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The climate-electricity nexus in the GCC: How rising temperatures drive electricity demand across Gulf states

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ABSTRACT

The GCC region is warming at 0.49°C per decade, nearly three times the global average, placing mounting pressure on electricity systems that already face extreme cooling demand. This study estimates country-specific income, price, and temperature elasticities of electricity demand for GCC countries over 1990-2022, using cointegration techniques. We find that a 1°C increase in annual average temperature would raise annual electricity consumption by 3.1% (Bahrain) to 5.8% (Saudi Arabia), translating into 32.2 TWh of additional regional demand, and 16.8 Mt of CO_2 emissions annually. The emission estimates are based on 2021 country-specific carbon intensities, reflecting each country's prevailing generation fuel mix (IEA, 2024; Ember, 2023). The additional generation would cost approximately $1.9 billion per year. Income elasticities range from 0.25 to 1.37, and price elasticities range from −0.08 to −0.61, revealing substantial cross-country heterogeneity driven by differences in appliance saturation, subsidy structures, and tariff reform histories. Decomposition analysis confirms that temperature, alongside population and income growth, is a first-order driver of electricity consumption, while the demand response to Saudi Arabia's 2016–2018 pricing reforms demonstrates that well-designed tariff adjustments can partially offset climate-driven demand growth. The findings highlight the urgency of improvements in the energy efficiency of buildings, advanced cooling technologies, and continued pricing reforms to decouple electricity demand from rising temperatures in support of GCC net-zero aspirations.

1. Introduction

The Gulf Cooperation Council (GCC) region faces a direct link between rising temperatures and electricity demand: hotter summers drive higher cooling loads, increasing both generation costs and carbon emissions. With average summer temperatures exceeding 45°C, near-100% air conditioning penetration in buildings (IEA, 2024), and over 90% of the population living in urban areas (World Bank, 2026), the GCC faces a significant challenge: rising temperatures are driving up electricity demand at precisely the moment when the region aims to contribute to the global decarbonization efforts to reduce fossil fuel dependence.

The region's climatic conditions, characterized by extreme summer temperatures, result in highly seasonal electricity demand. Cooling requirements, air conditioning, and refrigeration account for 70% of electricity consumption during peak summer months (Howarth et al., 2020; Al-Badi and AlMubarak, 2019). The temperature–electricity nexus operates through multiple sectoral channels. In the residential sector, rising temperatures increase air-conditioning loads, extend operating hours, and increase refrigeration needs. The commercial sector faces analogous pressures through office building cooling, shopping mall HVAC systems, and hotel and hospitality cooling. In the industrial sector, higher temperatures raise process cooling requirements, increase the energy intensity of desalination plants, elevate petrochemical cooling loads, and reduce equipment efficiency. Infrastructure is also affected by higher transmission losses, increased water-pumping

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demand, and extended public lighting and transport cooling needs. These sectoral impacts are compounded by the GCC region's particular vulnerabilities: extreme heat, near-100% air-conditioning penetration, rapid urbanization, energy-intensive industries such as desalination and aluminum smelting, and summer peak demand that is 2 to 3 times higher than winter levels (Al-Badi and AlMubarak, 2019). Understanding the breadth of these sectoral impacts is key to effective policy response.

Moreover, our analysis of temperature data from 1990 to 2022 reveals a clear warming trend across all GCC countries (Fig. 1, upper panel). The population-weighted average temperature has increased by 1.15°C over these 33 years, equivalent to a warming rate of approximately 0.49°C per decade (authors' calculation based on World Bank Climate Change Knowledge Portal data, 2026; see Fig. 1), which is substantially higher than the global average of 0.18°C per decade (IPCC, 2023). The temperature anomaly analysis (Fig. 1, lower panel) reveals a clear shift from predominantly negative anomalies in the 1990s to consistently positive anomalies since 2010, with the period from 2018 to 2022 exhibiting particularly pronounced warming (see Fig. 1).

In addition, as shown in Fig. 2, the six GCC countries collectively consumed 674.6 TWh of electricity in 2022, with a combined population of 54.9 million (see Fig. 2). This translates to an average per capita consumption of 12.29 MWh, approximately four times the world average of 3.3 MWh (IEA, 2024). Bahrain exhibits the highest per capita consumption at 23.48 MWh, followed by Kuwait (18.43 MWh), Qatar (17.43 MWh), UAE (17.15 MWh), Saudi Arabia (9.61 MWh), and Oman (8.52 MWh). Saudi Arabia dominates regional consumption in absolute terms, accounting for approximately 46% of the GCC's total electricity consumption (309.4 TWh).

Considering above-mentioned facts, this study pursues three primary objectives: (1) estimate income, price, and temperature elasticities of electricity demand for each GCC country using cointegration analysis; (2) employ decomposition analysis to disentangle the contributions of different factors to electricity consumption changes; and (3) quantify the implications of temperature-driven demand growth in terms of additional consumption, CO_2 emissions, and generation costs.

This paper adds new empirical evidence on the climate-electricity nexus in the GCC region. Its contributions can be distinguished along three dimensions. Methodologically, the study estimates income, price, and temperature elasticities of electricity demand for each of the six member states over the period 1990-2022, employing multiple cointegration estimators (FMOLS, DOLS, and GETS/Autometrics) to ensure the robustness of the inference. While individual-country electricity demand studies exist for some GCC states (e.g., Al-Sahlawi, 1999, for Saudi Arabia; Eltony and Mohammad, 1993, for Kuwait), no prior study has estimated temperature semi-elasticities for all six countries within a unified methodological framework, enabling direct cross-country comparison and regional aggregation. The novelty lies in the comprehensive scope and in translating elasticities into quantified regional impacts (TWh, CO_2, costs). Empirically, the estimated temperature semi-elasticities[1] range from 3.1% for Bahrain to 5.8% for Saudi Arabia, revealing significant heterogeneity in climate vulnerability across the region. The particularly high sensitivity for Saudi Arabia, where a 1°C rise in temperature is associated with a 5.8% increase in electricity consumption, is especially important given this country's leading contribution to regional demand. Moreover, the findings confirm that the GCC region is warming at approximately 0.49°C per decade, nearly three times the global average. From a policy perspective, the study employs decomposition analysis to translate the temperature elasticities into directly actionable metrics: a regional 1°C temperature increase is associated with approximately 32.2 TWh of additional electricity demand, 16.8 Mt of CO_2 emissions, and $1.9 billion in generation costs. These quantified impacts show the urgency of decoupling electricity demand from temperature variations through efficiency enhancement and accelerated decarbonization of power generation in support of the region's net-zero pledges by 2050-2060.

2. Literature review

This section reviews the studies that illustrate the relationship between electricity demand and price, income, and other variables. In addition, we focus studies used time series and panel data analysis in the case of different countries (including GCC countries). The findings of the reviewed studies are summarized in Table 1. As can be seen from Table 1, considerable differences in results are apparent, due to differences in data periods, demand specifications (e.g., functional form and variables included), sectors, and econometric techniques employed.

The key findings from the literature review are as follows:

Finding 1: Methodological variation. Different econometric techniques are used to estimate electricity demand elasticities. Ordinary Least Squares (OLS) is the most often used method, especially in previous research such as Al-Sahlawi (1990), Eltony and Mohammad (1993), Eltony (1995), and Al-Sahlawi (1999). Recent research, including Liddle and Huntington (2021), Campbell (2018), Hasanov et al. (2016), Javid and Qayyum (2014), Mikayilov et al., 2020a, Hasanov and Mikayilov (2020), Gasim et al. (2023), and Mikayilov et al. (2023), employ advanced techniques like ARDL, GETS, STSM, and GMM.

Finding 2: Income elasticities. Nearly all empirical papers reported positive income elasticities, i.e., as income increases, electricity consumption also increases. Long-run income elasticities are larger than the short-run ones, implying that, in the long run, economic growth has a greater impact on electricity demand. Significantly elevated long-run income elasticities are noted. It ranges from 0.09 to 2.7 (except for Ackah and Adu Al-Faris (2002) for Bahrain, which is unexpectedly high at 5.39).

Finding 3: Price elasticities. The price elasticity of electricity demand varies across studies and contexts. In the short run, price elasticities are typically small or close to zero, reflecting a low sensitivity to price changes (e.g., Al-Sahlawi, 1999; Atakhanova and Howie, 2007; Otsuka, 2015; Njeru et al., 2020). The price elasticities are generally negative in the long term, indicating greater responsiveness. The long-term price elasticity for GCC nations ranges from −3.39 to 0.00. Moreover, various studies, such as Faisal and Eatzaz (2011) and Pourazarm and Cooray (2013) for the short term, and Mikayilov and Al Ghamdi (2023) for the long term, reported that the price elasticities are insignificant. Recent studies by Mikayilov et al. (2020a), Mikayilov et al. (2023), and Hasanov and Mikayilov (2020) have investigated regional electricity consumption in Saudi Arabia. Their analyses revealed that income and price elasticities of electricity demand vary across regions.

Finding 4: Sectoral versus total electricity demand. Some research analyzes total electricity consumption, and others separate it into various sectors such as residential, commercial, industrial, agricultural, and government. On the other hand, studies such as those by Howarth et al. (2020) and Mikayilov et al. (2026a) estimated energy generation/demand as a function of temperature using regional data for Saudi Arabia. Howarth et al. (2020) revealed that for each 1°C rise in temperature, an extra 1.177 GW of electricity output was required. The analysis shows a strong correlation between temperature and electricity demand, characterized by significant regional and seasonal differences.

Among the regions, the Western area exhibits the greatest sensitivity to temperature fluctuations. Moreover, Mikayilov et al. (2026a) found

[1] A semi-elasticity measures the percentage change in the dependent variable (electricity consumption) for a one-unit change in the explanatory variable (temperature in °C), in contrast to a standard elasticity, which measures the percentage change in consumption for a one percent change in the explanatory variable. The semi-elasticity specification is preferred for the temperature variable because climate projections are expressed in absolute degrees of warming (e.g., +1.5°C or +2°C), not in percentage terms. This allows the estimated coefficients to be applied directly to IPCC and national climate scenarios without requiring an intermediate conversion step.

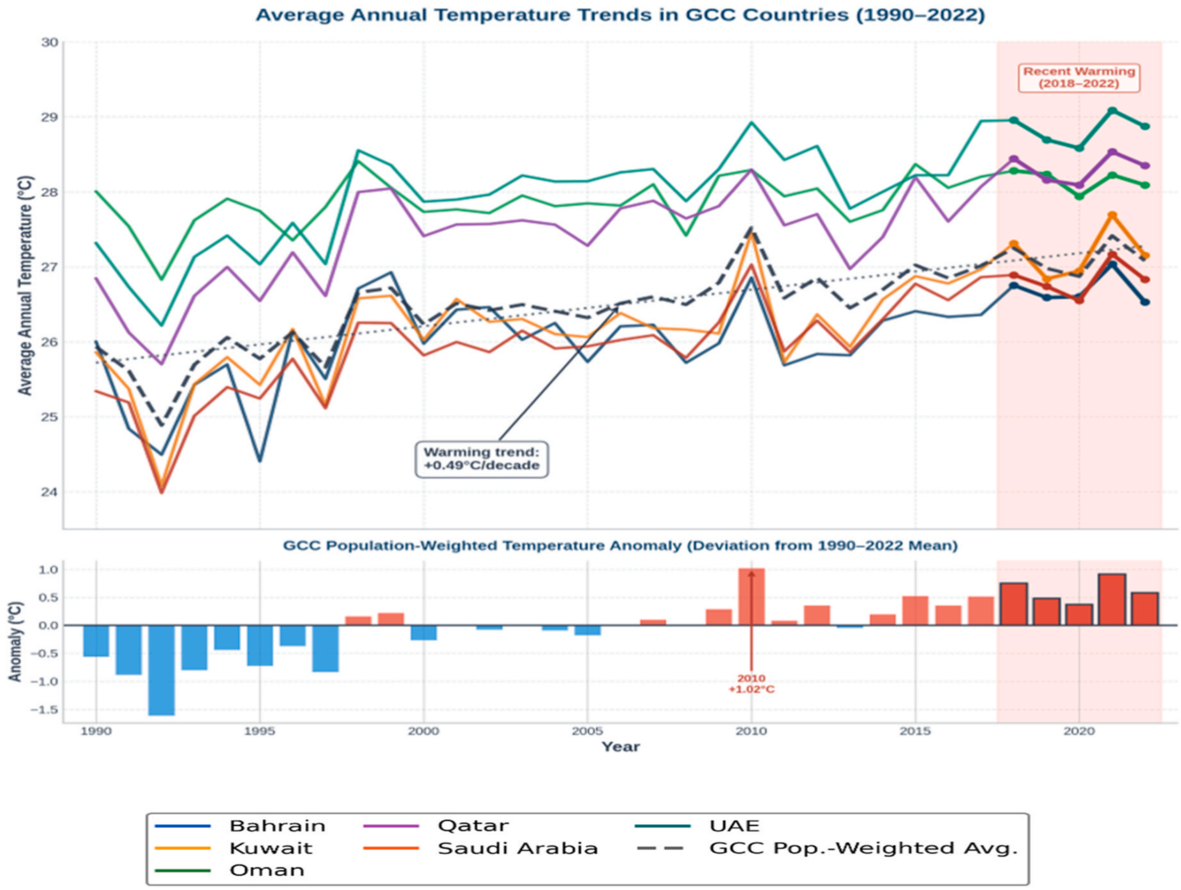


Fig. 1. Average Annual Temperature Trends in GCC Countries (1990-2022). Source: World Bank (2026).

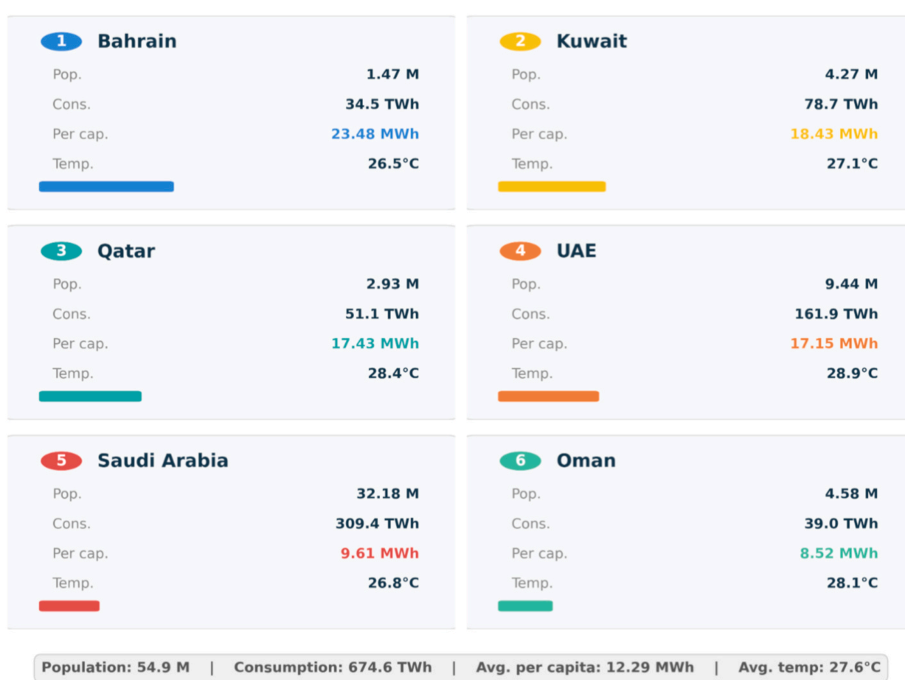


Fig. 2. GCC Countries: Key Statistics (2022). Ranked per capita electricity consumption. Source: EIA (2024), World Bank (2024), World Bank (2026).

substantial regional variations in temperature sensitivity, with the Western region exhibiting the greatest vulnerability, residential electricity demand rises by 12.9% for each 1°C increase, followed by the Southern (10.3%), Central (8.3%), and Eastern (4.8%) regions. In addition, Liddle and Huntington (2021) estimated electricity demand as a function of income, prices, and weather across 26 high-income and 29

Table 1
Summary of the relatively recent studies.

Study	Country	Period	Sector	Method(s)	Price elasticity		Income elasticity	
					SR	LR	SR	LR
Al-Sahlawi (1990)	Saudi Arabia	1970–1985	Aggregate	OLS	NR	NR	0.37	1.02
Eltony and Mohammad (1993)	GCC	1975–1989	Residential Commercial Industrial	OLS	−0.14 −0.20 −0.14	−0.14 −0.41 −0.20	0.20 1.12 0.60	0.20 2.37 0.89
Eltony (1995)	Kuwait	1974–1989	Residential Commercial Industrial	OLS	0.06 −0.13 −0.05	−0.39 −2.20 −0.27	0.09 0.11 0.02	0.57 1.93 0.13
Diabi (1998)	Saudi Arabia	1980–1992	Aggregate	OLS, GLS, MLE, CHTA and CCTA	−0.003 to −0.12	−0.14 to −0.01	0.05 to 0.33	0.09 to 0.49
Al-Sahlawi (1999)	Saudi Arabia	1975–1996	Aggregate Residential Industrial	OLS	−0.06 −0.10 NA	−0.46 −0.50 NA	0.21 0.13 0.08	1.60 0.70 0.66
Al-Faris (2002)	Saudi Arabia Kuwait UAE Oman Bahrain Qatar	1970–1997	Aggregate	Johansen cointegration	−0.04 −0.08 −0.09 −0.07 −0.06 −0.18	−1.24 −1.10 −2.43 −0.82 −3.39 −1.09	0.05 0.70 0.02 0.02 0.02 0.08	1.65 0.33 2.52 0.79 5.39 2.65
Eltony and Al-Awadhi (2007)	Kuwait	1975–2003	Commercial	ECM	−0.33	−1.64	0.34	0.50
Atakhanova and Howie (2007)	Kazakhstan	1994–2003	Aggregate Industrial Services Residential	GMM	0.00 0.00 −0.12 −0.12	NR NR NR −1.10	0.72 0.78 0.75 0.12	NR NR NR 0.59
Faisal and Eatzaz (2011)	Pakistan	1970–2008	Aggregate Commercial Residential Manufacturing Agricultural	ECM	insignificant insignificant insignificant insignificant insignificant	−1.27 −1.68 −1.22 −1.22 −0.51	insignificant insignificant insignificant 0.64 insignificant	1.56 1.47 1.97 1.61 1.25
Pourazarm and Cooray (2013)	Iran	1967–2009	Residential	ARDLBT	insignificant	0.00	insignificant	0.58
Javid and Qayyum (2014)	Pakistan	1972–2012	Aggregate Residential Commercial Industrial Agricultural	STSM	NR −0.07 −0.16 0.21 0.08	−0.09 −0.07 −0.26 0.21 0.08	1.43 0.20 0.17 0.59 0.43	1.89 0.20 0.17 1.29 0.42
Otsuka (2015)	Japan	1990–2010	Commercial Industrial	GMM	−0.007 −0.034	−0.023 −0.146	0.358 0.274	1.106 1.169
Shirani-Fakhr et al. (2015)	Iran	2000–2011	Industrial	STSM	−0.27	−0.47	0.36	0.85
Atalla and Hunt (2016)	Saudi Arabia Bahrain Oman Kuwait	1985–2012	Residential	STSM	−0.10 0.00 −0.09 0.00	−0.10 0.00 −0.10 0.00	0.00 0.00 0.72 0.30	0.48 0.71 0.86 0.43
Hasanov et al. (2016)	Azerbaijan	1995-2013	Aggregate	VECM, ARDLBT, DOLS, CCR, FMOLS	−0.4 to −0.3	−0.994 to −0.788	0.4 to 0.7	0.143 to 0.207
Campbell (2018)	Jamaica	1970–2014	Aggregate Commercial Industrial Residential	ARDL	−0.19 −0.17 −0.08 −0.19	−0.40 −0.15 −0.25 −0.82	0.46 0.35 Insignificant Insignificant	0.90 0.77 1.22 0.26
Njeru et al. (2020)	Kenya	1985–2016	Commercial	ARDL	−0.02	−0.03	0.85	1.13
Hasanov (2021)	Saudi Arabia	1984–2016	Industrial	ARDL		−0.09	0.35	0.20
Hasanov and Mikayilov (2020)	Saudi Arabia	1980–2018	Industrial	FMOLS, GETS		−0.3 to −0.2		0.50
Mikayilov et al. (2020a)	Saudi Arabia	1990-2016	Aggregate	GETS	−0.27 to −0.01	−0.607 to −0.060	0.05 to 0.47	0.102 to 0.931
Jia et al. (2021)	28 Chinese provinces.	2014	Residential	OLS	−0.953 for whole sample	NR	0.207 for Whole sample	NR
Liddle and Huntington (2021)	26 High-income and 29 middle-income countries	1978-2013	Residential	MG and DCCE	−0.093 to −0.069 (for high-income); −0.075 to −0.033 (for middle-income)	−025 to −0.22 (for high-income); −0.15 to −0.083 (for middle-income)	0.16 to 0.27 (for high-income); 0.32 to 0. 61 (for middle-income)	0.57 to 0.67 (for high-income); 0.81 to 1.22 (for middle-income)
Liddle and Hasanov (2022)	High-income (mostly OECD) and middle-income (mostly non-OECD) countries	1978–2016	Industrial	MG and DCCE	−0.059 (for high-income); Insignificant (for middle-income)	−0.27 to −0.26 (for high-income);	0.33 to 0.58 (for high-income); 0.34 to 0.66	0.52 (for high-income); 0.61 to 1.12

(continued on next page)

Table 1 (*continued*)

Study	Country	Period	Sector	Method(s)	Price elasticity		Income elasticity	
					SR	LR	SR	LR
						Insignificant (for middle-income)	(for middle-income)	(for middle-income)
Gasim et al. (2023)	Saudi Arabia	1986–2018	The sum of commercial and governmental;	STSM	NA	−0.08	0.38	0.43
			Industrial		−0.77	−0.60	1.31	1.03
Liddle and Hasanov (2023)	Middle-income (or high-growth) countries	1971–2019	Aggregate	MG, CCE, MO-OLS		−0.100 to −0.067		0.70 to 1.39
Mikayilov et al. (2023)	Saudi Arabia:	1990 -2019	Industrial	STSM				
	COA				−0.101	−0.178	0.449	0.449
	EOA				NR	−0.021[a]/-0.060[b]	0.523	0.523
	SOA				NR	−0.249 to −0.147	1.064	1.064
	WOA				−0.122	−0.122	0.562	0.562
Mikayilov and Al Ghamdi (2023)	Saudi Arabia:	1990-2021	Governmental	GETS	NR		NR	
	COA					Insignificant		0.206
	EOA					Insignificant		0.499
	SOA					Insignificant		1.876
	WOA					Insignificant		1.001
Mikayilov and Darandary (2023)	Saudi Arabia:	1990-2021	Commercial	STSM				
	COA				-	−0.795	1.090	1.090
	EOA				-	−0.181	-	0.537
	SOA				−0.267	0.557	-	2.678
	WOA				−0.334	−1.250	0.670	1.081
Mikayilov and Darandary (2024)	Saudi Arabia:	1990-2021	Region-specific Aggregate	GETS				
	COA				−0.087	−0.461	-	0.535
	EOA				-	−0.188	0.334	0.554
	SOA				−0.141	−0.378	-	1.445
	WOA				−0.096	−0.258	0.259	0.694
Mikayilov and Al-Mestneer (2024)	Saudi Arabia:	1990-2022	Region-specific Aggregate	GETS				
	COA				-	−0.240	0.483	0.660
	EOA				-	−0.102	0.443	0.443
	SOA				−0.092	−0.216	-	1.217
	WOA				−0.109	−0.263	0.305	0.738
This study	Bahrain	1990-2022	Country-specific Aggregate	FMOLS, DOLS, GETS	-	−0.177	-	1.372
	Kuwait	1990-2022				−0.077		0.256
	Oman	1990-2022				−0.332		0.249
	Qatar	1990-2022				−0.612		0.697
	Saudi Arabia	1990-2024				−0.165		0.312
	UAE	1990-2022				−0.475		0.316

Notes: ARDL = autoregressive distributed lagged model; OLS=Ordinary Least Squares Method; FMOLS=Fully Modified OLS; GMM = generalized method of moments; ECM = error correction model; CCTA = Cross-sectionally Correlated and Timewise Autoregressive model; CHTA = Cross-sectionally Heteroskedastic and Timewise Autoregressive model; GLS = Generalized Least Squares; GETS=General to Specific Modelling Approach; MLE = Maximum Likelihood Estimator; STSM = Structural Time Series Model; COA = a central operation area; EOA = an eastern operation area; SOA = a southern operation area; WOA = a western operation area (WOA). MG = Mean Group; CCE= Common Correlated Effects; MO-OLS = Mean Operator Ordinary Least Squares; DCCE = Dynamic Common Correlated Effects.
Source: Updated from Hasanov et al. (2016).

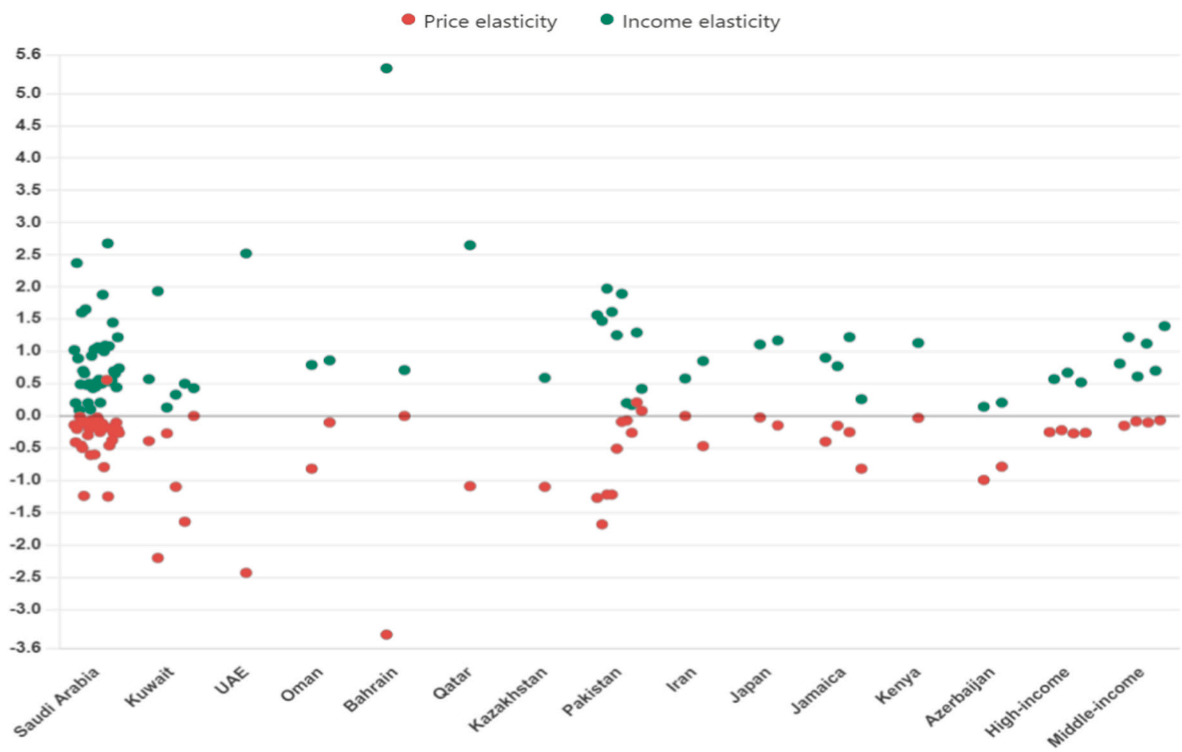


Fig. 3. The price and income elasticities across countries in existing studies.

middle-income countries. The estimation results revealed that the long-run elasticity of degree days was around 0.4 in high-income countries, whereas it was insignificant in middle-income countries. In high-income countries, Cooling Degree Days (CDD) were not statistically significant, whereas their elasticity was positive and statistically significant in middle-income countries. Furthermore, they found that the elasticity of Heating Degree Days (HDD) is significant in both high- and middle-income countries. Moreover, Atalla et al. (2018) found a statistically significant impact of HDD and CDD on electricity demand across 117 countries (including some GCC countries).

Additionally, the price and income elasticities from several studies across different countries or regions, as shown in Table 1, are presented in Fig. 3. A visual examination of Fig. 3 reveals a significant geographical imbalance in both the price and income elasticities.

Several factors contribute to the significant variation in elasticity estimates[2] across the studies reviewed in Table 1. First, differences in econometric methodologies are important: earlier studies that rely on OLS tend to yield less reliable estimates than more recent research using cointegration-based techniques (FMOLS, DOLS, ARDL) that properly address non-stationarity in the data. Second, the generally low price elasticities observed in GCC studies reflect the historically administered and subsidized electricity tariffs in the region. With prices set well below supply costs and changed infrequently, the price signal to consumers has been limited, limiting the potential for measurable demand responses. Countries that have implemented tariff reforms, such as Saudi Arabia in 2016 and 2018 and Qatar in 2016, tend to exhibit somewhat higher price sensitivity in studies covering the reform periods. Third, the wide range of income elasticities (from near zero to above one) reflects differences in economic development stages, the extent of industrialization, and the saturation of energy-intensive appliances such as air conditioning across countries and time frames. Countries at earlier stages of appliance saturation generally exhibit higher income elasticities, as income growth more directly drives the purchase of new electricity-consuming devices. Fourth, the level of data aggregation matters: studies using aggregate national data typically produce different elasticities than those based on sectoral or regional data (e.g., Mikayilov and Darandary, 2023; Mikayilov and Al Ghamdi, 2023) because aggregation can hide varied consumer responses among residential, commercial, industrial, and government sectors. Recognizing these sources of variation is key to understanding the elasticity estimates in this study and for setting realistic expectations about how future price, income, and climate changes may influence the GCC electricity demand trajectory.

Despite the extensive literature on GCC electricity demand, no prior study has estimated country-specific temperature semi-elasticities for all six member states within a consistent framework, nor translated these estimates into quantified climate-cost implications for the region's net-zero aspirations. This is the gap that this study addresses.

3. Theoretical framework

The theoretical foundation for modeling electricity demand draws on two complementary traditions: consumer demand theory and the production function approach. This section outlines both frameworks and explains how they converge on the empirical specifications adopted in this study, with particular attention to the climate dimension, which is central to electricity demand in hot regions such as the GCC.

3.1. Household demand for electricity

From the household perspective, electricity is a derived demand: consumers do not value electricity per se but rather the services it provides, cooling, lighting, refrigeration, cooking, and powering appliances

[2] A small number of studies report positive price elasticities, which are inconsistent with standard demand theory. These results likely reflect econometric issues rather than genuine economic behavior: specification errors, omitted-variable bias, multicollinearity among the drivers used, or the use of administered prices that exhibit insufficient variation to identify a true demand response. Studies employing more rigorous cointegration techniques and longer time series consistently find negative price elasticities, as expected by theory.

(Atalla and Hunt, 2016). In standard microeconomic theory, household demand for electricity can be derived by maximizing a utility function subject to a budget constraint. If we denote the utility derived from electricity services as a function of the quantity of electricity consumed (E), income (Y), the price of electricity (P), and a vector of other factors (Z), then the demand function can be written in reduced form as:

$$E = f(Y, P, Z)$$

where $\partial E/\partial Y > 0$ (electricity is a normal good), $\partial E/\partial P < 0$ (the law of demand), and Z captures non-economic factors such as climate, demographic structure, and the efficiency of the appliance stock. This framework has been widely applied in the energy demand literature (e.g., Atalla and Hunt, 2016; Campbell, 2018).

3.2. Industrial and commercial demand for electricity

From the production side, electricity serves as an intermediate input in the production of goods and services. Following the production function approach formalized by Hasanov (2021) and applied in Hasanov and Mikayilov (2020), industrial and commercial electricity demand can be derived from firms' cost-minimization or profit-maximization behavior. Consider a production function of the form:

$$Q = g(K, L, E, Z)$$

where Q is output, K is capital, L is labor, E is electricity, and Z captures exogenous factors again. Under cost minimization, the conditional demand for electricity is a function of output (or income as a proxy), the price of electricity relative to other inputs, and technological and structural factors. Hasanov (2021) extends this framework by incorporating demographic factors into the industrial energy demand function, demonstrating their theoretical and empirical relevance. Hasanov and Mikayilov (2020) further show that combining theoretical coherence with data coherence within a General-to-Specific Modeling (Gets) framework yields superior empirical results compared to imposing either a purely parsimonious or purely general specification.

3.3. The role of climate in electricity demand

The climate dimension introduces an additional factor that is particularly important in hot-arid regions such as the GCC. Temperature affects electricity demand through multiple channels. On the household side, rising temperatures increase the demand for cooling services, primarily air conditioning, which accounts for 60–70% of peak electricity consumption in GCC countries (Howarth et al., 2020). On the production side, higher temperatures reduce the thermal efficiency of industrial equipment, increase process cooling requirements, raise the energy intensity of desalination plants, and elevate transmission losses in the power grid (Mikayilov et al., 2026a). These effects are not merely seasonal: as documented by Howarth et al. (2020) and Mikayilov et al. (2026b), the secular warming trend in Saudi Arabia and the broader GCC region exerts a persistent upward pressure on electricity demand, compounding the effects of income and population growth.

Following the established literature (Atalla and Hunt, 2016; Hasanov et al., 2016; Mikayilov and Darandary, 2024), we incorporate temperature as an additional explanatory variable alongside income and price. Temperature enters the model at the level rather than in logarithmic form, yielding a semi-elasticity specification that is directly interpretable in the context of climate change scenarios (see Section 4.2).

3.4. Aggregate demand specification

Combining the household and production perspectives, and incorporating the climate dimension, the aggregate per capita electricity demand function takes the general form:

$$Ln(PCC_t) = \epsilon_0 + \epsilon_1\, Ln(PCIN_t) + \epsilon_2\, Ln(PR_t) + \epsilon_3 TEM_t + \varepsilon_t \tag{1}$$

where ϵ_1 represents income elasticity, ϵ_2 represents price elasticity, and ϵ_3 represents the semi-elasticity of temperature (percentage change per 1°C). PCC_t, $PCIN_t$, PR_t and TEM_t stand for per capita electricity consumption, per capita income, electricity price, and average temperature, respectively.

The logarithmic transformation of the dependent variable and economic regressors yields direct elasticity estimates for income (ϵ_1) and price (ϵ_2), while temperature in levels produces a semi-elasticity (ϵ_3) interpretable as the percentage change in per capita electricity consumption per 1°C increase in average temperature. This specification is consistent with the frameworks employed in Hasanov and Mikayilov (2020), Atalla and Hunt (2016), and Mikayilov et al. (2026a), and forms the basis for the country-specific cointegration analysis presented in the following sections.

4. Data and methodology

4.1. Data sources and variables

For econometric estimation of electricity demand in the GCC, we compile annual data for 1990–2022. The analysis incorporates four key variables:

Per Capita Electricity Consumption (PCC): Total electricity consumption divided by population, measured in megawatt-hours per capita (MWh/capita). Data sourced from the U.S. Energy Information Administration (EIA, 2024). This serves as the dependent variable in our analysis. The variable is transformed into a natural logarithm to facilitate the interpretation of elasticity.

Per Capita GDP (PCIN): Real gross domestic product per capita at constant 2015 US dollars, obtained from the World Bank's World Development Indicators (WDI, 2024). This variable represents the level of economic activity and standard of living, capturing how economic development affects electricity consumption. Logarithmic transformation yields income elasticity estimates.

Average Temperature (TEM): Annual mean temperature in degrees Celsius, obtained from the World Bank Climate Change Knowledge Portal (2026). Temperature enters the model in levels (not logarithms), yielding semi-elasticity estimates that represent the percentage change in electricity consumption per 1°C increase in temperature.

Electricity price (PR): Consumer Price Index (CPI) with base year 2015 = 100, used as a proxy for electricity prices, obtained from World Bank Indicators (WDI, 2024). While country-specific electricity prices would be preferable, their unavailability means CPI provides a consistent measure across countries. A logarithmic transformation allows interpretation in terms of price elasticity.

For **Saudi Arabia**, the following data is obtained from local sources. Namely, electricity consumption, electricity price, and population data are updated from Mikayilov and Al-Mestneer (2024). GDP data is taken from General Authority for Statistics (2025). The (estimation) sample period for the Saudi Arabia model spans from 1990 to 2024.

Descriptive statistics of the variables employed in the empirical analysis are provided in Table 2 (including mean, median, maximum, minimum, standard deviation, skewness, kurtosis, and the Jarque-Bera test value for normality).

Table 2 shows notable cross-country heterogeneity in the key variables. Because PCC, PCIN, and PR are entered in natural logarithms, their descriptive statistics are reported in log form. The mean values of log per capita electricity consumption (PCC) across the GCC range from about 8.5 MWh/capita in Oman to over 23 MWh/capita in Bahrain, reflecting differences in economic structure, urbanization, and cooling intensity. The standard deviations of log PCC indicate that within-country variation over time is also substantial, particularly for countries that experienced rapid demand growth (e.g., Qatar and the UAE) or

Table 2
Descriptive Statistics of the used variables.

Country	Variable	Mean	Median	Max	Min	Std. Dev.	Skew	Kurtosis	JB
Bahrain	**TEMB**	26.1	26.21	27.04	24.49	0.57	−0.76	3.63	3.74
	Ln(PCINB)	9.98	9.99	10.1	9.76	0.07	−1.18	4.77	11.93
	Ln(PRB)	4.45	4.39	4.68	4.26	0.15	0.38	1.59	3.53
	Ln(PCCB)	2.67	2.98	3.15	1.77	0.51	−0.85	1.82	5.87
Saudi Arabia	**Ln(PCCS)**	1.9	1.89	2.38	1.34	0.33	−0.06	1.78	2.07
	Ln(PCINS)	9.83	9.82	9.97	9.66	0.07	−0.17	2.34	0.75
	Ln(PSR)	−1.98	−1.97	−1.43	−2.54	0.28	−0.24	2.96	0.33
	TEMS	26.1	26.21	27.04	24.49	0.57	−0.76	3.63	3.74
Kuwait	**Ln(PCCK)**	2.68	2.76	2.91	1.95	0.21	−1.69	5.77	26.22
	Ln(PCINK)	10.33	10.35	10.63	9.61	0.21	−1.31	5.9	21.1
	Ln(PRK)	4.29	4.2	4.77	3.85	0.29	0.21	1.52	3.26
	TEMK	26.28	26.27	27.7	24.08	0.73	−0.58	4.11	3.54
Oman	**Ln(PCCO)**	1.44	1.41	2.14	0.7	0.48	−0.08	1.56	2.88
	Ln(PCINO)	9.85	9.85	10.04	9.7	0.08	0.21	3.01	0.23
	Ln(PRO)	4.4	4.28	4.68	4.16	0.19	0.27	1.27	4.51
	TEMO	27.9	27.94	28.41	26.83	0.33	−0.98	4.65	9.00
Qatar	**Ln(PCINQ)**	10.91	11.00	11.21	10.55	0.20	−0.57	−0.77	2.60
	Ln(PRQ)	4.25	4.29	4.68	3.72	0.34	−0.15	1.35	3.88
	TEMQ	27.52	27.61	28.53	25.7	0.68	−0.79	3.21	3.52
	Ln(PCCQ)	2.63	2.7	2.94	2.2	0.21	−0.68	2.19	3.41
UAE	**Ln(PCCU)**	2.41	2.48	2.84	1.88	0.25	−0.71	2.65	2.92
	Ln(PRU)	4.27	4.27	4.68	3.72	0.32	−0.11	1.41	3.53
	TEMU	28.07	28.22	29.09	26.22	0.71	−0.71	2.96	2.75
	Ln(PCINU)	10.83	10.96	11.11	10.45	0.22	−0.3	1.51	3.58

Notes: PCC denotes per capita electricity consumption in megawatt-hours per capita (MWh/capita), sourced from EIA (2024); for Saudi Arabia, updated from Mikayilov and Al-Mestneer (2024). PCIN denotes real per capita GDP in constant 2015 US dollars, sourced from World Bank (2026); for Saudi Arabia, from General Authority for Statistics (2025). TEM denotes annual mean temperature in degrees Celsius (°C), sourced from the World Bank Climate Change Knowledge Portal (2026). PR denotes the Consumer Price Index (2015 = 100), used as a proxy for electricity prices, sourced from World Bank Indicators; for Saudi Arabia, actual electricity prices are used, updated from Mikayilov and Al-Mestneer (2024). All variables except TEM are expressed in natural logarithms in the estimations. The sample period is 1990–2022 for all countries except Saudi Arabia (1990–2024).
Source: Authors' calculation

demand moderation following pricing reforms (e.g., Saudi Arabia).

Log per capita income (PCIN) varies widely across GCC states, consistent with well-documented differences in GDP levels between the larger, diversified economies (Saudi Arabia, UAE) and the smaller, hydrocarbon-intensive states (Qatar, Kuwait). The skewness of log PCIN is generally moderate, indicating that the distributions over the sample period are reasonably symmetric, though some countries show slight skewness reflecting periods of rapid oil-price-driven income growth.

Average temperature (TEM), the only variable entering the model at levels, displays the narrowest within-country variation, as expected for an annual mean climate variable. The small standard deviations (typically less than 1°C) indicate that temperature varies within a relatively tight band for each country over the 33-year sample period. Nevertheless, as documented in Section 1.2, even these modest changes carry significant implications for electricity demand given the high semi-elasticities estimated in this study. Cross-country differences in mean temperature are also relatively compressed (ranging from approximately 26.5°C in Bahrain to 28.9°C in the UAE), confirming the GCC region's uniform hotness.

The log price proxy (PR), measured as the natural logarithm of CPI, shows an upward trend over the sample period across all countries, with standard deviations that reflect the pace of overall price-level change. The Jarque-Bera test statistics indicate that the null hypothesis of normality cannot be rejected for most variables in their transformed form, supporting the validity of the standard inference procedures employed in the cointegration analysis.

4.2. Econometric methodology

Our empirical strategy proceeds in three stages: (i) testing for unit roots, (ii) testing for cointegration, and (iii) estimating the long-run elasticities using multiple cointegration estimators. This multi-stage approach ensures that the statistical properties of the data are properly accounted for before interpreting the estimated coefficients as long-run equilibrium relationships.

4.2.1. Unit root and cointegration testing

As a first step, we test the order of integration of each variable using the Augmented Dickey-Fuller (ADF) test. For each country and variable, the test is applied to both levels and first differences. This step is necessary to confirm that the variables are integrated of order one, I(1), which is a prerequisite for the cointegration analysis that follows. The maximum lag length is determined by the Schwarz Information Criterion (SIC), with a maximum of two lags given the annual frequency and sample size.

Having established the order of integration, we test for a long-run cointegrating relationship among the variables using the Engle-Granger two-step procedure. This involves estimating the long-run equation by OLS and testing the residuals for stationarity. A rejection of the null hypothesis of a unit root in the residuals provides evidence that the variables share a common stochastic trend and that the estimated relationship is not spurious.

4.2.2. Fully Modified OLS (FMOLS)

As our baseline estimation technique, we employ the Fully Modified OLS (FMOLS) method proposed by Phillips and Hansen (1990). FMOLS is designed specifically for estimating cointegrating relationships and has two important advantages over standard OLS applied to levels regressions. First, it corrects for endogeneity bias arising from regressors that are correlated with the error term, a common concern in energy demand models in which income, prices, and consumption may be jointly determined. Second, it corrects for serial correlation in the residuals, yielding asymptotically efficient estimates and valid standard errors. These properties make FMOLS particularly well-suited to our setting.

4.2.3. Dynamic OLS (DOLS)

As a complementary estimator, we employ the Dynamic OLS (DOLS) method of Stock and Watson (1993). DOLS augments the cointegrating regression with leads and lags of the first differences of the regressors. By including these lead and lag terms, DOLS parametrically absorbs the effects of endogeneity and serial correlation. The resulting estimator is asymptotically equivalent to FMOLS but may perform better in finite samples because it does not rely on non-parametric kernel estimation for the long-run covariance matrix. The consistency of results between FMOLS and DOLS provides reassurance that the estimated elasticities are not artifacts of a particular estimation method.

4.2.4. General-to-specific modeling (GETS) via autometrics

Our third and most flexible estimation approach is the General-to-Specific (GETS) methodology, implemented via the Autometrics algorithm (Hendry and Doornik, 2014). GETS begins with a General Unrestricted Model (GUM) that includes all potentially relevant variables, their lags, and a comprehensive set of candidate indicator variables. The algorithm then systematically simplifies the general model through a sequence of specification tests, eliminating statistically insignificant terms while retaining those supported by the data. The final specific model is the most parsimonious representation that is statistically congruent with the data-generating process.

A distinctive and powerful feature of GETS/Autometrics is its ability to automatically select exogenous interventions through indicator saturation techniques. Three types of indicators are considered:

Impulse Indicator Saturation (IIS) introduces a dummy variable for each observation in the sample and tests whether each is a statistically significant outlier. This is particularly valuable in GCC electricity demand modeling, where one-off events, such as the COVID-19 lockdowns in 2020, extreme weather events, or the start of major infrastructure projects, may yield isolated observations that deviate significantly from the underlying relationship. By identifying and absorbing these outliers, IIS prevents them from distorting the estimated elasticities.

Step Indicator Saturation (SIS) introduces a step dummy at every possible break point in the sample and tests for permanent level shifts in the relationship. In the GCC context, this captures structural breaks arising from policy reforms, notably the Saudi electricity price reforms of 2016 and 2018, Qatar's tariff adjustment in 2016, and the UAE's subsidy rationalization program, as well as lasting shifts in economic structure, urbanization patterns, or building stock efficiency.

Trend Indicator Saturation (TIS) tests for changes in the underlying trend of the relationship, capturing gradual shifts in energy efficiency, technological change, or evolving consumption patterns that may not be adequately captured by the model's economic variables.

The key advantage of this approach is that it allows the data to determine when, where, and how structural breaks and outliers affect the estimated relationship in each country. This avoids the twin risks of over-correction (imposing dummies for events that did not, in fact, significantly disturb the relationship) and under-correction (failing to account for breaks that the researcher did not anticipate). Moreover, the selected indicators collectively constitute the Underlying Energy Demand Trend (UEDT), which is subsequently used in the decomposition analysis (see Section 4.3).

By estimating the model with all three techniques, FMOLS, DOLS, and GETS, and comparing the results, we ensure that the reported elasticities are robust to the choice of estimator. The FMOLS results are presented as the baseline in Table 4; the DOLS and GETS results are reported in Appendix B.

4.3. Decomposition methodology

In addition to elasticity estimation, we employ a decomposition analysis to quantify each driver's contribution to observed changes in total electricity consumption. We adopt the additive Logarithmic Mean Divisia Index (LMDI) approach, widely recognized as the preferred index decomposition method in energy studies due to its exact (residual-free) decomposition property and ease of interpretation (Ang, 2004, 2005, 2015).

Since the elasticity model is specified in per capita terms, we reintroduce the population dimension to decompose changes in total consumption. Given that PCC = C/Pop (C = total electricity consumption), the growth rate of total consumption can be expressed as $\Delta\, ln(C) = \Delta\, ln(PCC) + \Delta\, ln(Pop)$. Substituting the estimated model and applying the additive LMDI framework yields:

$$\Delta\, ln(C) \approx \beta_1\, \Delta\, ln(PCIN) + \beta_2\, \Delta\, ln(PR) + \beta_3\, \Delta Temp + \Delta UEDT + \Delta\, ln(Pop)$$

where each term captures the contribution of income growth, price changes, temperature variation, the underlying energy demand trend (UEDT), and population growth, respectively. Consistent with the LMDI approach, the components sum precisely to the total observed change. The estimated elasticity coefficients from the cointegration analysis serve as weights that translate changes in each driver into their respective contributions to electricity consumption growth.

The population enters with a coefficient, mechanically recovered from the per capita-to-total conversion. The UEDT captures residual systematic variation not explained by income, price, or temperature. It is approximated by the dummy variables selected by the GETS/Autometrics algorithm, computed as the sum of the selected indicators multiplied by their estimated coefficients. UEDT thus absorbs the effects of structural changes, regulatory reforms, energy efficiency improvements, and other unobserved factors influencing electricity demand over time.

5. Empirical results

5.1. Unit root and cointegration tests

Using time series data, the analysis begins by testing the stationarity of the variables. The outcomes of the unit-root tests are reported in Table 3A. For the ADF test, a maximum lag length of two is considered, while the optimal lag length is determined based on the Schwarz information criterion. The findings of the unit-root tests in Table 3A indicate that all the used variables exhibit stationarity at the first difference. Hence, it becomes possible to proceed with testing the long-run cointegration relationship among the variables in the subsequent step.

As shown in Table 3B, the test results for three countries reject the null hypothesis of “no cointegration.” For the remaining three countries, as seen from the last row, the coefficient of the lagged value of residual meets the conditions of $0 < Rho < 1$, concluding the convergence of the residual series. That is, there is a cointegration relationship between the variables for the remaining three countries as well.

5.2. Elasticity estimates

The Empirical estimation results are presented in Table 4 .[3] The results in Table 4 are obtained using the FMOLS technique. These elasticity estimates offer valuable insights into the factors driving electricity consumption in the GCC region. The income elasticities of demand for all countries are positive and statistically significant, ranging from 0.25 in Oman to 1.37 in Bahrain.

All price elasticity estimates are negative (−0.08 to −0.61) and thus in line with the standard demand theory. The magnitudes of these elasticities indicate that overall demand is inelastic, with important country-specific exceptions: most price-responsive for Qatar and least for Kuwait.

[3] To verify the robustness of the baseline FMOLS results reported in Table 4, we re-estimate the long-run electricity demand model for each GCC country using DOLS and the GETS approach via Autometrics. The results are presented in Table B1 in the Appendix.

Table 3A
Unit-root test results.

	Ln(PCC)		Ln(PCIN)		Ln(PR)		TEM	
	Level	Differenced	Level	Differenced	Level	Differenced	Level	Differenced
Bahrain	−1.5436	−5.4499***	−3.3377*	−5.7197***	−0.2202	−3.5041**	−3.0724**	−8.1523***
Kuwait	−1.5522	−10.2573***	−5.7853***	−5.6101***	1.0026	−4.5343***	−2.9567**	−8.2471***
Oman	−0.4033	−5.4365***	−2.5508	−3.3816**	−0.0544	−2.9051*	−3.9315***	−8.1912***
Qatar	−0.9393	−5.5915***	−1.4157	−5.0018***	−0.7936	−2.9790**	−2.2539	−7.1120***
Saudi Arabia	−0.9976	−5.2650***	−1.0202	−5.2500***	−0.3357	−3.2906**	−1.3948	−7.6941***
UAE	−0.5668	−4.0215***	−1.6899	−2.6823*	−0.8975	−3.0878**	−2.2357	−7.0447***

Note: All variables are as defined in the Methodology section. The maximum lag is set to 2 based on the Schwarz Information Criterion. ***, **, and * stand for rejection of null hypothesis at 1%, 5% and 10% significance levels, respectively.
Source: Estimation results.

Table 3 B
The results of engle-granger tests.

Statistic/Country	Bahrain	Kuwait	Oman	Qatar	Saudi Arabia	UAE
Tau-statistic	−4.583**	−12.493***	−3.291	−3.010	−4.747***	−2.583
Z-statistic	−25.783**	−44.728***	−16.644	−14.571	−26.955***	−10.617
Rho-1	−0.806	−1.398	−0.520	−0.455	−0.842	−0.293
Rho	0.194	−0.398	0.480	0.545	0.158	0.707

Note: *, **, and *** indicate rejection of the null hypothesis at 10%, 5%, and 1% significance levels, respectively.
Source: Estimation results.

Table 4
Long-run elasticity estimates.

Variable	Bahrain	Kuwait	Oman	Qatar	Saudi Arabia	UAE
Income	1.372***	0.256***	0.249***	0.697***	0.312**	0.316***
Price	−0.177**	−0.077**	−0.332***	−0.612***	−0.165***	−0.475***
Temperature	0.031**	0.042***	0.038*	0.047**	0.058***	0.037*

Notes: ***, **, * indicate statistical significance at 1%, 5%, 10% levels. Temperature coefficients are semi-elasticities (% change per 1°C).
Source: Estimation results.

The cross-country variation in elasticity estimates reflects identifiable structural and institutional differences across GCC economies. Bahrain's comparatively high-income elasticity (1.37) is consistent with its position as a smaller, more diversified economy at an earlier stage of electricity-intensive capital stock accumulation. As incomes rise, Bahraini households and firms expand residential and commercial floor space, directly increasing demand for air-conditioned environments and electricity-consuming equipment. The lower income elasticities for the UAE (0.32), Saudi Arabia (0.31), Kuwait (0.26), and Oman (0.25) are consistent with the saturation hypothesis documented in the energy demand literature. Medlock and Soligo (2001) show that energy demand growth slows as economies mature through successive development stages, while Wolfram, Shelef, and Gertler (2012) provide micro-level evidence that the income elasticity of energy demand declines as household ownership of energy-using durables approaches saturation. Chang et al. (2014, 2016) demonstrate that income elasticities of electricity demand are not constant but vary with economic development. Mikayilov et al. (2020b) similarly find, for the Saudi case, that elasticities are responsive to the stage of economic development. In the GCC context, near-universal penetration of air conditioning, the dominant electricity-consuming asset, means that additional income growth generates proportionally less incremental electricity demand in larger, more established economies.

The variation in price elasticities across GCC countries can be attributed to country-specific characteristics. Qatar exhibits the highest price elasticity (−0.61), coinciding with its 2016 tariff reform, which introduced substantial increases in electricity and water prices for the first time, a visible, discrete price signal to which consumers could respond. Saudi Arabia's price elasticity (−0.17) is relatively modest despite the two waves of electricity price reforms in 2016 and 2018, suggesting that the demand response to tariff increases, though statistically significant, remained limited. This likely reflects both the very low initial tariff base from which the reforms departed and the climate-driven baseline dependence on air conditioning that constrains the scope for behavioral adjustment. At the other end of the spectrum, Kuwait's near-zero estimated price elasticity (−0.08) reflects the absence of significant tariff variation during the sample period, which means the data provide insufficient variation to estimate a statistically reliable price response. This does not imply that Kuwaiti consumers would be unresponsive to future price changes; indeed, the experience of Saudi Arabia and Qatar suggests that substantial tariff reforms do draw measurable demand reductions. Rather, the estimate should be interpreted with caution, as the lack of price variation prevents identification of the true price elasticity. These patterns highlight a key policy implication: the effectiveness of pricing as a demand management instrument in the GCC is conditional on the magnitude and visibility of the price adjustment and is likely to be most effective where reform represents a discrete departure from a long-standing subsidy baseline.

Our elasticity estimates are broadly consistent with the prior literature summarized in Table 1, though some notable differences merit discussion. For Saudi Arabia, our long-run income elasticity of 0.31 aligns closely with the estimates of Hasanov and Mikayilov (2020), who report an income elasticity of 0.5 using the GETS framework, and falls within the range reported by Mikayilov et al. (2023) for industrial electricity demand (0.45–0.56 across regions). The somewhat lower magnitude compared to earlier studies, such as Al-Sahlawi (1990), who reported income elasticities above unity, likely reflects the maturation and saturation of the Saudi electricity market over the intervening decades, as well as the moderating effect of the 2016 and 2018 price reforms captured by our extended sample period. For Kuwait, our income elasticity of 0.26 is consistent with the inelastic estimates found by Eltony (1995) and Eltony and Mohammad (1993), confirming the long-standing pattern of low income responsiveness in a highly subsidized market. Bahrain's markedly higher income elasticity (1.37) exceeds most prior GCC estimates but is plausible given its smaller, more diversified economy at an earlier stage of electricity-intensive capital stock saturation relative to its neighbors.

Turning to price elasticities, our estimates (−0.08 to −0.61) fall within the broad range reported in the GCC literature (−3.39 to 0.00; see Table 1), though they are concentrated at the inelastic end. This is consistent with the persistent subsidy environment across the region, which limits the price signal available to consumers. Qatar's relatively high price elasticity (−0.61) is comparable to the estimates reported by Atalla and Hunt (2016) for GCC residential demand and reflects the 2016 tariff reform, which introduced a visible price signal for the first time. Kuwait's near-zero elasticity (−0.08) corroborates Eltony's (1995) findings, which similarly found negligible price responsiveness in the Kuwaiti context. Our Saudi price elasticity (−0.17) is broadly consistent with earlier estimates by Diabi (1998), who reported a range of −0.14 to −0.01, and aligns with the inelastic end of Al-Sahlawi's (1999) estimates. The modest magnitude is consistent with the GCC pattern of limited price responsiveness in a subsidized environment, even following the 2016–2018 tariff reforms.

For temperature,[4] direct comparison with prior GCC studies is more limited, as few have estimated temperature elasticities using the same specification. Atalla and Hunt (2016) modeled GCC residential electricity demand but used a structural time-series approach with an underlying energy-demand trend rather than an explicit temperature variable. Mikayilov et al. (2026b) report a national temperature semi-elasticity of (total energy demand) 7.9% for Saudi Arabia, closely aligned with our estimate of 5.8%. At the regional level, Mikayilov et al. (2026a) find semi-elasticities (for the residential electricity consumption) ranging from 4.8% (Eastern region) to 12.9% (Western region), brackets within which our national estimate sits comfortably. The consistency of our temperature estimates with these independent studies lends confidence to the robustness of the findings.

Finally, the semi-elasticity temperature is relatively similar across GCC countries, with the expected positive sign (ranging from 0.03 to 0.06). It is important to note that our specification assumes a linear relationship between temperature and the log of per capita electricity consumption, implying a constant semi-elasticity across the observed temperature range. In practice, the temperature–electricity relationship is likely non-linear: marginal cooling demand tends to increase more steeply at higher temperatures, owing to the thermodynamic properties of air conditioning systems operating closer to capacity limits, behavioral responses such as extended operating hours and lower thermostat settings, and reduced equipment efficiency under extreme heat. However, since our climate variable, the annual average temperature, varies within a relatively narrow band across countries over the sample period (see Table 2), the linear specification provides a reasonable first-order approximation of the long-run relationship. Identifying non-linear temperature effects would require sub-annual data (monthly or daily) capable of exploiting the full within-year temperature range, including extreme heat episodes that disproportionately drive peak cooling loads. This represents a promising avenue for future research, particularly as higher-frequency data becomes available for GCC countries.

To provide deeper insights into our analysis, better represent the driving factors of electricity consumption, and facilitate comparisons across GCC countries, we reviewed additional information for each country. This included economic assumptions specific to each country and technical assumptions related to the technologies used to generate electricity.

Decadal trends in population and GDP growth rates, which provide context for interpreting the decomposition results, are presented in Appendix D (Figures D1 and D2).

Moving to Climatic factors, the decadal average temperature growth rates for 1992-2025 show a significant asymmetry across the GCC nations, with Saudi Arabia consistently recording the highest temperature rise (Fig. 4). The cumulative score for the warming trend persisted near the maximum for Saudi Arabia, with a value of 0.95 from 1992 to 2001 and incrementally increasing to 0.97 from 2022 to 2025. Qatar maintained intermediate scores (approximately 0.30) over the decade, substantially lower than Saudi Arabia's but considerably higher than the remaining GCC states. The remaining countries, Kuwait, Bahrain, Oman, and the UAE, all continued to have low and relatively stable temperature increase scores (typically between 0.04 and 0.09 throughout), indicating either little or a weaker change in average values compared with those observed in Saudi Arabia and Qatar. In sum, the data suggest that temperature vulnerability, as measured in this way, has become significantly more pronounced in Saudi Arabia and Qatar than in any other GCC country, with decadal increases being substantially weaker.

Fig. 5 illustrates the temperature sensitivity of electricity demand across all GCC countries. Saudi Arabia exhibits the highest semi-elasticity to temperature at 5.8%, meaning that a 1°C increase in average annual temperature leads to a 5.8% rise in annual electricity consumption. This pronounced sensitivity reflects the Kingdom's large geographic extent and its dominant share of regional electricity consumption. Qatar shows a semi-elasticity of 4.7%, while Kuwait (4.2%), Oman (3.8%), the UAE (3.7%), and Bahrain (3.1%) show relatively similar but lower sensitivities. The variation in temperature sensitivity across countries reflects differences in climate extremes, building stock efficiency, air conditioning penetration rates, and economic structure. These findings point that, while all GCC countries are vulnerable to temperature-driven increases in demand, Saudi Arabia faces disproportionately greater challenges in managing climate-induced growth in electricity demand.

6. Decomposition analysis

To complement our elasticity estimates, we employ decomposition analysis to disentangle the contributions of different factors to year-over-year changes in electricity consumption: population growth (Pop), economic activity (GDP), temperature variations (Tem), price effects (Pele), underlying efficiency trends (UEDT), and irregular factors (Irr).

6.1. GCC regional decomposition (2015–2022)

Fig. 6 presents the decomposition of year-over-year changes in total GCC electricity consumption over 2015-2022. Population growth is consistently one of the largest positive contributors, adding between 2.8 TWh (2017) and 20.5 TWh (2015) annually. GDP effects are similarly positive in most years, with notable peaks in 2015 (9.1 TWh) and 2022 (19.6 TWh), reflecting the post-pandemic economic recovery and high oil prices. Temperature effects fluctuate considerably, contributing positively in years of above-average heat (16.2 TWh in 2021, 8.6 TWh in 2015) and negatively in cooler years (−8.3 TWh in 2019, −10.3 TWh in 2022). The price effect is consistently negative but modest in absolute terms (−1.9 to −10.3 TWh), with the largest dampening effects in 2016 (−9.9 TWh) and 2018 (−10.3 TWh), corresponding to the Saudi and Qatari pricing reforms. The UEDT component shifts from moderately positive in 2015–2019 to a sharp spike of 15.5 TWh in 2020, likely reflecting the structural disruption caused by the COVID-19 pandemic, before returning to more typical values. The irregular component captures residual volatility, including large positive shocks in 2021 (13.3 TWh) and 2022 (17.6 TWh) associated with the post-pandemic demand

[4] In addition to the average temperature, we have also estimated the models with maximum average temperature (World Bank, 2026). The results are presented in Appendix C, Table C2. The results are quite similar to the results presented in Table 4.

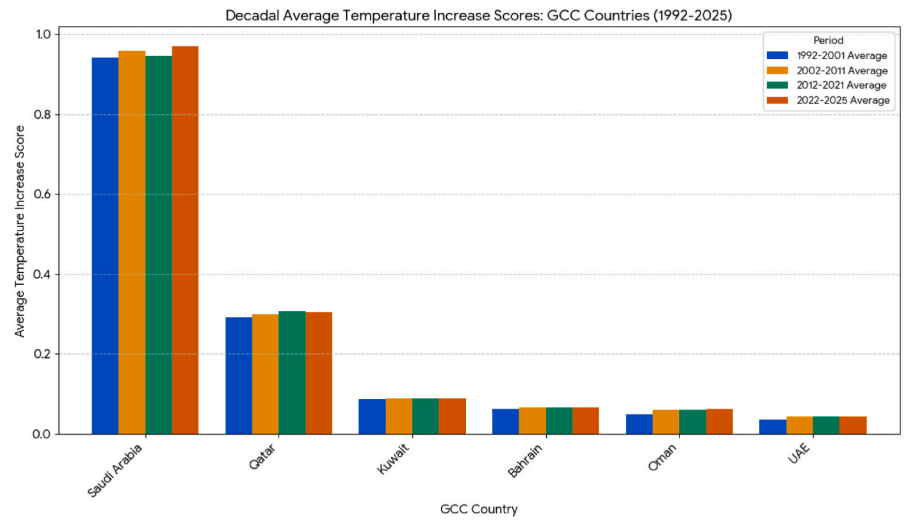
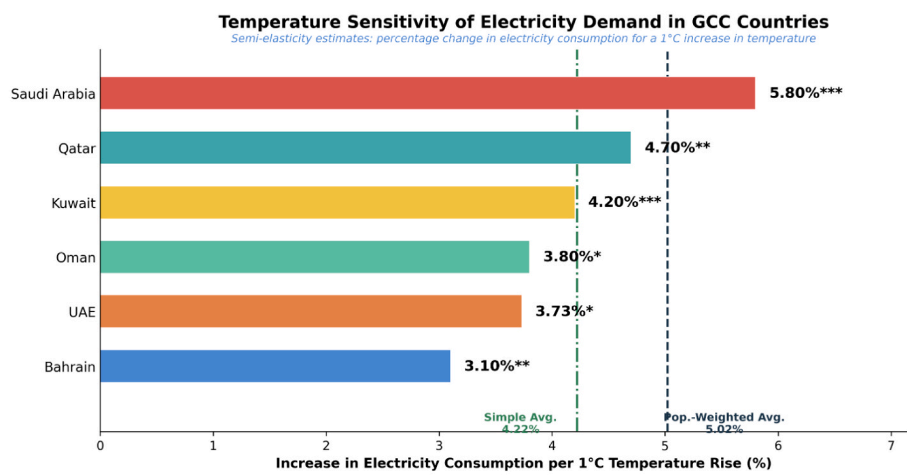


Fig. 4. Decadal Average Temperature Increase. Scores across GCC countries (1992-2025). Source: (Samborska, 2024).



Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Fig. 5. *Temperature Sensitivity of Electricity Demand. Source*: Estimation results.
Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

rebound and extreme heat events.

6.2. Country-specific decomposition

Fig. 7 presents decomposition results for each GCC country, revealing substantial heterogeneity in the drivers of electricity demand.

Saudi Arabia. Population growth is the dominant positive driver in most years, contributing 12–17 TWh annually in 2015, 2016, 2020, and 2022. The impact of the 2016 and 2018 electricity price reforms is clearly visible: the price effect reaches −7.9 TWh in 2016 and −8.2 TWh in 2018, making these the two years with the largest demand-dampening contributions from any single factor. By contrast, the price effect is negligible in non-reform years, confirming that the demand response was driven by the discrete tariff adjustments rather than gradual price evolution. Temperature contributions are substantial and volatile, reaching 9.6 TWh in 2021 (a particularly hot year) but turning sharply negative in 2019 (−4.8 TWh) and 2022 (−6.2 TWh) when temperatures moderated. GDP effects are relatively modest (1–4 TWh in most years) but turned negative in 2020 (−3.4 TWh) during the pandemic-induced recession.

Notably, the UEDT is zero throughout the sample for Saudi Arabia, meaning that the model with income, price, and temperature alone, without indicator dummies, accounts for the systematic variation in the data. The irregular component absorbs the remaining volatility, including a large positive contribution in 2018 (10.6 TWh) and a large negative one in 2022 (−13.5 TWh).

UAE. The UAE exhibits consistently positive UEDT contributions (4.0–5.2 TWh), suggesting that structural factors beyond income, price, and temperature, such as rapid urbanization, infrastructure expansion, and population composition changes, have sustained upward pressure on demand. Temperature effects are the most volatile component, swinging from +4.0 TWh in 2015 to −3.2 TWh in 2016 and back to +3.4 TWh in 2017. The price effect is notable for its magnitude relative to the UAE's size: it reaches −3.4 TWh in 2022, the largest among non-Saudi countries. GDP effects are substantial in 2022 (+3.6 TWh), reflecting the strong post-pandemic recovery. The large irregular component in 2022 (+14.8 TWh) warrants attention and may reflect the combined effects of Expo 2020 spillover activity, rapid population growth, and structural economic shifts.

The four smaller GCC economies display distinctive decomposition patterns that reflect their specific structural characteristics. In Kuwait, population growth dominates the positive contributions in most years,

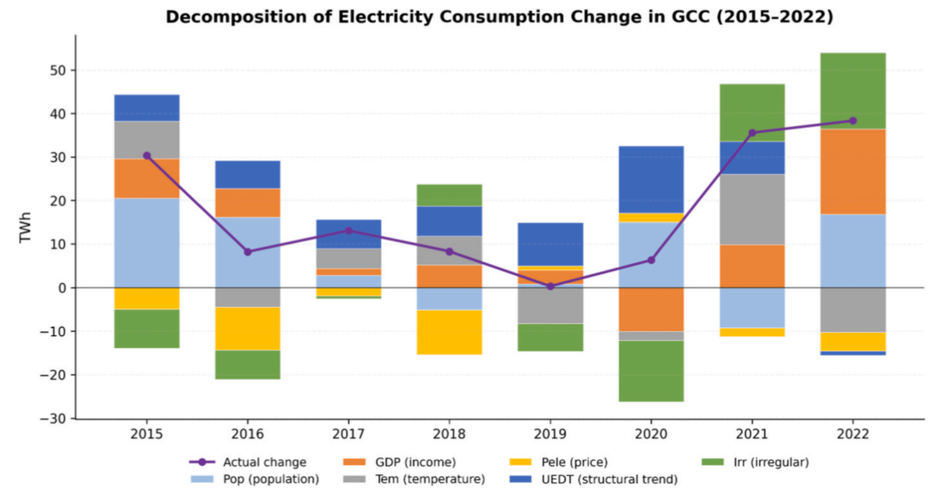


Fig. 6. *Decomposition of Electricity Consumption Change in GCC (2015-2022).*
Note: The stacked bars represent the estimated contribution of each driver to annual changes in electricity consumption, derived from the decomposition framework described in Section 4.3. The purple line shows the actual observed change. The sum of all bar components equals the model-fitted change, which is equal to the actual change. Total GCC electricity consumption increased from approximately 564 TWh in 2015 to 675 TWh in 2022.
Source: Estimation results. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

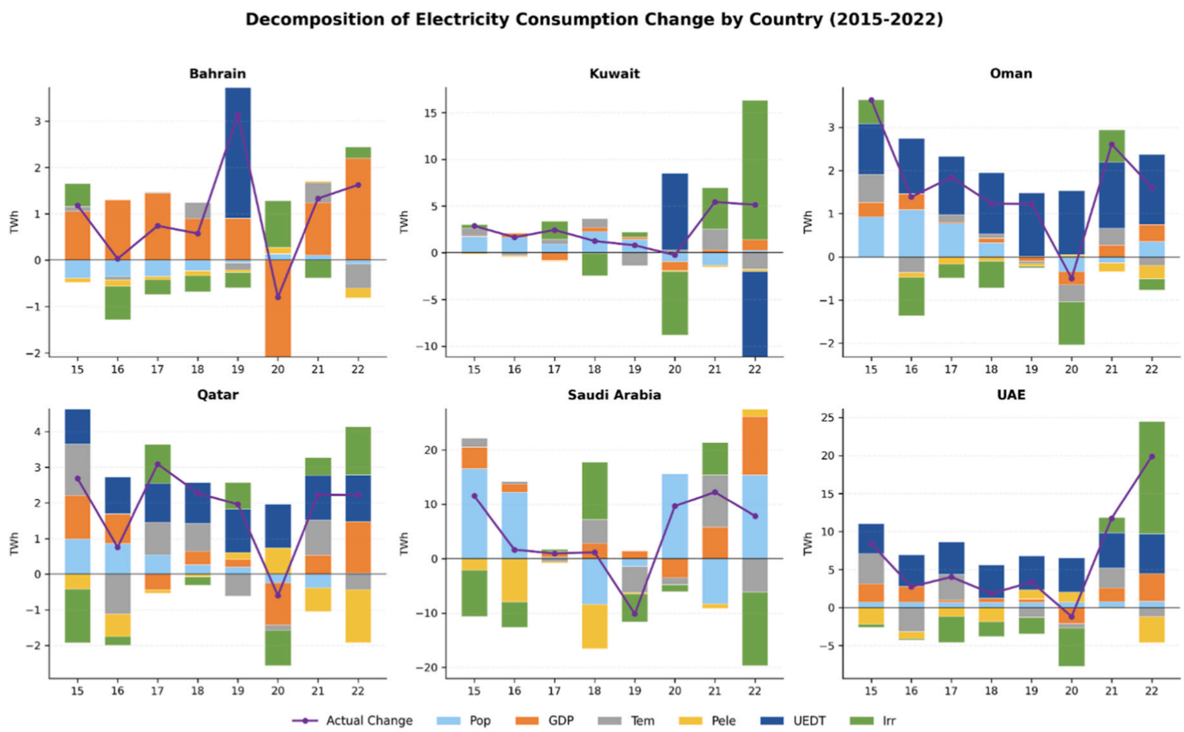


Fig. 7. *Decomposition by Country (2015-2022).*
Note: The stacked bars represent the estimated contribution of each driver to annual changes in electricity consumption, derived from the decomposition framework described in Section 4.3. The purple line shows the actual observed change. The sum of all bar components equals the model-fitted change, which is equal to the actual change.
Source: Estimation results. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

while the price effect is consistently negligible (−0.1 to −0.2 TWh), consistent with its near-zero price elasticity (−0.08) and the absence of tariff reform. The UEDT exhibits a sharp +8.2 TWh spike in 2020, followed by a reversal to −9.2 TWh in 2022, likely reflecting COVID-related structural disruptions and their unwinding. In Qatar, the UEDT is positive and growing throughout (1.0–1.3 TWh), reflecting structural transformation during the FIFA World Cup preparation phase, while price effects are more prominent than in other small GCC states, reaching −1.5 TWh in 2022, consistent with its relatively high price elasticity (−0.61). Bahrain's decomposition operates at a smaller scale (±1–3 TWh), with GDP as the primary positive driver (0.9–2.2 TWh in most years), consistent with its high income elasticity (1.37); a notable UEDT spike of +2.8 TWh dominates the 2019 change. In Oman, the UEDT is positive and steadily growing (1.2–1.6 TWh), suggesting persistent structural demand growth from ongoing industrialization, while 2020, the pandemic year, is the only period of negative actual

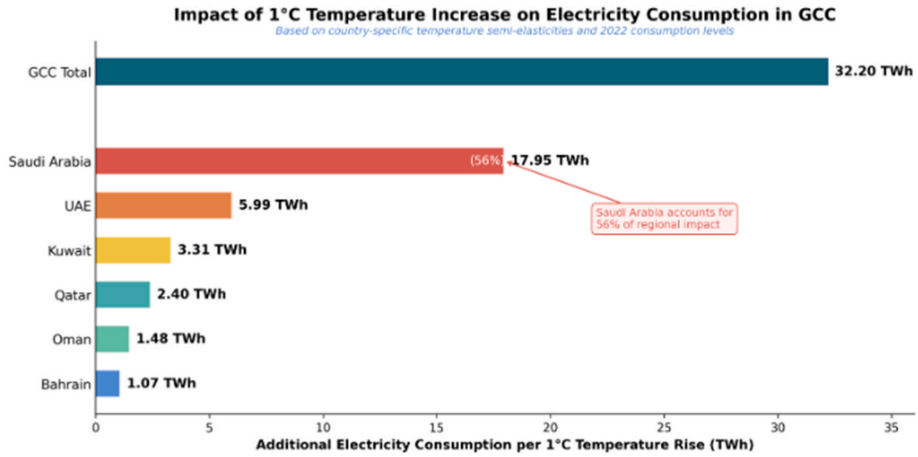


Fig. 8. *Impact of 1°C Temperature Increase on Electricity Consumption*
Source: Estimation results.

change (−0.5 TWh), driven by simultaneous negative contributions from population, GDP, and temperature.

7. Discussion of the findings

This section draws together the empirical findings to quantify their practical significance by assessing the impact of temperature on electricity demand, generation costs, and CO_2 emissions.

7.1. Temperature impact quantification

Fig. 8 quantifies the impact of a 1°C temperature increase on annual electricity consumption for each GCC country, based on 2022 consumption figures. Saudi Arabia leads, with an estimated additional demand of 17.95 TWh per year, accounting for approximately 56% of the total regional impact. This large contribution reflects both Saudi Arabia's high temperature sensitivity (5.8% semi-elasticity) and its substantial baseline consumption (309.4 TWh in 2022). The UAE would experience an additional 5.99 TWh, followed by Kuwait (3.31 TWh), Qatar (2.40 TWh), Oman (1.48 TWh), and Bahrain (1.07 TWh). The regional total of 32.2 TWh per year represents significant additional generation capacity requirements. These estimates highlight the magnitude of infrastructure investment needed to meet climate-induced demand growth while pursuing decarbonization objectives.

7.2. CO_2 emissions and electricity generation costs

Fig. 9 translates the temperature-driven increase in electricity demand into impacts on CO_2 emissions. Saudi Arabia's additional 17.95 TWh per year would generate approximately 10.21 Mt CO_2 per annum, reflecting its carbon intensity of 569 g CO_2/kWh from predominantly natural gas and oil-fired generation (IEA, 2024). The UAE would add 2.44 Mt CO_2, benefiting from its relatively lower carbon intensity (404 g CO_2/kWh) due to investments in nuclear power and renewable energy sources. Kuwait, Qatar, Oman, and Bahrain would contribute 1.95 Mt, 0.96 Mt, 0.66 Mt, and 0.63 Mt CO_2, respectively. The regional total of 16.83 Mt CO_2 per year represents a substantial annual increase in GCC emissions. The impact of an additional 1^0C of temperature on CO_2 emissions directly recalls the stated net-zero aspirations and highlights the urgency of decarbonizing electricity generation while managing temperature-driven demand growth.

Fig. 10 presents the additional electricity generation costs associated

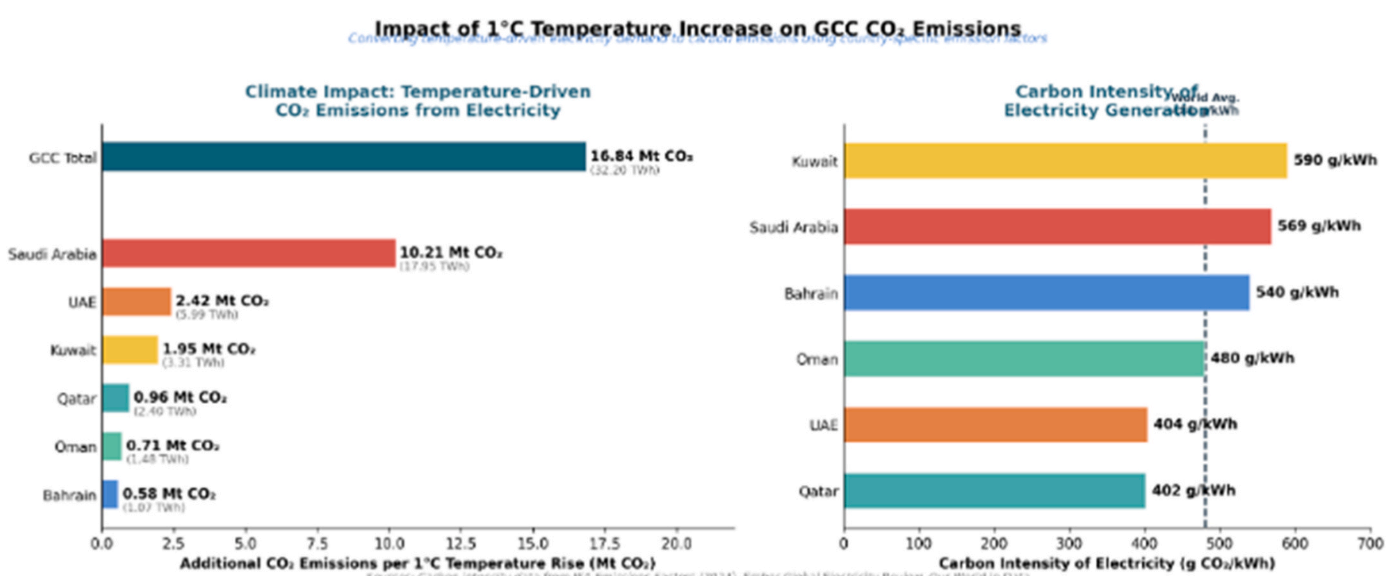


Fig. 9. *CO_2 Emissions Impact of 1°C Temperature Increase*
Source: Estimation results.

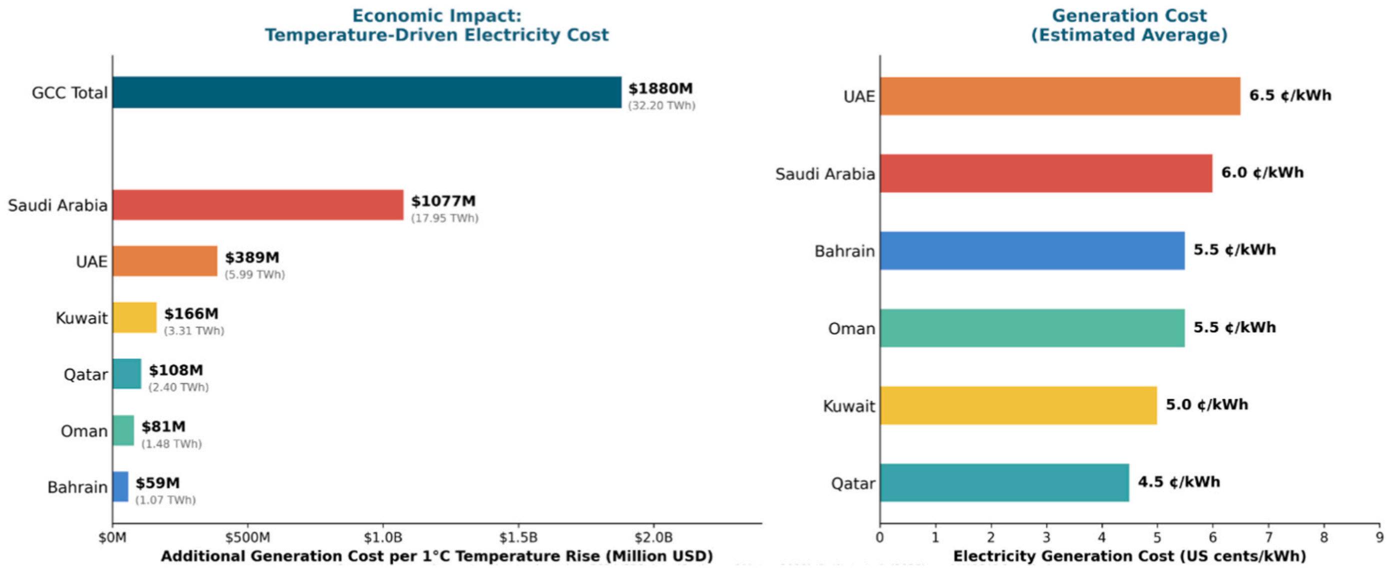


Fig. 10. *Additional Electricity Generation Cost of 1°C annual Temperature Increase*
Source: Estimation results based on relevant unit cost numbers from Gasim and Matar (2023), Petitet et al. (2025), IRENA (2024).

with temperature-driven increases in electricity demand. The generation cost per country is calculated as the product of the estimated additional electricity demand (TWh) and the country-specific average cost of electricity service (US cents per kWh). These cost estimates reflect the average cost of electricity service in each GCC country, encompassing generation, transmission, distribution, and capital expenditure. For Saudi Arabia, we use an estimate of 6.0 ¢/kWh, informed by the average electricity service cost reported by the Saudi Electricity Company (SEC) and the Saudi Electricity Regulatory Authority (SERA, former ECRA and WERA). Gasim and Matar (2023), using SERA and SEC financial data, document an average electricity service cost of 5.5 ¢/kWh for Saudi Arabia in 2019, comprising generation, transmission, distribution, capital expenses, and power purchase agreements with independent power producers. Our slightly higher estimate for 2022 reflects modest cost increases since 2019. For the remaining GCC countries, unit costs are estimated using a comparable methodology, adjusted for country-specific differences in generation mix, fuel procurement costs, and fleet efficiency, ranging from 4.5 ¢/kWh (Qatar) to 6.5 ¢/kWh (UAE). These estimates are consistent with the variable generation costs reported by Petitet et al. (2025), who find average variable costs of 3.5–5.9 ¢/kWh across GCC countries at international fuel prices. Our higher figures reflect the inclusion of capital recovery and network costs, in addition to variable generation costs. The additional electricity generation costs amount to $1.90 billion per annum. It is important to note that these estimates capture only the direct cost of producing the additional electricity required to meet cooling-driven demand growth. They do not include the broader economic costs of rising temperatures, such as reduced labor productivity, heat-related health expenditures, agricultural losses, water stress, or infrastructure damage. The generation cost estimates should therefore be interpreted as a lower bound on the total economic burden of climate warming in the GCC.

Saudi Arabia faces the most considerable cost burden, at approximately $1.07 billion per annum per 1°C increase, reflecting both its high demand impact and generation costs of roughly 6.0 ¢/kWh. The UAE would incur costs of $0.39 billion, while Kuwait ($0.17 billion), Qatar ($0.11 billion), Oman ($0.08 billion), and Bahrain ($0.06 billion) face smaller but still significant economic impacts. The regional total cost of $1.9 billion represents a recurring annual requirement that will continue to compound as warming persists.

7.3. Implications for net-zero aspirations

GCC countries have adopted net-zero targets ranging from 2050 (UAE, Oman) to 2060 (Saudi Arabia, Kuwait, Bahrain), with Qatar targeting to a 25% reduction in emissions by 2030, without a formal net-zero date. With temperatures projected to rise by 1.5–2°C by mid-century, temperature-driven electricity demand could increase by 40–80 TWh per annum regionally, substantially complicating the achievement of these targets without accelerated decarbonization of the power sector.

8. Conclusions

This study has estimated income, price, and temperature elasticities of electricity demand for the GCC countries over 1990-2022 using multiple cointegration techniques. The focus is on the temperature elasticities of electricity demand, as the region continues to warm at nearly three times the global average. Three principal findings emerge.

First, there is substantial cross-country heterogeneity in all three elasticities, reflecting differences in economic structure, subsidy regimes, tariff reform history, and climate exposure. Income elasticities range from 0.25 to 1.37, price elasticities from −0.08 to −0.61, and temperature semi-elasticities from 3.1% to 5.8%. The wide dispersion supports the country-specific modeling approach and points to the importance of nationally tailored policy responses.

Second, temperature is a major driver of electricity demand in the GCC. A 1°C increase generates approximately 32.2 TWh of annual additional demand, 16.8 Mt of CO_2 emissions per year, and $1.9 billion in annual generation costs across the region.

Third, the decomposition analysis reveals that population growth, income, and temperature are the dominant upward drivers of electricity consumption, while price effects remain limited by the persistence of subsidized tariffs in most countries. The visible demand response to Saudi Arabia price reforms in 2016 and 2018 and Qatar tariff adjustment in 2016 demonstrate that pricing can be an effective demand management instrument when reforms are sufficiently large and visible.

The elasticities estimated in this paper can help calibrate climate adaptation and resilience policy responses, aiming to improve building efficiency, deploy advanced cooling technologies, and continue pricing reforms, while simultaneously decarbonizing power generation through accelerated deployment of renewable energy and deeper regional grid integration.

8.1. Limitations and future research

Several limitations of this study merit acknowledgment. First, because consistent, long-span electricity price series are unavailable for most GCC countries, we use the Consumer Price Index (CPI) as a proxy for electricity prices in five of the six country models. Because energy constitutes a relatively small component of the overall CPI basket, and because GCC governments have historically subsidized electricity tariffs through administered block-rate structures that are infrequently adjusted and independent of broader consumer price movements, CPI and actual electricity prices may at times diverge. To assess the severity of this concern, we conducted two validation exercises (see Appendix A). For Saudi Arabia, where actual electricity price data are available over the full sample period, the correlation between the real electricity prices and the CPI is 0.80, and the linear trend slopes of the two series are identical (0.09), suggesting that CPI tracks the long-run evolution of electricity prices well; moreover, re-estimating the Saudi model with actual electricity prices yields qualitatively similar elasticity estimates. For Qatar, using electricity price data from Liddle (2022) over 2010–2019, the correlation is 0.60, and the trend slopes are comparable (0.27 vs. 0.33). While these results lend reasonable confidence to the CPI proxy in these two cases, we cannot verify the same correspondence for Bahrain, Kuwait, Oman, and the UAE, where comparable electricity price series are not yet publicly available. Future research should revisit the price elasticity estimates for these countries as country-specific electricity price data become available.

Second, the study relies on annual data from 1990 to 2022, a sample of 33 observations per country. While this is a common constraint in GCC energy demand research, the relatively short time span limits the power of unit root and cointegration tests and may affect the precision of the elasticity estimates, particularly for countries that experienced structural breaks in pricing policy (e.g., Saudi Arabia in 2016–2018, Qatar in 2016).

Third, using national annual average temperature as the climate variable, while standard in the literature, masks within-country spatial heterogeneity and seasonal variation in cooling demand. Future work could benefit from sub-national or monthly data to better capture the non-linear relationship between temperature extremes and electricity consumption.

CRediT authorship contribution statement

Jeyhun I. Mikayilov: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Sa'd Shannak:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Shahriyar Mukhtarov:** Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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We are grateful to anonymous referees, and the editors for their comments and suggestions that have helped to improve considerably the paper; nonetheless, we are of course responsible for all errors and omissions. Finally, the views expressed in this paper are those of the authors and do not necessarily represent the views of their affiliated institutions.

Appendix A. Validation of CPI as a Proxy for Electricity Prices

A key data limitation of this study is the use of the Consumer Price Index (CPI) as a proxy for electricity prices in five of the six GCC countries in the models. To assess the validity of this proxy, we conduct empirical validation exercises for the two countries where electricity price data are available: Saudi Arabia and Qatar.

Saudi Arabia. Real weighted electricity price data for Saudi Arabia are available for the full sample period (1990–2024) from Mikayilov and Al Mestneer (2024) and CPI data from Oxford Economics (2025). We compare the real electricity price series (Pele) with the CPI, both normalized to a common 2023 base year. Figure A1 plots the two series on a normalized scale. The correlation coefficient between the two series is 0.81, and the estimated slope coefficients of their linear trend lines are identical (0.09), indicating that CPI and electricity prices have evolved at effectively the same pace over the sample period.

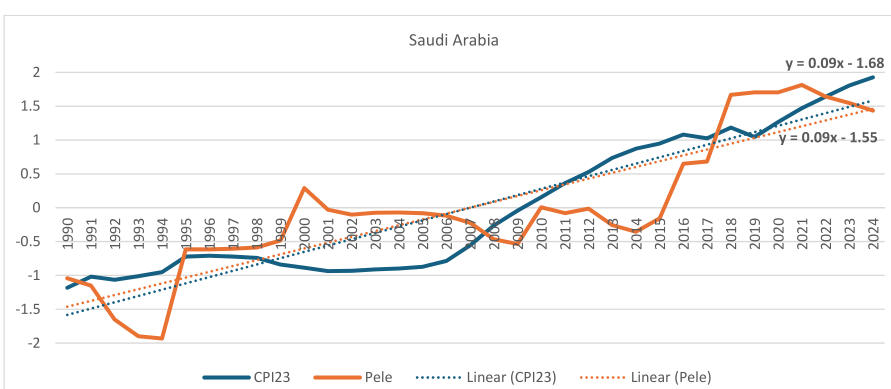

Fig. 1A. Electricity price and CPI, normalized scale, Saudi Arabia, 2023 = 100.
Source: Oxford Economics (2025), Mikayilov and Al Mestneer (2024).

Both series capture the structural break associated with Saudi Arabia's electricity price reforms in 2016 and 2018, though the electricity price series exhibits a sharper adjustment during the reform years, consistent with the expectation that CPI, as a broad basket measure, smooths over sector-specific tariff changes.

As a further check, we re-estimated Saudi Arabia's electricity demand model using CPI rather than actual electricity prices. The results are presented in Table A1.

Table A1
Saudi Arabia's model estimation results with CPI

Variable	Coefficient
Income	0.198
Price	−0.115
Temperature	0.118

The elasticity estimates are qualitatively similar across both specifications, lending empirical support for using CPI as a reasonable proxy in the Saudi case.

Qatar. Following a reviewer's suggestion, we obtained electricity price data for Qatar from Liddle (2022), covering the period 2010–2019. Although the overlapping sample is relatively short, the correlation between the real electricity prices and the CPI is 0.60, and the two series display broadly similar trajectories, including the structural break associated with Qatar's energy price reforms in 2016. The linear trend slopes are comparable (0.27 for electricity prices vs. 0.33 for CPI). Figure A2 plots the two series on a normalized scale (2015 = 100).

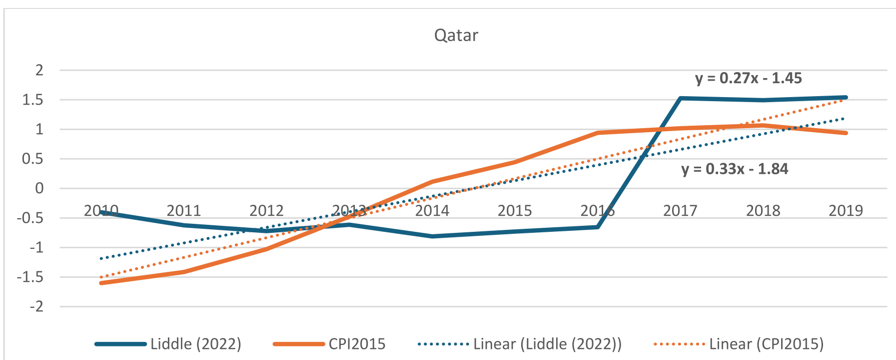

Fig. 2A. Electricity price (Liddle, 2022) and CPI, normalized scale, Qatar, 2015 = 100.
Source: Oxford Economics (2025), Liddle (2022).

The lower correlation between the two series likely reflects the smaller sample and the relatively larger magnitude of Qatar's tariff adjustment in 2016, which is partially smoothed in the CPI series.

Road fuel prices. Liddle and Huntington (2020) provide a road fuel price index with data for Bahrain, Kuwait, and the UAE. However, road fuel prices are unlikely to serve as a reliable proxy for electricity prices in the GCC context. Electricity generation in these economies is overwhelmingly based on natural gas, whereas road fuel prices reflect petroleum product markets subject to distinct subsidy regimes, pricing reform timelines, and demand-side dynamics. Moreover, the pass-through of international hydrocarbon prices to domestic retail tariffs differs substantially between the transport and power sectors, as electricity tariffs have historically been administered through block-rate structures that are infrequently adjusted and often independent of petroleum product price movements.

Implications. The validation exercises suggest that CPI tracks long-run electricity price trends reasonably well for Saudi Arabia and Qatar, though it may understate the magnitude of discrete tariff adjustments. For Bahrain, Kuwait, Oman, and the UAE, where comparable electricity price series are not publicly available, the same correspondence cannot be verified. The estimated price elasticities for these countries should accordingly be interpreted with caution and treated as conservative lower-bound estimates. Future research should revisit the price elasticity estimates as country-specific electricity price data become available for the remaining GCC states.

Appendix B. Robustness of Elasticity Estimates across Estimators

To verify the robustness of the baseline FMOLS results reported in Table 4, we re-estimate the long-run electricity demand model for each GCC country using Dynamic OLS (DOLS) and the General-to-Specific (GETS) approach via Autometrics. The results are presented in Table B1.

Table B1
Long-Run Elasticity Estimates (DOLS and GETS/Autometrics)

Variable	Bahrain		Kuwait		Oman		Qatar		Saudi Arabia		UAE	
	DOLS	Gets	DOLS	Gets	DOLS	Gets	DOLS	Gets	DOLS	Gets	DOLS	Gets
Income	1.580***	1.696***	0.366***	0.265**	0.235***	0.372**	0.674***	0.667***	0.620***	0.265*	0.382*	0.316***
Price	−0.235**	−0.148*	−0.081**	−0.070***	−0.284*	−0.085*	−0.554***	−0.829***	−0.273***	−0.143***	−0.436	−0.475***
Temperature	0.045*	0.040**	0.139***	0.133***	0.036*	0.040***	0.043*	0.031*	0.046***	0.086***	0.038	0.037*

Notes: ***, **, * indicate statistical significance at 1%, 5%, 10% levels. Temperature coefficients are semi-elasticities (% change per 1°C).
Source: Estimation results.

The three estimators yield broadly consistent results. All income elasticities are positive and statistically significant, ranging from 0.24 (Oman, DOLS) to 1.70 (Bahrain, GETS). Price elasticities are negative across all specifications, confirming the inelastic demand structure documented in the main text. Temperature semi-elasticities are positive throughout, with the GETS specification producing somewhat higher estimates for Kuwait (13.3%) and Saudi Arabia (8.6%) than FMOLS (4.2% and 5.8%, respectively), likely reflecting the different treatment of structural breaks and outliers in the GETS framework. The overall consistency across methods supports the reliability of the findings presented in the main text.

Appendix C. COVID-19 Robustness Check - Truncated Sample Estimates

To assess whether the inclusion of the pandemic-affected years 2020-2022 materially influences the estimated elasticities, we re-estimated the FMOLS models for all six GCC countries over the pre-pandemic period 1990-2019. Table C1 presents the truncated-sample estimates alongside the baseline (1990–2022) results.

Table C1
Long-Run Elasticity Estimates — Baseline vs. Pre-Pandemic Sample

Variable	Bahrain		Kuwait		Oman		Qatar		Saudi Arabia		UAE	
	baseline	robustness	baseline	robustness	baseline	robustness	baseline	robustness	baseline	robustness	baseline	robustness
Income	1.373***	1.281***	0.256***	0.252***	0.249***	0.232**	0.698***	0.702***	0.312***	0.440*	0.316***	0.274***
Price	−0.177**	−0.162**	−0.077**	−0.088***	−0.332*	−0.228*	−0.612***	−0.605***	−0.165***	−0.118***	−0.475***	−0.725***
Temperature	0.031**	0.033**	0.139***	0.042***	0.038*	0.029*	0.047**	0.047**	0.058***	0.054***	0.037*	0.029*

Notes: 'baseline' = 1990-2022; 'robustness = 1990-2019; ***, **, * indicate statistical significance at 1%, 5%, 10% levels. Temperature coefficients are semi-elasticities (% change per 1°C).
Source: Estimation results.

The results demonstrate that the main findings are robust to the exclusion of the pandemic period. Several observations merit discussion. First, all elasticities retain their expected signs across both sample periods for every country, confirming that the estimated relationships reflect estimated long-run structural patterns rather than artifacts of pandemic-era disruptions. Second, income elasticities are somewhat higher in the truncated sample for Saudi Arabia (0.44 vs. 0.31), consistent with the pandemic's temporary suppression of the income-consumption relationship through lockdowns and expatriate departures that simultaneously reduced economic activity and population. Third, the UAE's price elasticity increases notably from −0.48 to −0.73 in the truncated sample, suggesting that the post-pandemic recovery period, during which rising demand coincided with stable prices, may partially attenuate the measured price response in the full sample. Fourth, and most importantly for the central findings of this study, the temperature semi-elasticities are highly stable across the two samples: Saudi Arabia shows 5.8% vs. 5.4%, Qatar 4.7% vs. 4.7%, Kuwait 4.2% vs. 4.2%, Oman 3.8% vs. 2.9%, UAE 3.7% vs. 2.9%, and Bahrain 3.1% vs. 3.3%. This consistency confirms that the estimated climate sensitivity of electricity demand is not driven by the unusual demand patterns observed during the COVID-19 period.

Table C2
Long-Run Elasticity Estimates with average maximum temperature

Variable	Bahrain	Kuwait	Oman	Qatar	Saudi Arabia	UAE
Income	1.421***	0.244***	0.176***	0.741***	0.327**	0.338***
Price	−0.202***	−0.059*	−0.346***	−0.658***	−0.173***	−0.432**
Temperature	0.019*	0.031***	0.054**	0.015*	0.051**	0.041**

Notes: ***, **, * indicate statistical significance at 1%, 5%, 10% levels. Temperature coefficients are semi-elasticities (% change per 1°C).
Source: Estimation results.

Appendix D. Decadal trends in population and GDP growth rates

We reviewed population growth across the GCC countries (Figure D1) (IMF, 2025). The growth rates of GCC populations reveal a dynamic, non-uniform demographic history in the region. The most striking case of volatility was Qatar, which registered a peak growth rate (in the 10% range) during the 2000-2010 decade, only to fall sharply afterward. While countries across the Council, with perhaps the exception of the UAE and Oman, have experienced relatively robust (though high) growth compared to other middle-income developing countries through the most recent decade of 2010–20, a wider pattern emerges where average annual growth in each case is weaker than during their historical peaks.

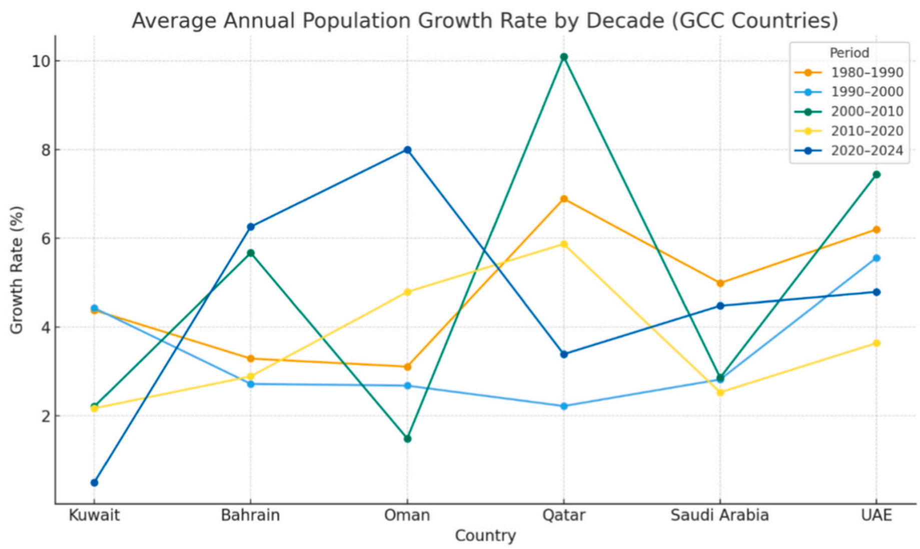

Fig. D1. Average Annual Population Growth Rate by Decade in the GCC countries.
Source: IMF, 2025.

Moreover, we have analyzed the annual GDP growth rates (Figure D2) (IMF, 2025). The GCC's past GDP growth performance shows severe exposure to global oil market cycles in two clear episodes. The 1980s were a period of severe economic contraction, with Kuwait, Saudi Arabia, and the UAE experiencing average negative growth rates as oil prices collapsed. This was followed by an enormous period of growth, including the even years of the 2000s boom, during which every country experienced high growth rates, with Qatar leading the region with a remarkable average annual growth rate of 12.6%, underscoring its significant influence on the gas market. For the post-2020 (and until 2028) outlook, the region's growth dynamic is forecast to revert to a range of 2.5% to 3.6%, trending toward normalization after an explosive economic process marked by turbulent, extreme up-and-down swings, into a more balanced and gradual long-term economic expansion characterized by more diversified profiles.

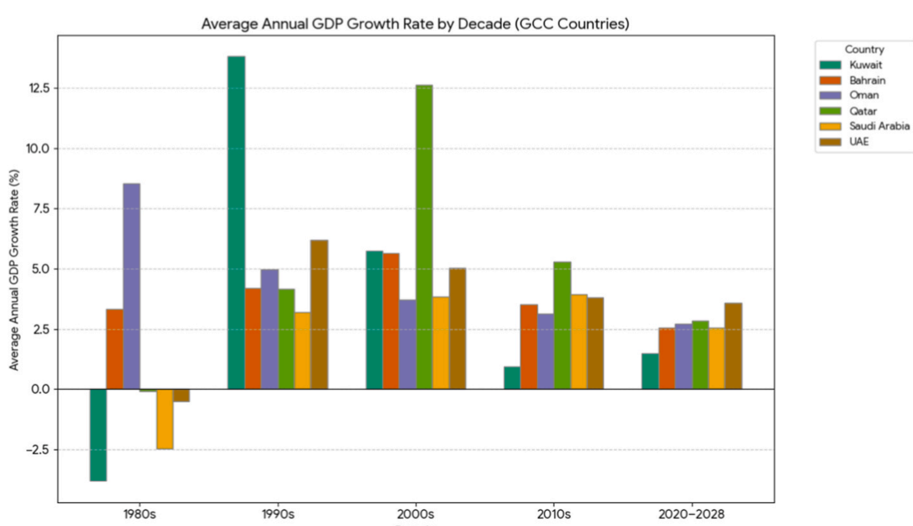

Fig. D2. Average Annual GDP Growth Rate by Decade in the GCC countries.
Source: IMF, 2025.

Data availability

Data will be made available on request.

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