temperature changes and energy demand. Policymakers can adapt energy strategies to climate variability and socio-economic dynamics using these insights.

1-2. Climate Change and Energy Demand in Egypt

Climate change and rising energy consumption challenge Egypt's energy policy. Rising temperatures and fluctuating weather patterns disrupt consumption trends, increasing electricity demand, especially for urban cooling. Increased heatwaves strain energy infrastructure ([Abubakar et al., 2023](#)). Droughts can destabilize agricultural productivity, causing energy price fluctuations and economic disruptions ([Algieri et al., 2024](#)). VAR models help understand these complexities and how sudden temperature shifts affect energy

consumption. Policies that improve energy resilience and climate change sustainability require this knowledge.

1-3. The Need for Empirical Analysis Using VAR Models

Temperature fluctuations that are unpredictable lead to energy consumption shocks, which require the application of VAR models for analyzing these interactions. VAR models serve as a statistical instrument that elucidates the dynamic interrelationships among time-series data, thereby facilitating the analysis of both immediate and lagged impacts of temperature variations on energy consumption. Research indicates that climate change undermines economic stability in Africa via nuanced mechanisms, rendering energy systems progressively susceptible to climate variability. Furthermore, research investigating the connection between climate change and financial markets indicates that VAR models proficiently differentiate between short-term disruptions and moderate-term structural changes (Albanese et al., 2024). This study employs VAR models within Egypt's energy sector to strengthen empirical findings and guide policies for climate adaptation.

1-4. Research Problem and Objectives

Egypt's energy consumption is intricately connected to temperature variations, a correlation anticipated to amplify with the advancement of climate change. This study utilizes VAR modeling to examine energy consumption trends from 1990 to 2023, emphasizing both short-term and moderate-term effects. The research emphasizes the necessity for sustainable energy policies, in addition to evaluating short-term fluctuations. Moreover, comprehending regional vulnerabilities highlighted by climate change is essential for guaranteeing energy security (Nicholas et al., 2017).

1-5. Dynamic Impact of Temperature Anomalies on Energy Consumption Shocks

Temperature anomalies significantly affect short- and moderate-term energy demand. Impulse Response Functions in a VAR framework are used to examine how these variations affect sudden energy

consumption changes. Studies have shown that climate change poses economic risks, especially for at-risk groups with limited adaptability (Abubakar et al., 2023). Supply chain disruptions and rising energy costs complicate matters (Algieri et al., 2024). The findings emphasize energy resilience through informed policy decisions.

1-6. Causal Relationships and Policy Implications

Effective energy policies in Egypt require understanding how temperature fluctuations affect energy consumption. Recent research suggests that extreme temperature changes alter energy demand patterns, requiring strategy changes. For sustainability, energy infrastructure must adapt to climate variability (Ogunsola et al., 2022). VAR models show short- and moderate-term energy supply and infrastructure planning effects. To reduce climate-related energy risks and meet Egypt's growing demand, renewable energy and efficiency investments are needed.

1-7. Significance of the Study

Egypt's energy future is greatly shaped by its changing temperature; hence this study explores how this link develops. This study breaks out how unique temperature patterns interact with energy usage using VAR technique instead of following standard methods, therefore providing a strong justification for more exact policy responses. Understanding these complex dynamics is more important than ever, especially with rising inflation and disruptions in food and energy supply chains that continue to expose vulnerabilities in our energy systems (Algieri et al., 2024). Global events, such as the Russia-Ukraine conflict, have further driven up energy prices, reinforcing the urgent need for stronger policies focused on renewable energy. In the end, this study provides policymakers with valuable insights to develop flexible strategies that can withstand the unpredictable nature of climate change.

2- Literature Review and Theoretical Framework

Egypt's changing climate and energy consumption patterns have become a focal point of debate among researchers, particularly given the country's distinct circumstances. Many scholars argue that

unexpected temperature fluctuations have a direct influence on energy demand, altering consumption trends in ways that are not always immediately evident. This situation puts urban settings in the spotlight, suggesting that smart city planning, with a few modest tweaks, can sometimes ease overall energy needs. Researchers also rely on VAR models, which generally provide a robust approach to unravel these intricate interactions, to shed light on the issue. In most cases, developing ideas about how seasonal temperature changes impact energy use proves essential, echoing earlier studies that advocate for well-informed policymaking to support sustainable energy strategies ([Russo L, 2017](#); [L Murphy, 2016](#)).

2-1. Climate Change and Energy Consumption: Theoretical Perspectives

Multiple economic and environmental factors affect climate change and energy consumption. Variations in temperature often increase energy demand, especially in Egypt, where extreme weather increases cooling and heating needs ([Algieri et al., 2024](#)). The importance of VAR models in analyzing demand spikes from even minor temperature changes is highlighted. Political unrest and rising global energy prices complicate energy consumption trends ([Smith et al., 2021](#)). Developing climate-resilient energy policies requires understanding these dynamics.

2-2. Empirical Evidence on Temperature Anomalies and Energy Demand

Temperature fluctuations are influencing our energy consumption in unforeseen manners. Substantial temperature fluctuations compel individuals to promptly modify their heating or cooling systems, influencing energy consumption ([Abubakar et al., 2023](#)). These patterns must be comprehended in light of Egypt's temperature variations. Energy demand is likely to increase, particularly during peak times, as urban areas expand, and temperatures escalate ([Algieri et al., 2024](#)). These strains antiquated energy infrastructure, necessitating the adoption of superior, more sustainable alternatives. Temperature fluctuations could jeopardize energy security and

economic development without improved resource management. Policymakers must evaluate these advancements to enhance Egypt's energy sector.

2-3. VAR Models in Climate and Energy Research

Egypt is affected by climate change, and recent research uses Vector Autoregression (VAR) methods to analyze the complex relationships between weather anomalies and energy use. VAR techniques help researchers understand how climate shifts affect energy demand amid rapid urbanization by revealing unexpected relationships between temperature variations and energy usage patterns over time. Recent studies suggest that climate change threatens economic stability and sustainable energy development, disproportionately affecting disadvantaged communities (Abubakar et al., 2023). Technology and regular assessments become more important as global energy systems diversify (Smith et al., 2021). Combining these perspectives helps explain how energy policies can address the climate crisis, promote sustainable development, and strengthen Egypt's energy sector.

This study uses vector autoregression (VAR) modeling to examine Egypt's energy consumption shock and temperature anomalies. To analyze short- to medium-term dynamic effects, it emphasizes impulse response functions (IRFs) and forecast error variance decompositions. Lütkepohl (2005) mentions VAR models' ability to capture economic time series dynamics and forecasting, which aligns with time series analysis econometric principles. Sims, Stock, and Watson (1990) argue that VAR in levels produces consistent impulse response estimates by focusing on variable relationships rather than parameter estimates.

2-4. Hypothesis Development

The hypothesis development section explores the relationship between energy consumption and temperature changes, proposing two main hypotheses.

The first hypothesis (H1): posits that temperature anomalies significantly impact energy consumption, as fluctuations increase

reliance on heating and cooling, exacerbating socioeconomic inequalities in Egypt (Abubakar et al., 2023).

The second hypothesis (H2): suggests that the effect of temperature anomalies varies across seasons, with urban expansion and hotter summers altering energy demand. Understanding these seasonal variations is crucial for policymakers to develop effective energy efficiency and climate resilience strategies.

3- Data and Methodology

This study examines the dynamic correlation between temperature anomalies and energy consumption in Egypt from 1990 to 2023 using the Vector Autoregression (VAR) model. The VAR framework excels at analyzing complex climate change-energy consumption relationships without presumptions. The method involves multiple analyses: We use VAR Granger Causality/Block Exogeneity Wald Tests to determine the direction of causality between temperature anomalies and energy consumption indicators after correlation analysis. Third, we generate Impulse Response Functions (IRFs) to study energy consumption variables' temporal dynamic responses to temperature shocks. Fourth, we analyze energy consumption fluctuations due to temperature anomalies using Variance Decomposition. Finally, we perform extensive diagnostic assessments to verify our VAR model's strength and reliability, validating its policy implications for Egypt's energy sector's climate change adaptation.

3-1. Model Variables and Data Sources

Table No. (1) presents the variables of the economic measurement model, together with their descriptions and the sources of their time series data.

3-2. Graphical Analysis of Model Variables

A graphical analysis of the model variables offers significant insights into the correlation between temperature fluctuations and energy use in Egypt. Analysis of trends from 1990 to 2023 indicates that notable temperature variations align with pronounced surges in energy

demand. This visual method emphasizes the relationships between temperature changes and essential energy metrics, like electricity and natural gas usage, while also illustrating wider economic and social trends, including urban growth and inflation. (Panel I on Change to C (IPCC), 2022).

Table 1: List of Variables and data sources

Variable	Source	Description
Temperature Anomalies (TA)	Climate Change Knowledge Portal (CCKP), World Bank Group (2023)	Deviations from historical average temperatures in Egypt, measured as observed annual average maximum surface air temperature from 1990 to 2023.
Electricity Consumption per capita (EC)	International Energy Agency (IEA) (2023)	Household and commercial electricity usage per capita in Egypt.
Natural Gas Final Consumption (NGC)	International Energy Agency (IEA) (2023)	Total natural gas consumption measured in terajoules (TJ) gross.
Renewable Energy Consumption (REC)	World Bank (2023)	Renewable energy consumption as a percentage of total final energy consumption.
Urbanization Rate (UR)	World Bank (2023)	Percentage of the population living in urban areas in Egypt.
Electricity, Gas & Other Fuel CPI (ENP)	Central Bank of Egypt (2023)	Price changes in energy markets, capturing inflationary trends in electricity, gas, and other fuels.

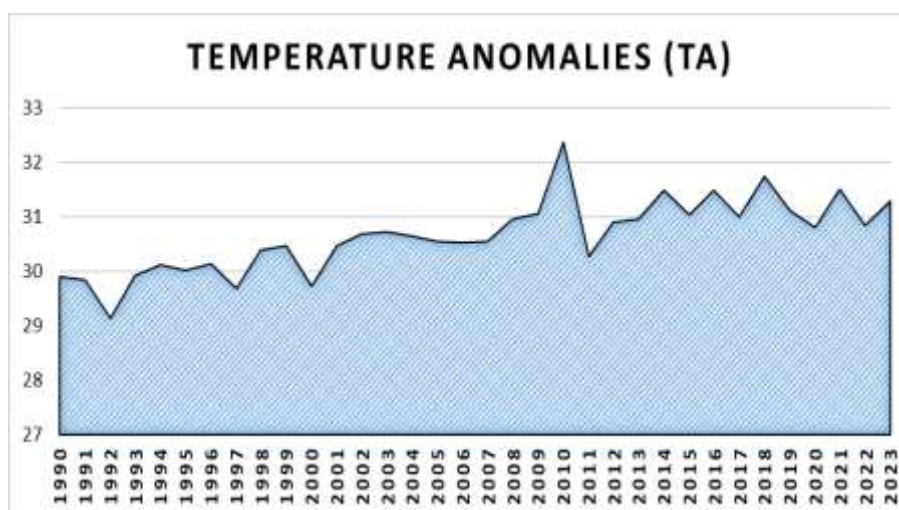
Source: by Author

3-2-1. Temperature Anomalies (TA)

Temperature Anomalies (TA) in Egypt denote the deviations from historical averages compared to the current annual maximum surface air temperature, measured in °C. They are not merely a fundamental indicator of climate change; many believe that TA may serve as a pivotal catalyst for alterations in energy consumption patterns. These anomalies capture both the seasonal fluctuations and the gradual, long-term increase in warming, providing a comprehensive view of how climate influences energy consumption. Research indicates that elevated temperatures necessitate increased cooling during summer months (and may lead to reduced heating in winter), yet overall energy consumption typically rises, particularly in warm regions such as Egypt. It is important to consider the influence of timing and the severity of these fluctuation elements that ultimately adjust both the quantity of energy consumed and the timing of its necessity,

complicating the overall landscape of energy demand. Considering that TA is central to this study, it typically correlates with increases in electricity and natural gas consumption, thereby highlighting its fundamental role in modeling energy dynamics in the context of changing climate conditions (Harvey et al., 2005).

Figure 1: Annual average maximum surface air temperature from (1990-2023)



Source: by Author using Climate Change Knowledge Portal (CCKP), World Bank Group (2023)

<https://climateknowledgeportal.worldbank.org/country/egypt/climate-data-historical>

Egypt's energy consumption is being reshaped by unpredictable temperature swings that stir up a lot more than just the weather. When temperature goes up, people naturally need more cooling—which in turn disrupts electricity use and puts extra pressure on an already strained system. Data stretching back to 1990 shows that these temperature oddities have been trending upward, with a major spike in 2010 when readings unexpectedly hit 32.36°C—an extreme outlier that really stands out. Since the early 2000s, temperatures have mostly lingered above 30°C, a trend that mirrors what's seen worldwide (World Bank Climate Change Knowledge Portal, 2023).

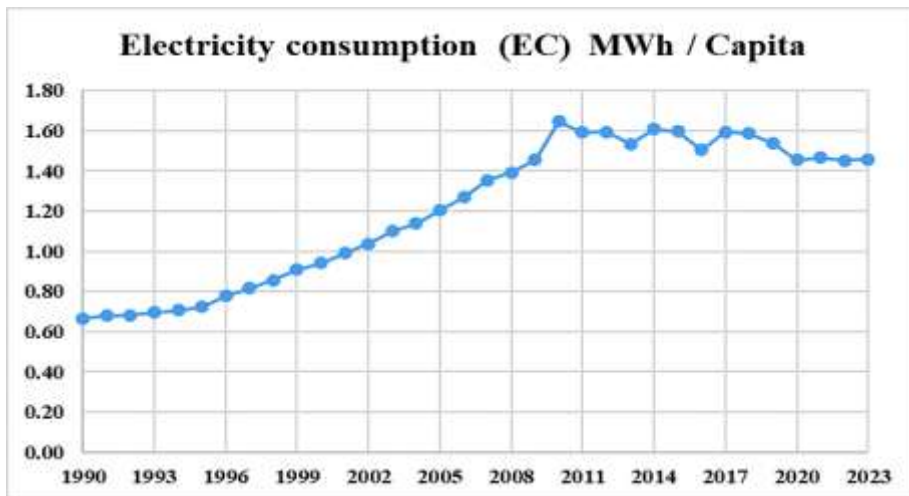
Higher temperatures increase cooling demands, causing energy supply issues. VAR models capture sudden and short-term dynamic

climate-energy use interactions. Smart policy requires understanding how temperature changes cause energy demand and supply shocks. This shows the system under pressure from a warming climate and suggests deeper insights to ease Egypt's energy infrastructure strain.

3-2-2. Electricity Consumption per Capita (EC)

The yearly per capita electricity consumption in Egypt quantifies energy allocation among households, commercial entities, and industries. The calculation is derived from the total annual electricity consumption divided by the population. Temperature markedly affects this consumption, as elevated temperatures lead to heightened usage of air conditioners and cooling systems. Prior research indicates that rising temperatures in areas such as Egypt lead to a non-linear increase in electricity usage. The VAR model elucidates the impact of anomalous temperature fluctuations on electricity consumption across various time lags, while accounting for additional variables. (Colelli F P et al., 2023).

Figure 2: Electricity consumption (EC) MWh / Capita from (1990-2023)



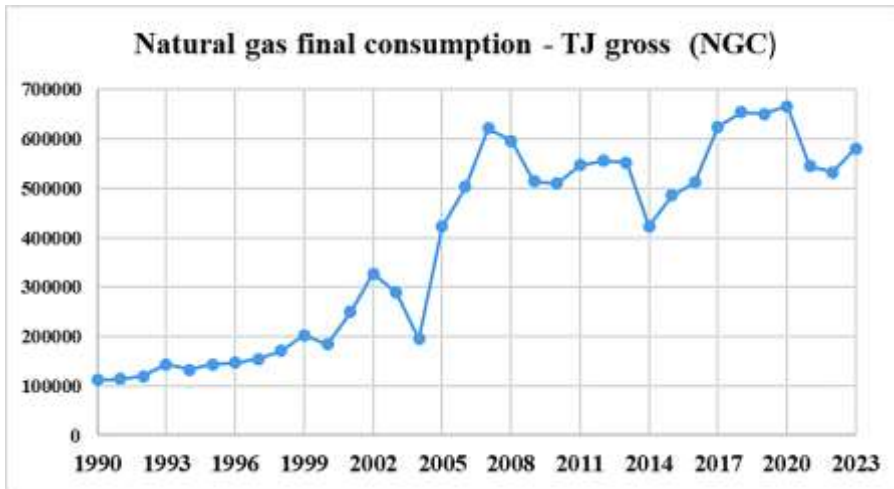
Source: by Author International Energy Agency (IEA). (2023) Egypt Energy Profile. <https://www.iea.org/countries/egypt>

According to Figure (2), from 1990 to 2023, per capita electricity consumption increased consistently, attaining 1.39 MWh as a result of economic growth, urban expansion, and heightened demands from residential and industrial sectors. In 2010, consumption peaked at 1.65 MWh, signifying a pivotal moment in the trend. Between 2011 and 2019, values varied from 1.54 MWh to 1.61 MWh, potentially attributable to energy conservation initiatives, economic fluctuations, or policy alterations. Since 2020, the figure has marginally decreased, attaining 1.46 MWh by 2023. This plateau indicates that per capita electricity consumption has stabilized, shaped by structural and economic factors impacting demand. The data indicates that the momentum for sustainable energy utilization has ceased ([A Calzadilla et al., 2015](#); [IEA, 2023](#)).

3-2-3. Natural Gas Final Consumption (NGC)

Natural gas final consumption, measured in terajoules (TJ) gross. This number shows that natural gas is a major piece of Egypt's overall energy puzzle. It's interesting, really, how much this consumption can change with the weather: when it gets warmer, the extra cooling needs might push up gas use for generating electricity, while milder winters often mean less direct heating ([Hamilton et al., 2010](#)). At the same time, grasping these twists and turns between temperature changes and gas usage is key to predicting future trends and making smarter choices about how we allocate energy resources.

Figure 3: Natural gas final consumption terajoules (TJ) gross from (1990-2023)



Source: by Author using International Energy Agency (IEA). (2023) Egypt Energy Profile. <https://www.iea.org/countries/egypt>

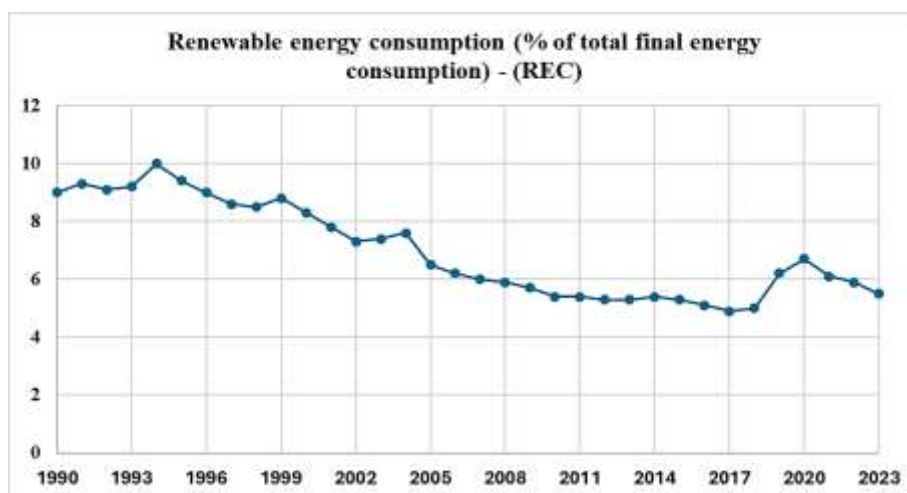
Figure (3) illustrates Egypt's gross terajoule natural gas usage from 1990 to 2023, which is quite intriguing. The graph indicates that as the nation increasingly depends on natural gas, its significance has escalated. Gas consumption remained stable throughout the 1990s, exhibiting only slight annual increases, perhaps influenced by local economic sentiments. Consumer expenditure surged in the early 2000s, reaching a zenith of 621,262 TJ in 2007. The growth appears to have aligned with a robust economy and heightened industrial demand, presumably due to the necessity for gas in power generation, industry, and residential use. However, the increase was not consistent. Significant declines occurred in 2004, 2014, and 2021, potentially attributable to economic deceleration, alterations in energy policy, or modifications in gas production and distribution .

Following a peak of 666,204 TJ in 2020, consumption declined in 2021 and 2022 before rebounding in 2023. Fluctuating energy laws, global price volatility, and Egypt's gradual integration of gas consumption with renewable sources typically induce these variations. The trend indicates a nation progressively augmenting its dependence on natural gas owing to economic expansions, industrial demands, policy modifications, and fluctuations in global energy markets (Göktepe et al., 2022; IEA, 2023).

3-2-4. Renewable Energy Consumption (REC)

Climate change pressures are ramping up, and Egypt is increasingly weaving renewable energy into its overall energy mix. Rising temperatures—typically seen as a direct sign of a warming climate—are pushing energy demands in unexpected ways, often making people lean on cleaner options. In most cases, studies hint that when unusual heat spikes occur, they nudge the system to rely on renewables a bit more as a kind of countermeasure against extreme weather. In a way, folding renewables into the country's energy plan not only builds a little extra resilience in the face of unpredictable weather but also syncs up, generally speaking, with broader global environmental aims (Tembin Hé et al., 2024). All in all, setting up solid strategies to boost renewable energy isn't solely about energy security; it's also about giving Egypt a stronger footing to confront the challenges of climate change and keep its economic growth sustainably driven.

Figure 4: Renewable energy consumption as a percentage of total final energy consumption from (1990-2023)



Source: by Author using World bank database
<https://data.worldbank.org/country/egypt-arab-rep?view=chart>

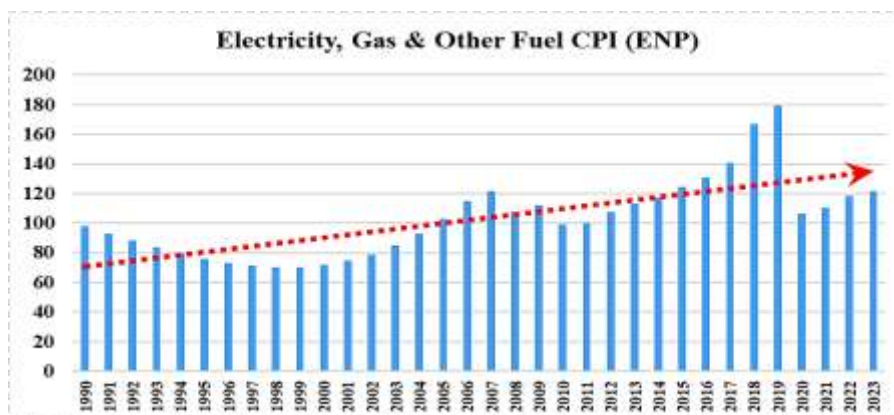
Figure 4 illustrates the trend in renewable energy consumption (REC) in Egypt from 1990 to 2023 is notable, reflecting a decline from

approximately 9% in 1990 to about 6.50% by 2005. The observed decline may result from increased reliance on fossil fuels, reduced investment in renewable infrastructure, or policy changes that favor traditional energy sources. From 2005 to 2017, the Renewable Energy Consumption (REC) remained at approximately 5-6%, indicating a stagnation in the adoption of renewable technologies. A slight recovery in 2019 and 2020 resulted in REC increasing to approximately 6.70%, but it subsequently declined to 5.50% by 2023. This indicates a necessity for enhanced incentives and more stringent regulations to advance Egypt's sustainability efforts. Following a peak in 2020, consumption declined in 2021 and 2022, but experienced a resurgence in 2023. The trend indicates an increasing dependence on natural gas, shaped by economic growth, industrial demands, policy adjustments, and global energy variations. The trend indicates an increasing dependence on natural gas, underscoring the necessity for enhanced incentives and regulations. (Ahmat et al., 2024; International Energy Agency, 2023).

3-2-5. Electricity, Gas & Other Fuel CPI (ENP)

In Egypt, fluctuations in energy prices are reflected in the fuel Consumer Price Index, which monitors electricity, gas, and other fuels (ENP). This index is crucial in the model, as price elasticity—reflecting the variation in consumption in response to price changes—operates independently of climate impacts. Bianchi et al. (2017) demonstrate that, usually, as energy costs rise, individuals try to reduce consumption through conservation and efficiency measures. Upon examining the VAR framework, one will observe that ENP frequently appears to be inversely correlated with consumption, primarily due to the similar price elasticity. What is the relationship between unusual temperature fluctuations and energy prices? Occasionally, the market merely responds to demand fluctuations; however, in several instances, it suggests potential policy initiatives targeting climate change. This complex interaction emphasizes the significance of ENP in comprehensively understanding the energy-climate nexus (Bianchi et al., 2022).

Figure 5: Egyptian energy market price changes (1990-2023)



Source: by Author using Central Bank of Egypt (2023) Time Series Data: Consumer Price Index. <https://www.cbe.org.eg/en/economic-research/time-series/downloadlist?category=706A9057F8454F7284BE8143070D88C4>

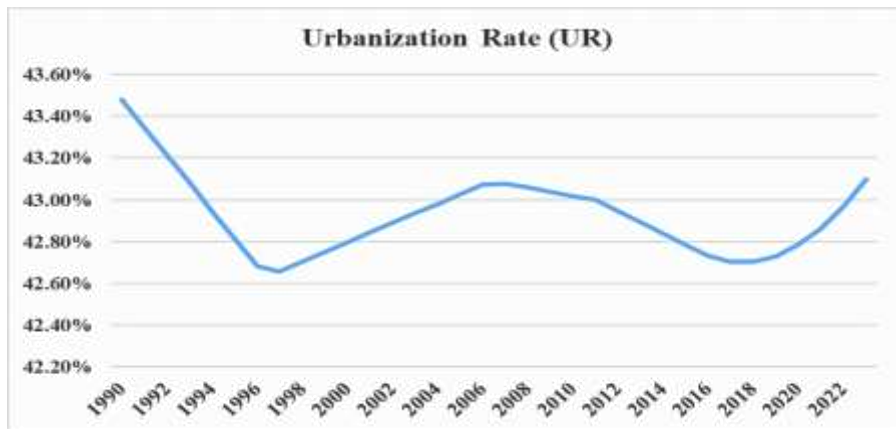
Egypt's energy sector has seen a noticeable shift thanks to subsidy cuts and a set of sweeping structural changes that many studies have pointed out as efforts to boost energy efficiency and make the market more flexible (Khalifa et al., 2020). In 2020, the index fell to 106.10—a drop most likely linked to the COVID-19 slowdown, which, in most cases, disrupted not only the energy sector but many others and even unsettled global supply chains. By 2023, however, there was a rebound, with the index climbing to 121.47; this seems to show a gradual return to pre-pandemic trends, even though inflationary pressures in energy still hint at broader economic shifts (Khalifa et al., 2020; CBE, 2023). These swings in the ENP index, generally speaking, really highlight how economic policies, global energy price shifts, and external jolts interact in unexpected ways with Egypt's energy market. All in all, managing energy policy here is a messy affair—local actions and worldwide events are so intertwined that staying ahead requires proactive, careful attention to sustain future progress.

3-2-6. Urbanization Rate (UR)

Egypt is experiencing a rapid move toward urban living that's really changing how energy gets used across the country—especially when you consider how much temperatures tend to swing around

unpredictably. More people are settling in cities, and that means a larger group relies on central energy supplies, which, in many cases, makes the whole system more sensitive to shifts in the climate. It's a bit tangled: as urban populations grow, they naturally drive up energy needs, and when extreme temperature events hit, the resulting energy shocks can be hard to manage (Abubakar et al., 2023).

Figure 6: The urbanization rate (UR) denotes the proportion of Egypt's population residing in urban areas from (1990-2023)



Source: by Author using World bank database

The graph displays the urbanization rate (UR) from 1990 to 2023, highlighting variations in the proportion of the population residing in urban regions. The UR was 43.48% in 1990, but it consistently decreased until 1997, when it reached a nadir of 42.66%. Subsequent to this era, the urbanization rate commenced its recovery, progressively rising from 1998 to 2007, culminating at 43.08%. Between 2008 and 2018, the UR shown a declining tendency, reaching its second-lowest figure of 42.70% in 2018. The rate remained mostly constant until 2019, subsequently experiencing a significant increase from 2020, culminating at 43.10% in 2023 (Worldbank, 2023). This pattern indicates that urbanization in this region has experienced cyclical trends, likely affected by economic, social, and policy variables impacting migration and urban development.

4- Model Specification

This study employs a Vector Autoregression (VAR) approach to examine the dynamic interrelationships among energy consumption, temperature anomalies, and other pertinent variables. The VAR model with two lags can be articulated in the subsequent general format:

$$Y_t = c + A_1 Y_{t-1} + A_2 Y_{t-2} + \varepsilon_t$$

Where:

- $Y_t = [\ln(EC)_t, \ln(NGC)_t, \ln(REC)_t, \ln(TA)_t, \ln(ENP)_t, \ln(UR)_t]'$ is the vector of endogenous variables at time t
- $c = [c_1, c_2, c_3, c_4, c_5, c_6]'$ is the vector of constants
- A_1, A_2 are the coefficient matrices for lags 1 and 2
- $\varepsilon_t = [\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t}, \varepsilon_{4t}, \varepsilon_{5t}, \varepsilon_{6t}]'$ is the vector of error terms

Specifically, for your variables, the VAR model can be written as:

$$\begin{bmatrix} TA_t \\ UR_t \\ EC_t \\ NGC_t \\ ENP_t \\ REC_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \end{bmatrix} + \sum_{i=1}^p \begin{bmatrix} a_{11,i} & a_{12,i} & a_{13,i} & a_{14,i} & a_{15,i} & a_{16,i} \\ a_{21,i} & a_{22,i} & a_{23,i} & a_{24,i} & a_{25,i} & a_{26,i} \\ a_{31,i} & a_{32,i} & a_{33,i} & a_{34,i} & a_{35,i} & a_{36,i} \\ a_{41,i} & a_{42,i} & a_{43,i} & a_{44,i} & a_{45,i} & a_{46,i} \\ a_{51,i} & a_{52,i} & a_{53,i} & a_{54,i} & a_{55,i} & a_{56,i} \\ a_{61,i} & a_{62,i} & a_{63,i} & a_{64,i} & a_{65,i} & a_{66,i} \end{bmatrix} \begin{bmatrix} TA_{t-i} \\ UR_{t-i} \\ EC_{t-i} \\ NGC_{t-i} \\ ENP_{t-i} \\ REC_{t-i} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \\ \varepsilon_{6t} \end{bmatrix}$$

The VAR model consists of the following six equations:

$$\ln(EC)_t = c_1 + A_{11}\ln(EC)_{t-1} + A_{12}\ln(EC)_{t-2} + A_{13}\ln(NGC)_{t-1} + A_{14}\ln(NGC)_{t-2} + A_{15}\ln(REC)_{t-1} + A_{16}\ln(REC)_{t-2} + A_{17}\ln(TA)_{t-1} + A_{18}\ln(TA)_{t-2} + A_{19}\ln(ENP)_{t-1} + A_{110}\ln(ENP)_{t-2} + A_{111}\ln(UR)_{t-1} + A_{112}\ln(UR)_{t-2} + \varepsilon_{1t} \quad (1)$$

$$\ln(NGC)_t = c_2 + A_{21}\ln(EC)_{t-1} + A_{22}\ln(EC)_{t-2} + A_{23}\ln(NGC)_{t-1} + A_{24}\ln(NGC)_{t-2} + A_{25}\ln(REC)_{t-1} + A_{26}\ln(REC)_{t-2} + A_{27}\ln(TA)_{t-1} + A_{28}\ln(TA)_{t-2} + A_{29}\ln(ENP)_{t-1} + A_{210}\ln(ENP)_{t-2} + A_{211}\ln(UR)_{t-1} + A_{212}\ln(UR)_{t-2} + \varepsilon_{2t} \quad (2)$$

$$\ln(REC)_t = c_3 + A_{31}\ln(EC)_{t-1} + A_{32}\ln(EC)_{t-2} + A_{33}\ln(NGC)_{t-1} + A_{34}\ln(NGC)_{t-2} + A_{35}\ln(REC)_{t-1} + A_{36}\ln(REC)_{t-2} + A_{37}\ln(TA)_{t-1} + A_{38}\ln(TA)_{t-2} + A_{39}\ln(ENP)_{t-1} + A_{310}\ln(ENP)_{t-2} + A_{311}\ln(UR)_{t-1} + A_{312}\ln(UR)_{t-2} + \varepsilon_{3t} \quad (3)$$

$$\ln(TA)_t = c_4 + A_{41}\ln(EC)_{t-1} + A_{42}\ln(EC)_{t-2} + A_{43}\ln(NGC)_{t-1} + A_{44}\ln(NGC)_{t-2} + A_{45}\ln(REC)_{t-1} + A_{46}\ln(REC)_{t-2} + A_{47}\ln(TA)_{t-1} + A_{48}\ln(TA)_{t-2} + A_{49}\ln(ENP)_{t-1} + A_{410}\ln(ENP)_{t-2} + A_{411}\ln(UR)_{t-1} + A_{412}\ln(UR)_{t-2} + \varepsilon_{4t} \quad (4)$$

$$\ln(ENP)_t = c_5 + A_{51}\ln(EC)_{t-1} + A_{52}\ln(EC)_{t-2} + A_{53}\ln(NGC)_{t-1} + A_{54}\ln(NGC)_{t-2} + A_{55}\ln(REC)_{t-1} + A_{56}\ln(REC)_{t-2} + A_{57}\ln(TA)_{t-1} + A_{58}\ln(TA)_{t-2} + A_{59}\ln(ENP)_{t-1} + A_{510}\ln(ENP)_{t-2} + A_{511}\ln(UR)_{t-1} + A_{512}\ln(UR)_{t-2} + \varepsilon_{5t} \quad (5)$$

$$\ln(UR)_t = c_6 + A_{61}\ln(EC)_{t-1} + A_{62}\ln(EC)_{t-2} + A_{63}\ln(NGC)_{t-1} + A_{64}\ln(NGC)_{t-2} + A_{65}\ln(REC)_{t-1} + A_{66}\ln(REC)_{t-2} + A_{67}\ln(TA)_{t-1} + A_{68}\ln(TA)_{t-2} + A_{69}\ln(ENP)_{t-1} + A_{610}\ln(ENP)_{t-2} + A_{611}\ln(UR)_{t-1} + A_{612}\ln(UR)_{t-2} + \varepsilon_{6t} \quad (6)$$

Where:

- **ln(EC):** Measures electricity consumption per capita.
- **ln(NGC):** Captures fossil fuel energy usage.
- **ln(REC):** Measures renewable energy consumption.
- **ln(TA):** Measures deviations from historical average temperatures.
- **ln(ENP):** Captures price changes in energy markets.
- **ln(UR):** Measures population living in urban areas.
- **c₁ to c₆:** Constant terms or intercepts.
- **A_(ij):** Coefficient for variable j's effect on variable i.
- **ε_{1t} to ε_{6t}:** Error terms for each equation.

5- Unit Root Tests

Unit root tests are essential for stationarity monitoring. These tests detect unit roots in time series variables, indicating instability.

Conclusions in Table 2 support the idea that most variables are stationary. Numerous studies suggest that ignoring this phase may distort economic trends and their relationships. Research suggests that ignoring these tests may distort economic modeling and predictions, thereby skewing policy decisions (Abubakar et al., 2023). Despite flaws, comprehensive Unit Root testing aligns data and supports our conclusions.

Table 2. Final outcomes of Unit Root tests

Variable	Test	Level (With Constant)	First Difference (With Constant)	Stationarity
EC	PP	$t = -4.3942$ ($p = 0.0015$) ***	$t = -22.0092$ ($p = 0.0001$) ***	I(0)
	ADF	$t = -4.2738$ ($p = 0.0021$) ***	$t = -5.8161$ ($p = 0.0000$) ***	
NGC	PP	$t = -6.6464$ ($p = 0.0000$) ***	$t = -21.8340$ ($p = 0.0001$) ***	I(0)
	ADF	$t = -6.2089$ ($p = 0.0000$) ***	$t = -6.0441$ ($p = 0.0000$) ***	
REC	PP	$t = -4.2628$ ($p = 0.0021$) ***	$t = -12.3219$ ($p = 0.0000$) ***	I(0)
	ADF	$t = -4.4118$ ($p = 0.0014$) ***	$t = -5.8592$ ($p = 0.0000$) ***	
TA	PP	$t = -23.9463$ ($p = 0.0001$) ***	$t = -42.9728$ ($p = 0.0001$) ***	I(0)
	ADF	$t = -10.4476$ ($p = 0.0000$) ***	$t = -6.1361$ ($p = 0.0000$) ***	
ENP	PP	$t = -5.2192$ ($p = 0.0002$) ***	$t = -25.6150$ ($p = 0.0001$) ***	I(0)
	ADF	$t = -5.2338$ ($p = 0.0002$) ***	$t = -6.6045$ ($p = 0.0000$) ***	
UR	PP	$t = -3.0071$ ($p = 0.0446$) **	$t = -1.1647$ ($p = 0.6772$) No	I(0)
	ADF	$t = -4.1692$ ($p = 0.0027$) ***	$t = -1.6889$ ($p = 0.4268$) No	

Source: by Author Using EViews output

Table 2 shows that all variables (EC, NGC, REC, TA, ENP, and UR) are stationary at level I(0), as confirmed by Phillips-Perron and ADF tests with significant p-values ($p < 0.01$ for most variables). The unit root hypothesis is rejected in both test methods, boosting econometric specification confidence (Hamilton, 1994). First-differencing would misspecify models and lose valuable information due to stationarity (Enders, 2014). Thus, a VAR model in levels is better than cointegration approaches or VECM for analyzing Egypt's dynamic temperature anomaly-energy consumption relationships (Lütkepohl, 2005; Sims et al., 1990).

6- Lag Length Selection

Choosing the appropriate lag length for the VAR model is a different issue that requires attention as it should reflect the actual dynamics concealed in the data.

Table 3. Lag Selection Criteria for the VAR Model

Lag	LogL	LR	FPE	AIC	SC	HQ
0	302.4073	NA	3.63e-16	-18.52546	-18.25063	-18.43436
1	452.6816	234.8036	3.00e-19	-25.66760	-23.74382*	-25.02992
2	507.1624	64.69588*	1.22e-19*	-26.82265*	-23.24992	-25.63839*

Source: EViews output

Table 3 shows VAR lag order selection results by criterion, indicating a two-lag model, capturing fundamental dynamics and allowing for impulse responses and Granger causality tests.

7- Correlation Analysis

The correlation matrix in Egypt shows the linear relationships between temperature anomalies and energy-related variables, with coefficients ranging from -1 to 1, indicating a substantial or weak relationship, or zero for insignificant associations.

Table 4. Correlation Matrix of Temperature Anomalies and Energy Consumption in Egypt

Correlation Probability	EC	NGC	REC	TA	ENP	UR
EC	1.000000 —					
NGC	0.961224 0.0000	1.000000 —				
REC	-0.964038 0.0000	-0.932999 0.0000	1.000000 —			
TA	0.829362 0.0000	0.780432 0.0000	-0.798074 0.0000	1.000000 —		
ENP	0.742471 0.0000	0.768209 0.0000	-0.792435 0.0000	0.630347 0.0001	1.000000 —	
UR	-0.269411 0.1234	-0.223142 0.2046	0.174359 0.3240	-0.268485 0.1247	-0.000320 0.9986	1.000000 —

Source: EViews output

Analysis of Temperature Anomalies in Relation to Electricity Consumption

TA and electricity consumption (EC) are correlated 0.8294, p-value 0.0000. A statistically significant positive relationship exists. Historical temperature deviations indicate higher electricity demand. This may be due to warm-weather cooling and cold-weather heating. This supports the literature that temperature fluctuations affect electricity demand patterns ([Chimeli et al., 2005](#)).

Analysis of Temperature Anomalies and Natural Gas Consumption

Temperature anomalies (TA) and natural gas consumption (NGC) have a strong positive correlation of 0.7804 ($p = 0.0000$). The trend is linked to increased gas-powered heating and cooling system use due to temperature fluctuations. The findings show Egypt's energy sector's vulnerability to climate-driven demand changes.

Analysis of Temperature Anomalies and Their Impact on Renewable Energy Consumption

TA and renewable energy consumption (REC) have a strong negative correlation (-0.7981 ; $p = 0.0000$). The evidence suggests that during significant temperature fluctuations; renewable energy consumption decreases due to increased dependence on fossil fuel-based energy

sources to meet immediate demand. Variable renewable energy sources and increased energy demands during severe weather may affect this transition.

Temperature Anomalies and Energy Price Fluctuations

Temperature anomalies (TA) and electricity, gas, and fuel prices (ENP) have a moderate positive correlation of 0.6303 with a p-value of 0.0001. This finding suggests temperature anomalies may affect energy market prices. Supply-demand imbalances exacerbated by climate variability may increase production costs and market instability.

Analysis of Temperature Anomalies in Relation to Urbanization Trends

The correlation coefficient between temperature anomalies (TA) and urbanization rate (UR) is -0.2685, with a p-value of 0.1247. A weak and statistically insignificant correlation suggests that temperature anomalies do not significantly affect Egyptian urbanization patterns. Economic development and infrastructure improvement may play a bigger role in urban expansion.

The findings demonstrate how temperature anomalies affect energy consumption and Egypt's energy security and economy. The positive correlations between TA, electricity consumption, and natural gas usage suggest increased energy demand during severe weather. The negative correlation with renewable energy consumption shows the challenges of integrating renewables into a climate-constrained energy system. The observed price volatility highlights the economic effects of temperature anomalies.

The findings emphasize the need for flexible energy policies that promote climate change resilience, energy-efficient infrastructure investment, and renewable energy use. To reduce economic strain and ensure Egypt's energy sector's sustainability, policymakers must assess temperature-induced energy consumption variations.

8. Estimation of the VAR Model

The study analyzes consumption shocks in Egypt with a VAR model, elucidating the interaction between electricity and natural gas usage under varying pressures. The analysis reveals elasticities in coefficients, demonstrating how a 1% change in one factor affects the dependent variable by an equivalent percentage. The paper analyzes how anomalous temperature readings influence fluctuations in energy demand, supply variations, and price volatility, especially in the MENA region, where climate change exacerbates the vulnerability of the energy infrastructure. An appropriately configured VAR model can elucidate critical connections among variables, aiding policymakers in tackling climatic variability and sustainable energy requirements.

8-1. Electricity Consumption Equation (EC)

$$EC = 0.7136 * EC(-1) + 0.0187 * EC(-2) + 0.0182 * NGC(-1) + 0.0734 * NGC(-2) - 0.2867 * REC(-1) + 0.1697 * REC(-2) - 0.1363 * TA(-1) + 0.1560 * TA(-2) - 0.0454 * ENP(-1) - 0.0465 * ENP(-2) + 4.0206 * UR(-1) - 4.1381 * UR(-2) - 0.0755$$

Electricity consumption demonstrates significant persistence, evidenced by a coefficient of 0.7144 at lag 1, signifying that 0.714% of the previous year's electricity consumption growth persists into the current year. Temperature anomalies initially exert a negative impact (-0.1363 at lag 1), indicating that a 1% rise in temperature anomalies results in a 0.14% moderate-term decline in electricity consumption, potentially attributable to transient energy efficiency enhancements or behavioral modifications. Nonetheless, the moderate-term effect is positive (0.1560 at lag 2), suggesting that elevated temperatures lead to a rise in electricity demand, presumably due to heightened cooling requirements. Urbanization is a major catalyst for electricity demand, with a 1% increase in urbanization resulting in a 4.02% increase in electricity consumption, underscoring the expansion of infrastructure and escalating household energy usage in urban locales. The adverse effect of energy prices (0.0453 at lag 1) indicates that increasing electricity, gas, and fuel costs may prompt short-term energy

conservation behaviors. (International Energy Agency, 2022; Caporin et al., 2019; Juntunen et al., 2022).

8-2. Natural Gas Consumption Equation (NGC)

$$\text{NGC} = 2.6097 * \text{EC}(-1) - 0.1599 * \text{EC}(-2) + 0.1103 * \text{NGC}(-1) - 0.1503 * \text{NGC}(-2) - 0.2828 * \text{REC}(-1) + 1.4607 * \text{REC}(-2) - 3.8928 * \text{TA}(-1) - 3.0742 * \text{TA}(-2) + 0.8563 * \text{ENP}(-1) + 0.1119 * \text{ENP}(-2) + 39.0440 * \text{UR}(-1) - 38.9079 * \text{UR}(-2) + 29.5085$$

As electricity demand rises by 1%, natural gas consumption increases by 2.61% at lag 1, highlighting natural gas's dominance in Egypt's power generation sector. This data indicates that a 1% rise in temperature anomalies leads to a 3.89% decrease in natural gas demand in the short run. As temperatures increase, heating needs diminish while cooling needs grow, resulting in a shift from gas-powered to electric options. Urbanization plays a crucial role, with a 1% increase in urbanization resulting in a 39.04% rise in natural gas consumption. The positive impact of rising energy prices (0.8563 at lag 1) implies that supply constraints or inelastic industrial demand may hinder the reduction of natural gas demand. A robust model fit ($R^2 = 0.9569$ and Adjusted $R^2 = 0.9298$) indicates that urbanization trends and climate variability significantly influence natural gas consumption in (World Bank, 2023).

8-3. Renewable Energy Consumption Equation (REC)

$$\text{REC} = -0.6113 * \text{EC}(-1) - 0.1732 * \text{EC}(-2) + 0.0977 * \text{NGC}(-1) - 0.0124 * \text{NGC}(-2) + 0.8030 * \text{REC}(-1) - 0.6428 * \text{REC}(-2) + 0.9313 * \text{TA}(-1) - 0.3309 * \text{TA}(-2) + 0.0514 * \text{ENP}(-1) - 0.0658 * \text{ENP}(-2) + 5.3723 * \text{UR}(-1) - 8.7652 * \text{UR}(-2) + 11.3963$$

The study demonstrates a substitution effect between conventional and renewable energy consumption, where a 1% increase in electricity consumption leads to a 0.61% decrease in renewable energy consumption. Temperature anomalies have a significant positive effect, with a 1% increase in temperature anomalies resulting in a 0.93% rise in renewable energy consumption. Additionally, urbanization significantly influences renewable energy adoption; a

1% increase in urbanization corresponds to a 5.37% increase in renewable energy consumption ([Richter L et al., 2024](#)).

The energy price index exhibits a short-term positive effect on renewable investments but a moderate-term negative effect due to issues related to affordability. The model effectively elucidates the dynamics of renewable energy adoption, highlighting the necessity for ongoing policy support for renewables in Egypt, as indicated by the R^2 (0.9678) and Adjusted R^2 (0.9475) values ([International Renewable Energy Agency, 2022](#)).

8-4. Temperature Anomalies Equation (TA)

$$TA = -0.0339 * EC(-1) + 0.0235 * EC(-2) - 0.0020 * NGC(-1) + 0.0262 * NGC(-2) - 0.0907 * REC(-1) + 0.0275 * REC(-2) - 0.3955 * TA(-1) - 0.1529 * TA(-2) - 0.0132 * ENP(-1) + 0.0102 * ENP(-2) + 0.0000 * UR(-1) - 1.1634 * UR(-2) + 9.5043$$

The small coefficients of electricity and natural gas consumption in the temperature anomalies equation indicate that energy consumption has a limited direct effect on climate fluctuations in the short term. Temperature anomalies exhibit strong mean reversion (-0.3955 at lag 1), suggesting that extreme deviations stabilize over time. Given its role in reducing temperature anomalies (-0.0907 at lag 1), renewable energy consumption may help mitigate climate change by lowering emissions. Additionally, urbanization increases temperature anomalies (-1.1634 at lag 2), signifying that cities generate more carbon and warm local areas. The R^2 (0.7328) and Adj. R^2 (0.5641) suggest that the model partially accounts for climate variability; however, external factors such as global emissions and natural climate cycles also influence Egypt's temperature anomalies ([IPCC, 2021](#)).

8-5. Energy Price Index Equation (ENP)

$$ENP = -0.8327*EC(-1) + 0.4764*EC(-2) - 0.1947*NGC(-1) + 0.0122*NGC(-2) - 1.7742*REC(-1) + 0.6715*REC(-2) + 0.8916*TA(-1) + 0.0340*TA(-2) + 0.5080*ENP(-1) + 0.2559*ENP(-2) + 30.0775*UR(-1) - 29.5029*UR(-2) + 0.2666$$

The consumption of electricity exerts a dual influence on energy prices. At lag 1, the effect is significantly negative (-0.8327), signifying that a 1% rise in previous electricity consumption results in a 0.83% decline in energy prices. This may result from factors including postponed regulatory actions, subsidized pricing models, or economies of scale in electricity production. At lag 2, electricity consumption exerts a positive influence (0.4764), indicating that a prior rise in consumption ultimately contributes to price pressures, potentially due to deferred supply constraints, heightened fuel costs, or policy modifications facilitating price recovery. In contrast, temperature anomalies exert a significant positive influence (0.8916 at lag 1), indicating that a 1% increase in temperature anomalies results in a 0.89% rise in energy prices, presumably due to heightened energy demand for cooling and supply limitations during severe weather conditions (Nawaz W, 2018).

Urbanization perpetuates price inflation, as a 1% increase in urbanization results in a 30.08% escalation in energy prices, indicative of infrastructure development expenses and heightened demand (Jemmali H, 2018). The R^2 (0.9163) and Adj. R^2 (0.8634) validate the model's robustness, underscoring the necessity for energy price stabilization policies to alleviate delayed supply constraints and climate-induced price volatility (International Monetary Fund, 2022; Nawaz W, 2018).

8-6. Urbanization Equation (UR)

$$UR = 0.0016*EC(-1) - 0.0021*EC(-2) - 0.0008*NGC(-1) + 0.0007*NGC(-2) - 0.0030*REC(-1) + 0.0043*REC(-2) + 0.0005*TA(-1) + 0.0022*TA(-2) + 0.0005*ENP(-1) + 0.0015*ENP(-2) + 1.8242*UR(-1) - 0.9447*UR(-2) + 0.4334$$

Electricity consumption has a complex relationship with urbanization, with a positive effect of 0.0016% at lag 1 indicating initial support for urban growth and a negative effect of -0.0021% at lag 2 suggesting infrastructure or economic constraints. Complementary factors show that renewable energy consumption has a complex trajectory, starting with a negative effect (-0.0030) and ending with a positive effect (0.0043). Temperature anomalies have a delayed positive effect

(0.0022 at lag 2), while energy prices have a modest positive correlation. The model's autoregressive coefficients ($UR(-1) = 1.8242$, $UR(-2) = -0.9447$) show that historical urbanization levels strongly influence future growth, while the constant term of 0.4334 indicates fundamental structural determinants of urban development.

8-7. The Dynamic Link Between Climate Change and Energy Shocks in Egypt

In Egypt, the VAR model provides compelling evidence that anomalous temperature patterns significantly influence energy consumption. Research indicates a notable trend: as temperatures begin to rise, electricity consumption initially decreases; however, this decline soon reverses, resulting in an overall increase in usage. This alteration occurs concurrently with a swift increase in renewable energy, while simultaneously, the consumption of natural gas significantly declines. Urbanization emerges as another critical factor complicating this scenario (Malhi GS et al., 2021). As urban areas expand due to demographic changes, they inherently increase energy demand and influence consumption patterns in unforeseen manners. Ultimately, comprehending these interconnected effects is crucial for formulating energy policies that address both current challenges and future pressures from climate change and urbanization in Egypt.

9. Diagnostic Testing

Diagnostic tests confirm the reliability of the VAR model used in the analysis of temperature anomalies on energy consumption shocks in Egypt. The model adheres to essential econometric assumptions, providing reliable insights into the dynamic interactions between temperature anomalies and energy consumption shocks in Egypt. The VAR Residual Normality Test indicates that the residuals follow a multivariate normal distribution, with a Jarque-Bera joint test value of $p = 0.1804$, above the typical 5% cutoff. Overall skewness and kurtosis measures are in a favorable range, although Component 1 shows signs of not being normal ($p = 0.0466$). This evidence suggests that the basic assumptions of the econometric framework are still valid. (Lütkepohl, 2005).

Table 5. VAR Residual Normality Test Summary

Test Component	Skewness (p-value)	Kurtosis (p-value)	Jarque-Bera (p-value)
Component 1	0.0646	0.0994	0.0466
Component 2	0.0759	0.1437	0.0711
Component 3	0.6451	0.7176	0.8424
Component 4	0.3571	0.6401	0.5867
Component 5	0.9761	0.5235	0.8155
Component 6	0.5928	0.0991	0.2225
Joint Test	0.2445	0.2150	0.1804

Source: by Author Using EViews output

The Serial Correlation Test examines residuals for autocorrelation, which may indicate model misspecification.

Table 6. VAR Residual Serial Correlation LM Test Summary

Lag	LRE Stat (p-value) *	Rao F-Stat (p-value)	Decision
1	0.7981	0.8319	No serial correlation
2	0.8066	0.8392	No serial correlation
3	0.0698	0.1003	No serial correlation
Joint (1–2 lags)	0.7103	0.9401	No serial correlation

Source: by Author Using EViews output

Table no. 8 shows that the VAR Residual Serial Correlation LM Test confirms the absence of serial correlation, with p-values for all lags exceeding 0.05. The Rao F-statistic also supports this, with p-values consistently above 0.05. This absence of serial correlation is crucial as it prevents standard errors and misleading hypothesis tests, indicating the VAR model is well-specified and does not miss any significant lag dynamics. (Enders, 2014).

the Heteroscedasticity Test checks if the variance remains stable—a critical step in verifying that all model assumptions are met and that our inferences are reliable.

Table 7. VAR Residual Heteroskedasticity Test Summary

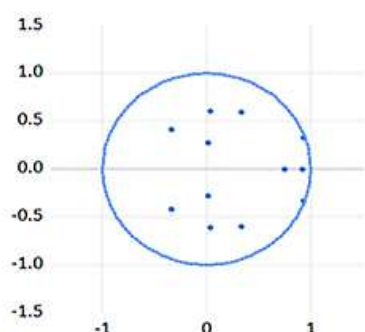
Test	Chi-Square	df	p-value	Decision
Joint Test	523.3741	504	0.2665	No heteroskedasticity

Source: by Author Using EViews output

The p-value of 0.2665 exceeds the conventional 0.05 threshold, meaning we fail to reject the null hypothesis of constant variance. This suggests that heteroskedasticity is not a concern, and the residuals exhibit a stable variance structure within the model (Gujarati & Porter, 2020).

Figure 7. Roots of Residuals

Inverse Roots of AR Characteristic Polynomial



Roots of Characteristic Polynomial Summary

Root	Modulus
$0.9268 \pm 0.3257i$	0.9824
0.9159	0.9159
0.7540	0.7540
$0.3403 \pm 0.6246i$	0.7113
$0.0183 \pm 0.5991i$	0.5994
$-0.3492 \pm 0.4131i$	0.5410
$0.0114 \pm 0.2827i$	0.2829

Stability Condition: No root lies outside the unit circle; thus, the VAR model satisfies the stability condition.

Source: EViews output

The characteristic polynomial's inverse roots show that the process is stationary—every modulus ends up inside the unit circle. The inverse root plot shows that all points are within the boundary, ensuring that system shocks will dissipate over time rather than explode. Lütkepohl (2005) noted that stationarity validates parameter estimates and the model's dynamic structure, making it essential for good inference.

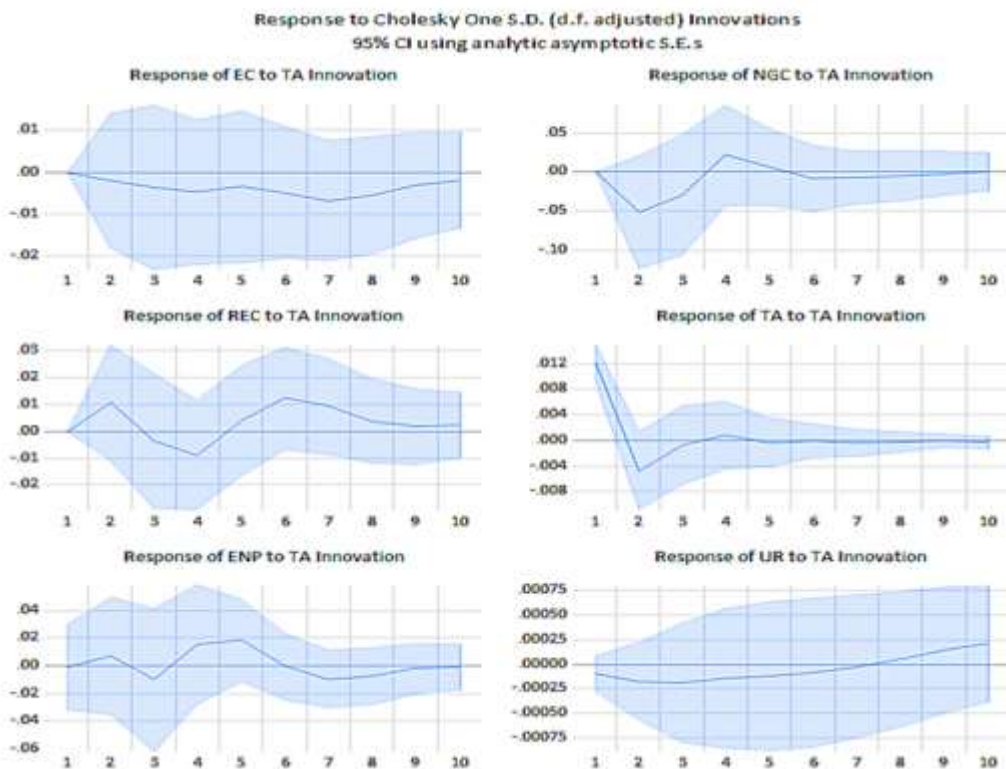
Diagnostic tests show that the estimated VAR model for analyzing temperature anomalies and energy consumption shocks in Egypt is statistically robust. The residuals follow a multivariate normal distribution with only slight deviations in one component, according to the normality test. The serial correlation test proves the model is autocorrelation-free, ensuring unbiased and consistent coefficient estimates. The heteroskedasticity test shows that residual variances remain stable, improving policy analysis model reliability .

The results support using impulse response functions (IRFs) and variance decomposition analysis to study the dynamic effects of temperature anomalies on energy demand, highlighting Egypt's energy sector's dependence on climate adaptation policies (Sims, 1980).

10. Impulse Response Analysis

Impulse Response Analysis (IRA) is a crucial tool in analyzing the dynamic transmission of shocks, particularly in Egypt, focusing on the impact of temperature anomalies on energy consumption over time. It provides insights into the economic burden of climate-related disturbances and aids policy formulation.

Figure 8. Impulse Response



Source: EViews output

Interpreting Impulse Response Analysis

The figure shows how Temperature Anomalies (TA) shocks affect Egyptian energy consumption variables. The electricity consumption per capita response is mildly negative in periods 4–8, suggesting initial suppression and equilibrium by period 10 (Auffhammer & Mansur, 2014). Natural Gas Final Consumption Response is volatile, with a negative response in Period 2 and a sharp positive spike in Period 4. Renewable Energy Consumption response has two cycles, indicating temperature sensitivity and phase adaptation. The initial shock dissipates quickly in response to temperature anomalies. The Electricity, Gas & Other Fuel CPI response has a delayed positive peak around period 5, suggesting temperature-driven demand changes affect energy market pricing structures. The Urbanization Rate response has little immediate impact and a gradual positive trend, suggesting resource allocation shifts may cause longer-term urbanization pressures. Unique energy subsectors' response patterns support the VAR approach for complex climate-energy interactions (Dell et al., 2014; Kilian, 2009; Ciscar & Dowling, 2014).

11- Variance Decomposition

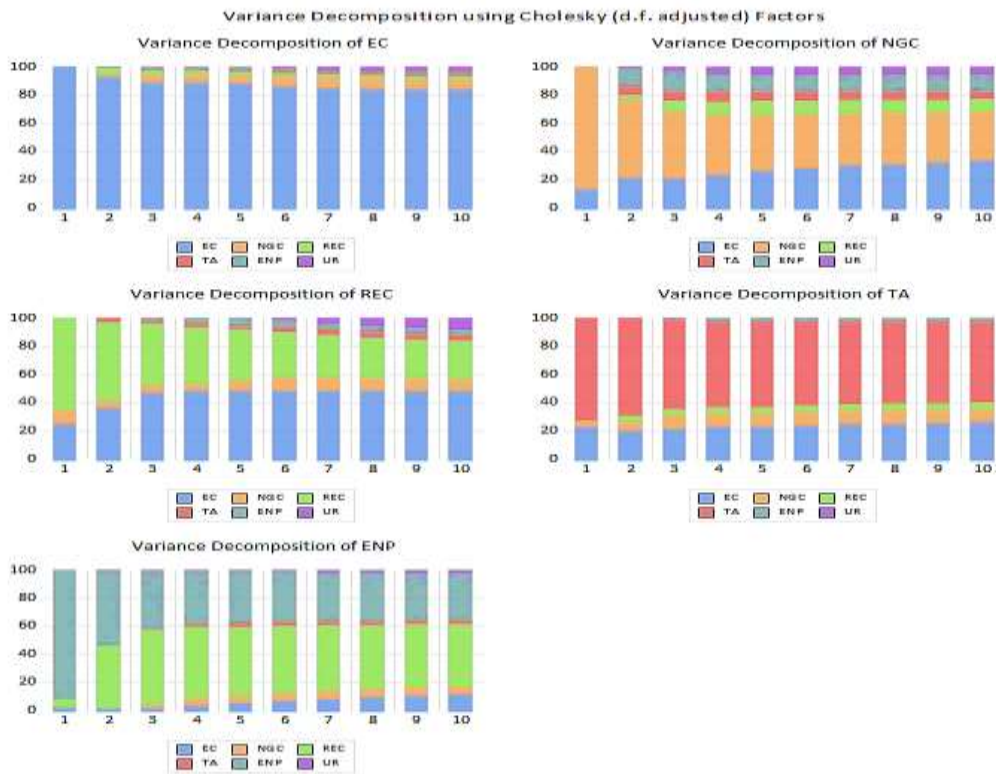
According to Figure 8, the analysis of system behavior reveals that Electricity Consumption (EC) accounts for 84% of the system's volatility, demonstrating a strong reliance on infrastructure and habits. Renewable Energy Consumption (REC) and Net Generation Capacity (NGC) contribute 6.82% each, indicating the integration of alternative energy sources into the overall composition.

By period 10, natural gas consumption self-reliance decreases, suggesting a closer relationship between the gas and electric sectors. Renewable energy consumption accounts for 27.52% of variation, while electricity accounts for 48.20%. Natural gas is 8.31%, indicating a complementary relationship between fossil fuels and renewable energy. Energy contributes 25.71% to temperature anomalies, but they still explain 57.66% by period 10. Renewable energy explains 44.67% of energy price volatility, while prices explain 33.09%. By period 10, urbanization affects 53.39%, while renewable energy contributes 20.22%, suggesting that green energy

infrastructure influences urban growth (Omri, 2014; Apergis & Payne, 2012).

The Cholesky ordering of (EC,NGC,REC,TA,ENP,UR) explains Egypt's energy-climate system's structural interrelations, but it is less ordered than desired. A decline in self-determined roles across many variables and substantial bidirectional correlations, particularly between temperature anomalies and diverse consumption patterns, reinforce the concept of climate-energy feedbacks in emerging economies (Ozturk, 2010; Würzburg et al., 2013; Liddle, 2014).

Figure 9. Cholesky decomposition



Source: EViews output

12. VAR Granger Causality/Block Exogeneity Wald Tests

The Granger causality test results illuminate Egypt's dynamic electricity, natural gas, renewable energy, temperature anomalies, energy price index, and urbanization linkages. The findings reveal

Egypt's energy market and environmental dynamics' structural interconnections by showing significant causal links between major energy and climate variables.

VAR Granger Causality and Block Exogeneity Wald Tests show complex relationships between Egypt's electricity use, natural gas use, renewable energy use, temperature, energy costs, and urbanization. These statistical analyses illuminate climate change's economic effects and inform energy adaptation. Strategic energy agreements may reduce climate disruptions (Zentner et al.), while diverse energy management strategies may strengthen system resilience to temperature anomalies and resource constraints.

Table 8. VAR Granger Causality/Block Exogeneity Wald Tests Summary

Dependent Variable	Significant Excluded Variables ($p < 0.05$)	Joint Significance (All Variables) (p-value)
Electricity Consumption (EC)	Natural Gas Consumption (NGC) (0.0065), Temperature Anomalies (TA) (0.0257), Energy Price Index (ENP) (0.0070)	Significant P= (0.00377)
Natural Gas Consumption (NGC)	Electricity Consumption (EC) (0.0151), Temperature Anomalies (TA) (0.0222), Energy Price Index (ENP) (0.0055)	Significant P= (0.0035)
Renewable Energy Consumption (REC)	Electricity Consumption (EC) (0.0178)	Significant P= (0.0075)
Temperature Anomalies (TA)	No significant causal relationships	Significant P= (0.0183)
Energy Price Index (ENP)	Renewable Energy Consumption (REC) (0.0012)	Significant P= (0.0026)
Urbanization Rate (UR)	No significant causal relationships	Not Significant P= (0.7317)

Source: by Author Using EViews output

12-1. Causal Linkages in Egypt's Energy and Climate Variables

Granger causality tests identify energy system directional interactions. Egypt's gas-fired power facilities are operationally dependent on natural gas availability ($p = 0.0065$), temperature anomalies ($p = 0.0257$), and energy costs ($p = 0.0070$). Temperature

Granger causality shows seasonal heating and cooling needs affect power demand (Stern, 2010). These variables' collective exogeneity in energy use is confirmed by a joint significance test ($p = 0.00377$).

12-2. Interconnectedness of Energy Demand Determinants

Natural gas consumption has a bidirectional Granger causality with electricity demand ($p = 0.0151$), temperature ($p = 0.0222$), and energy price ($p = 0.0055$). This shows the relationship between power generation and gas demand and how supply constraints electricity output (Pesaran & Smith, 2014). Block exogeneity tests ($p = 0.0035$) show that these factors drive natural gas consumption.

Electricity consumption Granger-causes renewable energy adoption ($p = 0.0178$). The finding may suggest the need for policy incentives aimed at diversifying energy sources. Renewable energy exhibits limited direct Granger causality with other energy sectors, indicating structural and policy barriers to wider implementation.

Renewable energy stabilizes energy prices—a strong causal relationship ($p = 0.0012$). Rising renewable energy sources reduce reliance on volatile fossil fuel markets, stabilizing prices (Suganthi & Samuel, 2012; Copiello et al., 2020). Joint exogeneity testing ($p = 0.0075$) emphasizes these relationships and renewables' role in moderate-term energy affordability.

12-3. Energy-Climate Interaction and Causality

The statistical analysis reveals that temperature anomalies do not demonstrate immediate Granger causation on energy consumption patterns; however, they significantly affect moderate-term climate trends ($p = 0.0183$). Energy consumption and emissions contribute to incremental climate changes, highlighting the necessity for enduring adaptation strategies (Pesaran & Smith, 2014). Furthermore, urbanization in Egypt exhibits no Granger causality with respect to energy consumption or climate variables ($p = 0.7317$), in contrast to patterns observed in other emerging economies (Fernández et al., 2022). This anomaly may be ascribed to Egypt's distinctive urbanization dynamics.

The VAR Granger causality framework highlights Egypt's energy sector's intricate interdependencies, including electricity and natural gas markets, temperature and energy price influence, and renewable energy's stabilizing effect.

13. Policy Implications and Recommendations

A. Energy Infrastructure for Climate Change

- Due to the strong correlation (0.8294) between temperature anomalies and electricity consumption, resilient energy infrastructure is essential.
- Climate-adaptive power systems that can withstand temperature fluctuations strengthen grid resilience.
- Smart grid technologies can efficiently manage demand surges during extreme temperature events, reducing system strain.

B. Natural gas supply strategy

- Broaden the natural gas supply chain to alleviate the considerable adverse effects of temperature fluctuations on consumption (-3.8928 at lag 1).
- Increase natural gas supply chain diversity to reduce volatility.
- According to impulse response analysis, build strategic storage facilities to offset sharp consumption fluctuations.
- Address the VAR model's delayed price response with a flexible pricing mechanism that reflects real-time demand variations.

C. Renewable Energy Transition Acceleration

- Renewable energy consumption rises 5.37% for every 1% increase in urbanization, highlighting the need for strategic renewable energy investment.
- Develop renewable energy in cities to meet demand.
- Use the strong positive relationship (0.9313 at lag 1) between temperature anomalies and renewable adoption to increase climate-triggered subsidies.

- Incentives for electricity providers to integrate renewables can reduce the substitution effect (0.61% decline in renewables per 1% increase in electricity consumption).

D. Urbanization-energy planning integration

- For every 1% urban expansion, electricity demand rises 4.02% and natural gas usage rises 39.04%.
- Implement urban energy efficiency policies to lower per-capita energy use.
- Create city renewable-powered cooling centers to reduce heatwave household cooling loads.
- Temperature anomalies increase electricity consumption over time, so building codes should require thermal efficiency.

E. Price-stabilization mechanisms

- Given the 0.89% energy price increase per 1% temperature anomaly, energy pricing policies must balance affordability and market stability.
- Energy pricing should adapt to climate-induced demand shifts.
- Provide targeted subsidies for vulnerable populations during extreme weather to avoid economic hardship.
- Create market-based incentives for energy efficiency investments to reduce variance decomposition analysis lagged price adjustments.

F. Research and Real-Time Monitoring

- Policymakers must improve climate-energy surveillance for data-driven decision-making.
- Track real-time temperature anomalies and energy consumption with an integrated climate-energy monitoring system.
- Temperature forecasts can be used to predict energy demand for proactive grid management.

Egypt can establish a sustainable, resilient, and adaptable energy system in line with global climate commitments, promoting economic growth and energy security through policy implementation.

Conclusion

This study investigates the impact of temperature anomalies on Egypt's energy sector from 1990 to 2023, employing Vector Autoregression (VAR) methodology. Temperature fluctuations significantly affect energy consumption, demonstrating strong correlations with electricity usage, natural gas consumption, and the integration of renewable energy sources. The economic consequences of climate change are evident through various channels, including fluctuations in energy prices, alterations to infrastructure, and imbalances in supply and demand .

The research also showed that temperature anomalies significantly influence both electricity consumption and natural gas utilization. The results have substantial ramifications for Egypt's energy policy, highlighting the necessity for investments in climate-resilient energy infrastructure and the diversification of the natural gas supply chain. This study enhances the literature on climate economics and energy policy by providing evidence-based recommendations for policymakers to bolster energy resilience amid climate uncertainty

References:

- 1- A Calzadilla, A Scott, A Turton, A Wales, AA Misselhorn, B Lankford, B Martin, et al. (2015) Climate and southern Africa's water-energy-food nexus.
- 2- Abubakar, Attahir, Mamman, Suleiman O., Sohag, Kazi (2023) Climate change and inclusive growth in Africa.
- 3- Albanese, M, Caporale, GM, Colella, I, Spagnolo, et al. (2024) The effects of physical and transition climate risk on stock markets: some multi-country evidence.

- 4- Apergis, N., Payne, J. E. (2012) Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model. Volume (Vol 34, Issue 3), 733-738. Energy Economics.
- 5- Bianchi, Andrea (2017) Energy audit for PETRATEX. <https://core.ac.uk/download/344683656.pdf>
- 6- Bianchi, Andrea (2022) Energy Audit for PETRATEX. <https://core.ac.uk/download/570945206.pdf>
- 7- Caporin, Massimiliano, Di Fonzo, Tommaso, Khalifa, Ahmed (2019) Scenario-based forecast for the electricity demand in Qatar and the role of energy efficiency improvements.
- 8- Central Bank of Egypt (2023) Time Series Data: Consumer Price Index. <https://www.cbe.org.eg/en/economic-research/time-series/downloadlist?category=706A9057F8454F7284BE8143070D88C4>
- 9- Chimeli, A. B., Ohio University, De Souza Filho, F. D. A., & Fundação Cearense de Meteorologia e Recursos Hídricos. (2005). CLIMATE FORECASTING AND EMERGENCY POLICIES EVIDENCE OF OPPORTUNITIES FROM CEARÁ, BRAZIL [Journal-article].
- 10- Ciscar, J. C., & Dowling, P. (2014). Integrated assessment of climate impacts and adaptation in the energy sector. Energy Economics, 46, 531-538.
- 11- Colelli F. P., De Cian E., Wing I. S. (2023) Intensive and extensive margins of the peak load: Measuring adaptation with mixed frequency panel data.
- 12- Copiello, Sergio, Grillenzoni, Carlo (2020) Economic development and climate change. Which is the cause and which the effect?
- 13- De Juan Fernández, Aránzazu, Poncela, Pilar, Rodríguez Caballero, Carlos Vladimir, Ruiz Ortega, et al. (2022) Economic activity and climate change.
- 14- Dell, M., Jones, B. F., Olken, B. A. (2014) What do we learn from the weather? The new climate-economy literature. Volume (Vol 52, Issue 3), 740-798. Journal of Economic Literature.
- 15- Göktepe, Orhan (2022) From the Global Warming to Global Chaos. doi: <https://core.ac.uk/download/553019675.pdf>
- 16- Gujarati, D. N., & Porter, D. C. (2020) Basic Econometrics. McGraw-Hill.
- 17- Gurdeep Singh Malhi, Manpreet Kaur, Prashant Kaushik (2021) Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. Volume (13), 1318-1318. Sustainability.
- 18- Hamidou Tembiné, Allahsera Auguste Tapo, Sidy Danioko, Ali Traoré (2024) Machine Intelligence in Africa: a survey.
- 19- Hamilton, J. D. (1994). *Time series analysis*. Princeton University Press.

- 20- Hamilton, Lawrence C., Keim, Barry D., Wake, Cameron P. (2010) Is New Hampshire's climate warming?
- 21- Harvey, Chris J. (2005) Effects of El Niño events on energy demand and egg production of rockfish (Scorpaenidae: Sebastes): a bioenergetics approach.
- 22- Hatem Jemmali (2018) Dynamic Impacts of Climate Changes and Environmental Sustainability on Food Water Poverty in a Panel of Selected MENA Countries. Volume (2018).
- 23- Intergovernmental Panel on Climate Change (IPCC) (2022-05-19) The Ocean and Cryosphere in a Changing Climate. Cambridge University Press.
- 24- International Energy Agency (IEA). (2023) Egypt Energy Profile. <https://www.iea.org/countries/egypt>
- 25- International Monetary Fund (IMF). (2022). Egypt: Energy Sector Reform and Policy Framework. Washington, DC: IMF.
- 26- International Renewable Energy Agency (IRENA). (2022). Renewable Energy Statistics 2022. Abu Dhabi: IRENA.
- 27- Juntunen, V. (Veera) (2022) Relation between geomagnetic activity and electricity consumption in Finland via Northern Annular Mode (NAM).
- 28- Khalifa, Muhammad Saeed Ahmed (2020) Multi-scale Spatial Analysis of the Water-Food-Climate Nexus in the Nile Basin using Earth Observation Data.
- 29- Kilian, L. (2009) Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. Volume (Vol 99, Issue 3), 1053-1069. American Economic Review.
- 30- L. Murphy (2016) Policy Instruments to Improve Energy Performance of Existing Owner Occupied Dwellings. Architecture and the Built Environment.
- 31- Laura Russo (2017) Cities and energy consumption: how to reduce CO2 emissions and address climate change.
- 32- Liddle, B. (2014). Impact of population, age structure, and urbanization on carbon emissions/energy consumption: Evidence from macro-level, cross-country analyses. Population and Environment, 35(3), 286-304.
- 33- Lucas Richter, Tom Bender, Steve Lenk, Peter Bretschneider (2024) Generating Synthetic Electricity Load Time Series at District Scale Using Probabilistic Forecasts. Volume (17), 1634-1634. Energies.
- 34- Lütkepohl, H. (2005). New Introduction to Multiple Time Series Analysis. Springer Science & Business Media.

- 35- M. Auffhammer (2018) Climate adaptive response estimation: Short and long run impacts of climate change on residential electricity and natural gas consumption using big data.
- 36- N. Ahmat, Shanthini Christopher, Jumadil Saputra, Muhammad Najit Sukemi, Mohd Nasir Nawawi (2024) The Impact of Energy Consumption, Economic Growth, and Non-Renewable Energy on Carbon Dioxide Emission in Malaysia. *International Journal of Energy Economics and Policy*.
- 37- Nicholas, Hoe (2017) An economic analysis of anthropogenic climate change on local rice output in Malaysia.
- 38- Ogunsola, Akindele John. (2022) Energy consumption and economic growth: evidence from African oil exporting countries.
- 39- Omri, A. (2014). An international literature survey on energy-economic growth nexus: Evidence from country-specific studies. *Renewable and Sustainable Energy Reviews*, 38, 951-959.
- 40- Ozturk, I. (2010). A literature survey on energy-growth nexus. *Energy Policy*, 38(1), 340-349.
- 41- Pesaran, M. H., & Smith, R. P. (2014). Signs of impact effects in time series regression models. *Economics Letters*, 122(2), 150-153.
- 42- Sims, C. A. (1980). Macroeconomics and Reality. *Econometrica*, 48(1), 1-48.
- 43- Sims, C. A., Stock, J. H., & Watson, M. W. (1990). Inference in linear time series models with some unit roots. *Econometrica*, 58(1), 113-144.
- 44- Smith, L. V., Tarui, N., & Yamagata, T. (2021). Assessing the impact of COVID-19 on global fossil fuel consumption and CO₂ emissions. *Energy Economics*, 97, 105170.
- 45- Stern, D. I. (2010). Energy quality. *Ecological Economics*, 69(7), 1471-1478.
- 46- Suganthi, L., & Samuel, A. A. (2012). Energy models for demand forecasting—A review. *Renewable and Sustainable Energy Reviews*, 16(2), 1223-1240.
- 47- W. Enders (2014) *Applied Econometric Time Series*. Wiley.
- 48- Waqas Nawaz (2018) *Emphasizing on the Significance of Safety for Overall Sustainable Development*. Volume (2018).
- 49- World Bank Climate Change Knowledge Portal (CCKP), (2023). <https://climateknowledgeportal.worldbank.org/country/egypt/climate-data-historical>
- 50- World Bank. (2023a). *World Development Indicators: Egypt, Arab Rep.* Retrieved from <https://data.worldbank.org/country/egypt-arab-rep?view=chart>



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- 51- World Bank. (2023b). Egypt: Urbanization and Climate Adaptation Report. Washington, DC: World Bank.
- 52- Würzburg, K., Labandeira, X., & Linares, P. (2013) Renewable generation and electricity prices: Taking stock and new evidence for Germany and Austria. Volume (Vol 40), S159-S171. Energy Economics.
- 53- Zentner, Matthew A. (2025) Assessing the design of international water supply and hydropower arrangements for managing certain climate change scenarios.