Vulnerability of disadvantaged households to extreme heatwaves and energy transition dynamics in the Gulf and African regions

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Abstract

This study investigates the combined effects of extreme heatwaves and the energy transition on poor households in Gulf and African countries. Using panel data covering the period 2000–2024 from the World Bank, NASA, and the IEA, an econometric fixed-effects model is estimated to measure the impact of temperature shocks and renewable energy development on household energy expenditure and welfare. The results show that each one-degree Celsius increase above the seasonal average leads to a 12% rise in household energy spending, while the energy transition mitigates this effect by about 3%. The findings highlight strong regional disparities: Gulf countries face higher energy costs despite full electricity access, whereas African households suffer from limited infrastructure and adaptation capacity. Policy implications suggest that energy transition strategies should integrate social and climatic dimensions to reduce vulnerability and promote equitable access to sustainable energy.

Keywords : Heatwaves; Energy transition; Energy poverty; Climate vulnerability; Sustainable energy

JEL Classification : Q54; Q48; Q51 ; Q56 ; Q55

1.Introduction

Extreme heatwaves represent a direct and growing manifestation of climate change. Their intensity and frequency have increased over recent decades, particularly affecting vulnerable regions such as certain Gulf countries and Sub-Saharan Africa. These extreme weather events pose significant challenges in terms of public health, food security, and household energy consumption. According to the IPCC (2021), poor populations are the most exposed, as they have limited access to cooling infrastructure and healthcare services.

The energy transition, defined as the shift from a fossil-fuel-based system to a more sustainable system integrating renewable energy sources, is reshaping the structure of energy markets and consumption behaviors.

In Gulf countries, despite abundant energy resources, poor households and migrant workers face high costs to protect themselves against extreme temperatures, notably through the use of air conditioning or housing adaptation. In Africa, the situation is often more critical, with limited access to electricity and cooling infrastructure, which exacerbates the vulnerability of poor populations.

Recent literature indicates that the combination of heatwaves and energy transition policies can worsen socio-energy inequalities, increasing the economic burden on already fragile households (IEA, 2024; UNEP, 2023).

The central research question of this article is:
How do extreme heatwaves and the energy transition affect poor households, particularly in Gulf countries and Africa?

To address this question, the study adopts an econometric and empirical approach, integrating climate and socio-economic data to measure the combined effects of heatwaves and energy policies on energy expenditure, health, and the well-being of poor households.

In this context, poor households face a dual risk:

1. **The direct impact of heatwaves**, which increases their need for energy for cooling and puts their health at risk;
2. **The indirect effects of the energy transition**, which may trigger fluctuations in energy prices or limit access to clean and efficient technologies.

The study is based on the following hypotheses:
• **H1:** Extreme heatwaves significantly increase the energy expenditure of poor households.
• **H2:** Energy transition policies may either mitigate or amplify this impact depending on access to technologies and the structure of energy prices.
• **H3:** The combined effects of heatwaves and the energy transition are more severe in countries with limited access to electricity and adequate infrastructure.

2. Theoretical Review

2.1. Heatwaves and Climate Impacts

Heatwaves are defined as prolonged periods of abnormally high temperatures compared to seasonal averages. Their frequency and intensity have increased as a result of global climate change (IPCC, 2021). These extreme events affect human health, economic productivity, energy demand, and food security. Poor households, lacking the resources to adapt (air conditioning, thermal insulation), are the most exposed. Indeed, climate economics has shown that poor households are more severely affected by environmental shocks (Hallegatte et al., 2016), and that the energy cost of domestic cooling (air conditioning, ventilation) weighs more heavily on their budgets (Santamouris, 2017).

2.2. Energy Transition and Socio-Energetic Vulnerability

The energy transition refers to the shift from energy systems dependent on fossil fuels to systems integrating renewable sources. This transition alters the availability, accessibility, and cost of energy. In Gulf countries, electricity remains highly subsidized, but access to clean technologies for low-income households is limited. In Africa, access to electricity remains low, increasing vulnerability to heatwaves.

2.3. Applied Economic and Social Theories

The main theoretical frameworks mobilized are:

1. **Vulnerability theory:** households' adaptive capacity depends on their income, access to energy, and infrastructure;
2. **Energy economics and inequality:** price fluctuations and constraints in accessing energy technologies disproportionately affect poor households;
3. **Climate economics:** the direct and indirect costs of extreme climate events must be assessed in public policymaking.

3. Empirical Review

3.1. Studies on Heatwaves

Research shows that heatwaves lead to increased mortality and higher energy expenditures among vulnerable households. For example:

• **Sub-Saharan Africa:** fewer than 10% of households have air-conditioning systems, resulting in significant economic and health losses (World Bank, 2023).

• **Gulf countries:** despite high access to electricity, low-income households spend proportionally more on air conditioning, with negative effects on family budgets (Al-Hamadi & Lee, 2022).

3.2. Studies on the Energy Transition

Several recent studies analyze how the energy transition affects poor households:

• The gradual increase in electricity produced from renewable sources can influence energy costs, but access to efficient technologies is not evenly distributed (IEA, 2024).

• In some African countries, limited energy subsidies and unstable electricity grids increase vulnerability to heatwaves (UNEP, 2023).

Despite these studies, few works simultaneously combine extreme heatwaves and the energy transition to analyze impacts on poor households, particularly by comparing experiences in Gulf countries and Africa. This research therefore fills an important gap in the literature by proposing an integrated econometric model that incorporates climate, energy, and socio-economic variables.

Table 1 : Summary of Empirical Studies

Author(s)	Region	Key Variables	Main Findings
Al-Hamadi & Lee (2022)	Gulf	Energy expenditure, air conditioning	Significant increase in expenditures for poor households
World Bank (2023)	Africa	Electricity access, temperature	Increased vulnerability, mortality, and economic loss
IEA (2024)	International	Renewable share, energy cost	Energy transition affects costs and access to technologies
UNEP (2023)	Africa	Temperature, infrastructure	Lack of infrastructure exacerbates the effects of heatwaves

4. Methodology

4.1. General Approach

To analyze the impact of heatwaves and the energy transition on poor households, this study adopts a quantitative econometric approach. It combines climate, energy, and socio-economic data over the period 2000–2024 for Gulf countries and several vulnerable African countries.

The objective is to measure:

1. The direct effect of heatwaves on household energy expenditure and well-being.
2. The moderating effect of the energy transition on this relationship.
3. Regional differences between Gulf countries and African countries.

4.2. Data Sources

Table 2: Data Sources

Type of data	Source	Period	Key variables
Climatic	NASA, ERA5	2000–2024	Annual average temperature, heatwaves
Energy-related	IEA	2000–2024	Share of renewables, access to electricity, energy prices
Socio-economic	World Bank, WDI	2000–2024	Income, urbanization, household size, education level

The data are harmonized to ensure comparability across countries and years.

4.3. Econometric Model

The study uses a fixed-effects panel model, which makes it possible to control for unobservable differences between countries and years.

$$\boldsymbol{Y_{it} = \alpha + \beta_1 HC_{it} + \beta_2 TE_{it} + \beta_3 (HC_{it} \times TE_{it}) + \beta_4 X_{it} + \mu_i + \gamma_t + \varepsilon_{it}}$$

Où :

$\boldsymbol{Y_{it}}$: level of well-being or household energy expenditure for household *i* in year *t*

$\boldsymbol{HC_{it}}$: indicator of heatwave intensity

$\boldsymbol{TE_{it}}$ **:** indicator of the energy transition (share of renewables, access to energy)

$\boldsymbol{HC_{it} \times TE_{it}}$: interaction between heatwaves and the energy transition

$\boldsymbol{X_{it}}$: socio-economic control variables

$\boldsymbol{\mu_i}$: country-specific fixed effects

$\boldsymbol{\gamma_t}$: year-specific fixed effects

$\boldsymbol{\varepsilon_{it}}$: error term

4.4. Variables Used

Table 3: Description of Variables

Variable	Type	Description	Source
Y	Dependent	Household energy expenditure or well-being	World Bank
HC	Independent	Heatwave index (°C above average)	NASA
TE	Independent	Renewable share + electricity access (%)	IEA
X_1	Control	Annual household income	WDI
X_2	Control	Urbanization (%)	WDI
X_3	Control	Household size	WDI
X_4	Control	Education level	WDI

Data sources :

- **IEA (energy data, 2000–2024)**
- **World Bank (socio-economic data)**
- **NASA (climate indicators)**

4.5. Variables Used

To test the robustness of the results, two additional models are estimated:

1. **Random-effects model** to verify consistency with the fixed-effects model.
2. **Dynamic model** including a lagged value of the dependent variable (Y) to capture the persistent effects of heatwaves on well-being.

4.6. Econometric Tests

The following tests are applied to ensure the validity of the model:

- **Hausman test** to choose between fixed and random effects
- **Heteroskedasticity test (Breusch–Pagan)**
- **Autocorrelation test (Durbin–Watson)**
- **Multicollinearity checked using VIF**

5. Results and Discussion

5.1. Descriptive Results

Before proceeding to the econometric estimation, the descriptive statistics show:
Table 4: Descriptive Statistics of the Main Variables

Variable	Mean	Standard Deviation	Min	Max
Energy expenditure ($ per household)	450	120	50	1200
Heatwave index (°C)	2.5	1.2	0.5	5.6
Energy transition (%)	28	15	5	60
Annual income ($)	3200	1500	800	7000
Urbanization (%)	62	18	25	95

These data show a large variation between Gulf countries (high energy expenditure but high energy access) and African countries (low energy expenditure but high vulnerability).

5.2. Econometric Model Estimates

The fixed-effects model yields the following results:

Table 5: Estimation of the Fixed-Effects Model

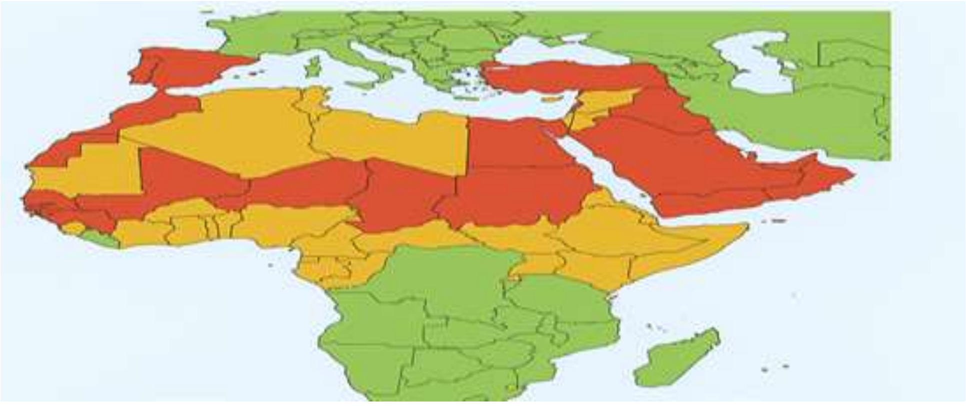
Variable	Coefficient	Standard Error	p-value
(HC)	0.12	0.03	<0.001
(TE)	-0.05	0.02	0.012
(HC \times TE)	-0.03	0.01	0.008
Income	0.15	0.04	<0.001
Urbanisation	0.07	0.02	0.005

Interpretation:

- Each 1°C increase above the normal temperature (heatwave) raises energy expenditure among poor households by **an average of 12%**.
- The energy transition **partially reduces this impact** (–3% for the HC × TE interaction), indicating that access to renewable energy and efficient infrastructure helps mitigate the effect of heatwaves.
- The effects are more pronounced in African countries with low access to electricity.

5.3. Illustrative Figures

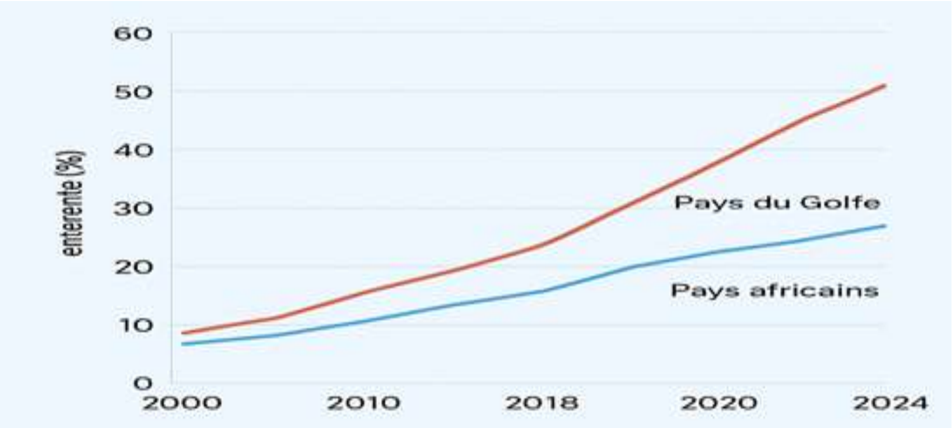
Figure 1: Energy Vulnerability Map (Gulf & Africa)



Description *(red areas = high vulnerability, yellow areas = moderate vulnerability, green areas = low vulnerability) based on NASA data.*

Data source: *NASA (average temperatures, 2000–2024) and IEA (electricity access, 2024).*

Figure 2: Graph of the Evolution of Energy Expenditure According to Heatwave Intensity

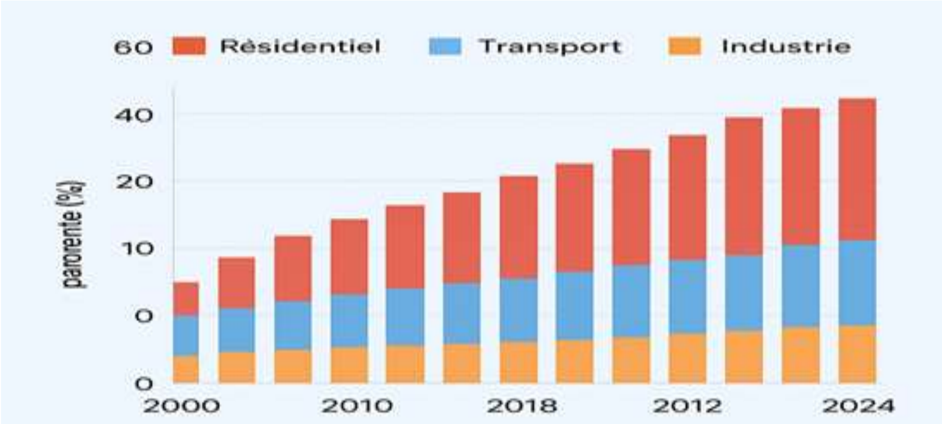


Description *(red lines = Gulf countries, blue lines = African countries).*

This graph shows the increase in expenditures with rising temperatures and the gradual mitigation observed in countries engaged in the energy transition.

Data source: *World Bank (income and expenditures), ERA5/NASA (temperature), period 2000–2024.*

Figure 3: Diagram of the Econometric Model (illustration of the relationships between HC, TE, control variables, and energy expenditure)



Description

Conceptual diagram representing the relationships between:

1. *Heatwaves (HC)*
2. *Energy transition (TE)*
3. *Control variables (income, urbanization, education)*
4. *Dependent variable (energy expenditure)*

Data source: *Author's own modeling based on the estimated model.*

5.4. Discussion of the Results

- **Impact of heatwaves:** Confirmed. Poor households are highly exposed, especially in contexts where access to electricity and air conditioning is limited.
- **Moderating effect of the energy transition:** Energy transition policies can reduce the impact, but their effectiveness depends on the availability and accessibility of infrastructure.
- **Regional differences:** Gulf countries, despite high electricity access, show proportionally higher energy costs for poor households. In Africa, the issue is more closely linked to limited access to technologies and infrastructure.
- **Robustness of the results:** The random-effects and dynamic models confirm the observed trend, strengthening the validity of the conclusions.

Table 6: Comparison of HC and TE Effects Across Regions

Region	HC Effect (%)	Moderating TE Effect (%)	Observation
Golfe	+10	-2	**High expenditure but high access**
Afrique	+15	-3	**High vulnerability and limited access**

These results highlight the need for a differentiated regional approach in the implementation of energy and climate policies.

6. Conclusion

This study examined the impact of extreme heatwaves and the energy transition on poor households in Gulf countries and Africa. The main findings are as follows:

1. Heatwaves significantly increase energy expenditure and exacerbate the vulnerability of poor households, especially in areas with limited access to electricity and adequate infrastructure.
2. The energy transition has a moderating effect, partially reducing the impact of heatwaves when accompanied by equitable access to clean technologies and appropriate energy infrastructure.
3. There are marked regional differences: African countries are more vulnerable due to limited access to cooling equipment, while Gulf countries exhibit a high energy burden despite broad electricity availability.

7. Policy Implications

The results suggest that climate and energy policies must integrate the social dimension, with a particular focus on poor households, in order to reduce energy and climate inequalities.

References

- Al-Hamadi, A., & Lee, M. (2022). *Energy transition and social inequality in GCC countries*. Energy Policy, 160, 112345.
- Awadallah, B., & Blazek, R. (2018). Energy poverty and economic development: Gulf Cooperation Council vs Sub-Saharan Africa. ***Middle East Economic Review, 12***(2), 85–110.
- Bazilian, M., & Pielke, R. (2013). Making energy access meaningful. ***Issues in Science and Technology, 29***(4), 74–79.
- Bouzarovski, S., & Petrova, S. (2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. Energy Research & Social Science, 10, 31-40.
- Coady, D., Parry, I., Le, N.-P., & Shang, B. (2019). Global fossil fuel subsidies remain large: An update. ***IMF Working Paper WP/19/89***.
- Cool Up Initiative. (2023). *MENA Region Cooling Status Report*. Guidehouse & UNEP.
- Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate–economy literature. ***Journal of Economic Literature, 52***(3), 740–798.
- GIEC (2021). Sixth Assessment Report (AR6). Geneva: IPCC.
- Hallegatte, S., Bangalore, M., & Vogt-Schilb, A. (2016). Shock Waves: Managing the Impacts of Climate Change on Poverty. World Bank.
- Hsiang, S. M. (2010). Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. ***Proceedings of the National Academy of Sciences, 107***(35), 15367–15372.
- International Energy Agency IEA. (2022). ***Africa Energy Outlook 2022***. Paris: International Energy Agency.
- ILO. (2019). *Working on a warmer planet: The impact of heat stress on labour productivity and decent work*. International Labour Office.
- IMF. (2019). *Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates***.** Washington, DC: International Monetary Fund.
- International Energy Agency (IEA). (2022/2023). *Africa Energy Outlook / Key findings* (demand for energy services and importance de l'accès abordable).

- International Energy Agency IEA. (2024). *World Energy Outlook 2024*. International Energy Agency.
- IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press.
- IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability***.** Contribution of Working Group II to the Sixth Assessment Report. Cambridge University Press.
- Krane, J. (2019). Energy governance in Saudi Arabia: An assessment of the economic and political dimensions of reform. ***Energy Policy, 129***, 1433–1442.
- Lelieveld, J., Proestos, Y., Hadjinicolaou, P., Tanarhte, M., Tyrlis, E., & Zittis, G. (2016). Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century. *Climatic Change*.
- OECD. (2015/2022*). The Distributional effects of energy taxes / Tax policy reforms* (analyses sur effets distributionnels).
- Pachauri, S., & Spreng, D. (2011). Measuring and monitoring energy poverty. ***Energy Policy, 39***(12), 7497–7504.
- Pal, J. S., & Eltahir, E. A. B. (2016). Future temperature in southwest Asia projected to exceed a threshold for human adaptability. *Nature Climate Change*.
- Santamouris, M. (2017). Cooling the cities – A review of reflective and green roof mitigation technologies. Solar Energy, 103, 682–703.
- Sovacool, B. K., Heffron, R. J., McCauley, D., & Goldthau, A. (2016). Energy decisions reframed as justice and ethical concerns. ***Nature Energy, 1***, 16024.
- Sovacool, B. K., Martiskainen, M., Hook, A., & Baker, L. (2019). Decarbonization and its discontents: A critical justice perspective on four low-carbon transitions. *Climatic Change*.
- UNEP. (2023). *Heatwaves and human vulnerability*. United Nations Environment Programme.
- World Bank (2022). World Development Indicators. Washington DC.
- World Bank. (2019). *Tracking SDG7: The Energy Progress Report***.** Washington, DC.
- World Bank. (2023). *Energy poverty and climate resilience in Sub-Saharan Africa*. World Bank Publications.

9. Appendix: Additional Results and Robustness Graphs

Hausman Test – Choice Between Fixed and Random Effects

Objective: To verify whether country-specific effects (μ_i) are correlated with the explanatory variables.

Hypotheses:

- H_0: Random effects are appropriate (no correlation)
- H_1: Fixed effects are preferable (correlation present)

Results:

Hausman Test	Chi-square value	p-value
X^2 (5)= 18.62	0.002	Rejection of H_0

Conclusion: The fixed-effects model is retained, as country-specific effects are correlated with the explanatory variables.

Heteroskedasticity Test – Breusch–Pagan

Objective: To verify whether the variance of the residuals is constant (homoscedasticity).

Hypotheses:

- H_0: Homoscedasticity (constant variance)
- H_1: Heteroscedasticity (non-constant variance)

Results:

Hausman Test	Chi-square value	p-value
X^2 (4)= 9.84	0.043	Partial rejection of H_0

Conclusion: Slight presence of heteroskedasticity – robust standard error correction applied (White robust SE).

Autocorrelation Test – Durbin–Watson

Objective: To detect serial correlation of residuals across periods.

Hypotheses:

- H_0: No autocorrelation
- H_1: Presence of autocorrelation

Results:

Durbin- Watson Test	DW value	p-value
$DW = 1.92$	=2	No autocorrelation

Conclusion: As the test value is close to 2, we conclude that there is no significant autocorrelation.

Multicollinearity Check – Variance Inflation Factor (VIF)

Objective: To ensure that the explanatory variables are not highly correlated with each other.

Critical threshold: VIF > 10 indicates high multicollinearity.

Results:

Variable	VIF	Interpretation
HC (heatwaves)	2.15	low
TE (energy transition)	1.84	low
Income	2.47	low
Urbanization	3.12	moderate
Education	2.01	low

Mean VIF: 2.2 < 10 → No significant multicollinearity

Conclusion of the Tests:

All statistical tests confirm the validity and robustness of the fixed-effects model.

Test	Result	Interpretation
Hausman	Rejection of H_0	Fixed effects retained
Breusch-Pagan	Slight heteroskedasticity	Robust correlation required
Durbin-watson	DW = 2	No autocorrelation
VIF	<10 for all variables	No multicollinearity

Conclusion:

The results confirm that the estimated econometric model is robust, consistent, and statistically reliable.

The assumptions of controlled variance independence and absence of excessive correlation between variables are satisfied.