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Regional Electricity Demand Impacts in Saudi Arabia: A Study on the Government Sector

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ABSTRACT

This research presents a comprehensive analysis of electricity demand factors in Saudi Arabia, focusing on the government sector across regions. The findings show that income statistically impacts government sector electricity demand in all regions. This impact aligns with regional development characteristics. Notably, more established regions exhibit smaller electricity demand responses to income changes, indicating a stabilization effect. This observation is consistent with economic reasoning and suggests that as regions develop economically, the increase in energy demand reaches a saturation point.

No significant correlation between price changes and government sector electricity demand across regions is discovered. This may be attributed to a commitment to maintaining high-quality working circumstances despite price fluctuations. Temperature conditions significantly impact public electricity consumption in the central region, where hotter weather increases electricity usage, potentially due to the availability of appliances like air conditioners in public facilities. The central region, hosting many government institutions, is the highest electricity consumer in the government sector.

In conclusion, this research offers valuable insights into the intricacies of electricity demand determinants in Saudi Arabia, particularly the government sector. It highlights the importance of considering regional variations and sector-specific characteristics when framing energy policies and strategies to implement economic and environmental sustainability.

Keywords: electricity demand, public sector, electricity prices, Saudi Arabia, econometric model; Autometrics.

JEL Classification: C32, O13, Q41, Q48

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1. INTRODUCTION

Energy consumption plays a critical role in nations' economic development and environmental sustainability worldwide. As a significant contributor to the overall energy demand, the government sector's electricity consumption patterns warrant closer examination, particularly in countries with rapidly growing economies and populations. As one of the world's largest oil producers (BP, 2021), Saudi Arabia is amid an energy transition aimed at diversifying its energy mix and reducing its dependence on fossil fuels (Saudi Vision, 2030). The government sector, which encompasses a wide range of public services and facilities, plays a significant role in shaping the country's overall energy demand. Understanding the regional differences in government electricity consumption patterns can provide valuable insights into the effectiveness of current energy policies and inform the development of targeted strategies for promoting energy efficiency, conservation, and sustainable energy practices nationwide. The main portion, 83%, of electricity consumed by the public sector goes to air conditioning, ventilation, heating, lighting, and refrigeration (Damoom et al., 2018). In other words, in the Kingdom's hot weather circumstances, more than half of the electricity consumed by the government sector is used to grant relevant indoor weather conditions (Damoom et al., 2018). In addition to achieving targeted economic growth, improving energy efficiency in the government sector is one of the main pillars of attaining a sustainable energy transition (Belaid & Massie, 2023).

Saudi Arabia has reformed electricity prices several times since 1984 to improve energy efficiency and rationalize consumption while keeping electricity affordable to end users. The relatively low electricity prices are one of the reasons for the gradual growth in electricity consumption in Saudi Arabia. This study first reviews the history of changes to electricity prices in the Kingdom. The study utilizes the newly collected price data to model electricity consumption by the government sector at a regional level.

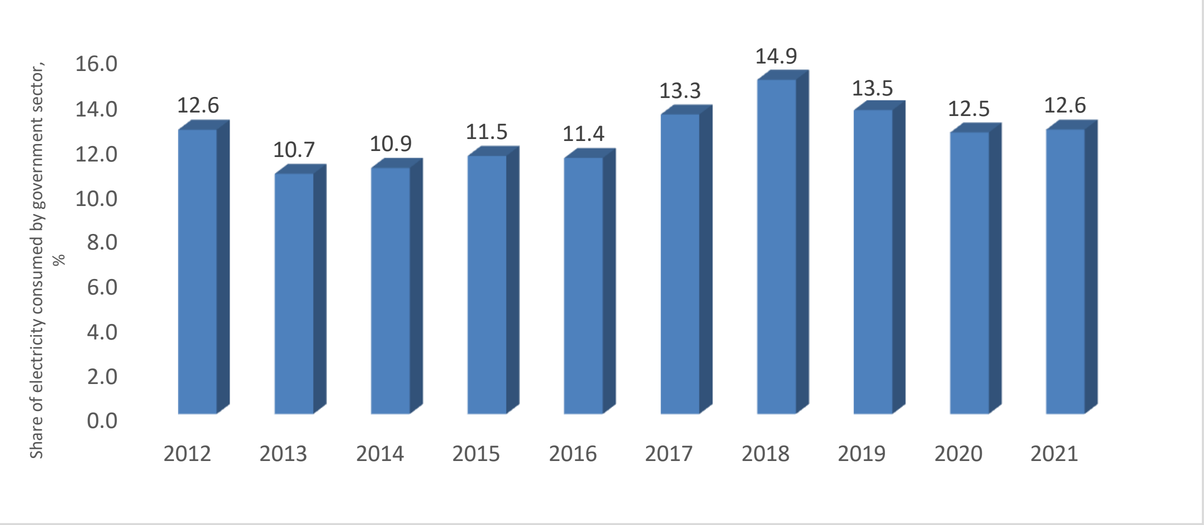
Literature shows a gap in the literature specifically focused on government electricity consumption at the regional level in Saudi Arabia; our study aims to address this gap by investigating the determinants of electricity demand across the Central, Eastern, Southern, and Western regions. This study investigates the factors influencing government electricity consumption in each region, considering income, population, climate, and regional development characteristics. By examining these factors and their impact on electricity demand, our analysis aims to shed light on each region's unique challenges and opportunities in pursuing sustainable energy management.

The remaining part of the paper is structured as follows: Section 2 presents the background of the public sector electricity consumption in Saudi Arabia, the evolution of electricity prices is given in Section 3, and Section 4 portrays the reviewed literature. The econometric methodology and data are described in Sections 5 and 6. Section 7 presents the results of empirical estimations, and section 8 discusses them. The conclusion and policy suggestions are given in Section 9.

1.1 Background of Government Sector Electricity Consumption Behavior

Based on the data for the last five years, the government sector contributes 13% of electricity consumed in the Kingdom. Figure 1 presents the historical path of the share of electricity consumed by the government sector in total consumed electricity in Saudi Arabia.

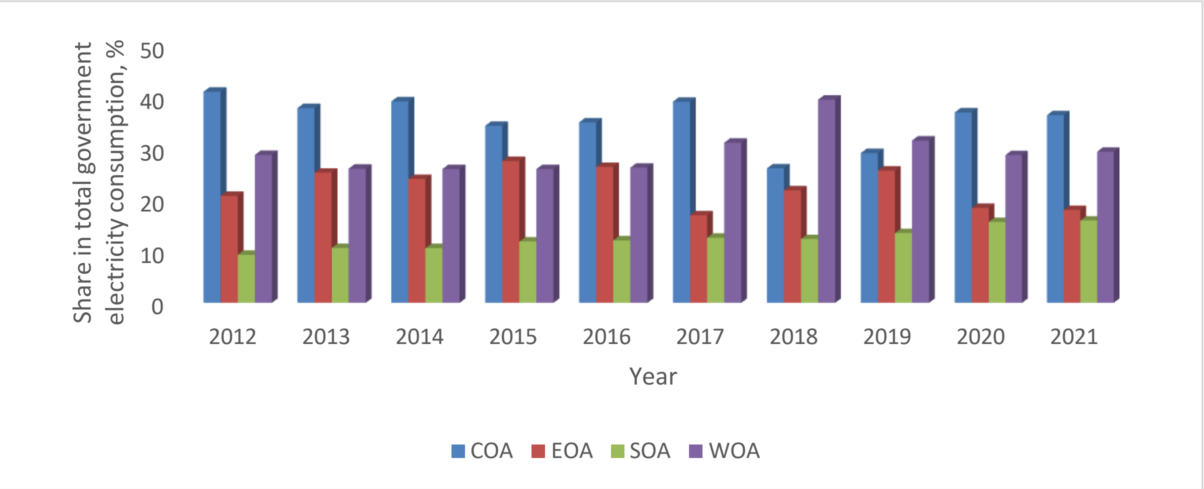
Figure 1. Share of the kingdom's total government sector electricity consumption.



Source: Authors' calculation based on SAMA (2022).

Figure 2 presents the government sector electricity consumption shares across regions. As can be seen from Figure 2, the central region is the main contributor to the electricity consumed by the public sector, with few exceptions. This is mainly because the region hosts many government institutions.

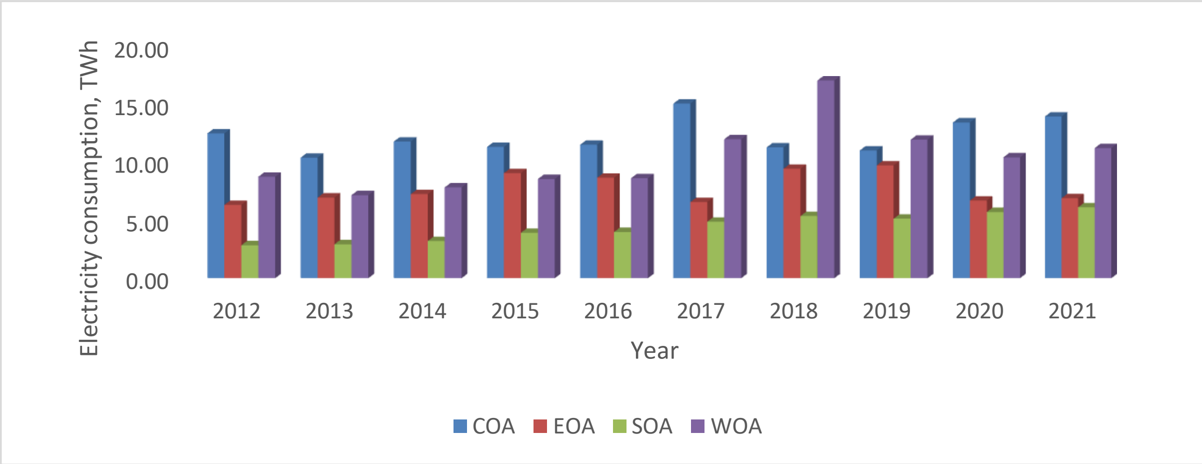
Figure 2. Government sector electricity consumption shares across regions.



Source: Authors' calculation based on SAMA (2022).

Figure 3 gives the government sector's regional electricity consumption numbers for the last ten years. As seen in Figure 3, the consumption numbers for electricity demonstrate relatively volatile behavior across regions and over time. The heterogeneity across the regions is mainly due to the different characteristics of the regions, such as climatic, socio-economic, demographic, etc.

Figure 3. Government sector electricity consumption across regions.



Source: SAMA (2022).

2. THE EVOLUTION OF ELECTRICITY PRICES

The pricing reforms started in 2016 have significantly impacted electricity consumption nationwide, with government customers typically paying higher rates than other customers. However, the impact of the pricing changes has been mitigated to some extent through various government subsidies and incentives, including those aimed at promoting energy efficiency and renewable energy. What follows first is the overall classification of electricity prices in Saudi Arabia. Then, the historical trajectories of government-sector electricity prices will be elaborated.

2.1. Overall classification of electricity prices

Electricity prices in Saudi Arabia vary according to the consumption segments and sectors. The major end-use sectors include residential, commercial, agricultural, industrial, government, charitable, healthcare, and educational institutions. The historical electricity price changes for the different sectors have been compiled into one data set. This data set is extended and more detailed than Mikayilov's (2023) and includes charitable, healthcare, and educational institutions.

Before 1984, different electricity prices were used across the different regions of Saudi Arabia. On November 23, 1984, the government introduced new tariffs that were consistent across the Kingdom, distinguishing between two different sectors: industry and non-industry (ECRA 2008). Changes in these tariffs occurred in 1985 in the residential, commercial, and government sectors and remained for seven years to 1992, followed by another change in 1995 that remained for five years. Below, we see the evolution of electricity prices for the government sector.

2.2 Electricity prices for the Government sector

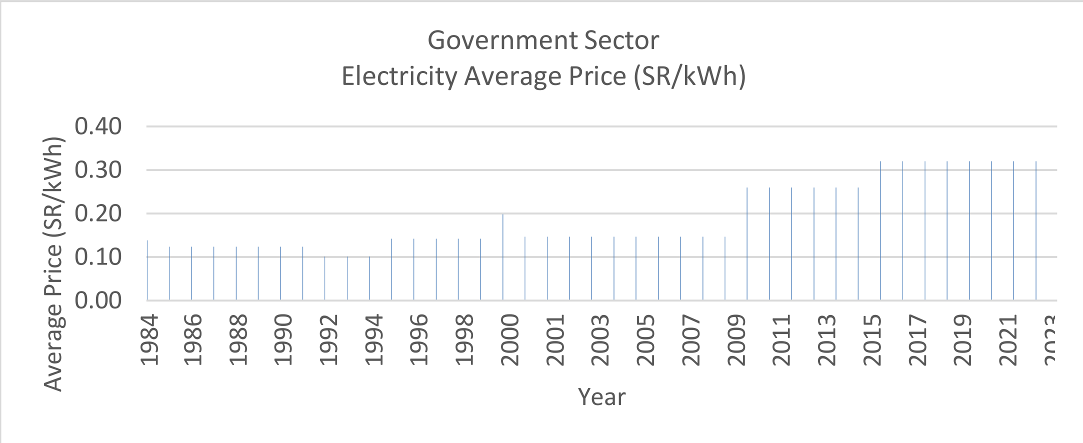
Electricity prices for the government sector in Saudi Arabia are subject to regulatory policies implemented by the Kingdom's Electricity and Cogeneration Regulatory Authority (ECRA).

The tariffs are set based on a standardized methodology that considers the cost of production, transmission, and distribution and investments in infrastructure and generation capacity.

As a result of the government's ongoing efforts to enhance the efficiency of the electricity sector, the tariff structure for electricity prices has been revised several times over the past few years. ECRA aims to ensure that electricity prices are fair and equitable, promoting sustainable economic growth while maintaining affordability for all customers.

The price for the government sector reached 0.32 Saudi Riyals per kilowatt-hour (SR/kWh) in 2016 and remained the same. The historical price data for the government sector is depicted in Figure 4.

Figure 4. Government sector electricity average prices.



Source: Authors' analysis based on the collected data.

After having an initial idea of the demand for electricity by the government sector across Saudi Arabia and the evolution of prices over time, the following section reviews the studies devoted to electricity demand modeling at a regional level.

3. LITERATURE REVIEW

Quite a few studies have explored electricity consumption patterns in Saudi Arabia, focusing on various sectors, factors, and regions. This literature review summarizes the research conducted on electricity consumption, particularly emphasizing electricity consumption at the regional level in Saudi Arabia. Using regional data, Mikayilov et al. (2020a, 2023a) explored the demand relationships for the total electricity consumption. They concluded that demand responses are heterogeneous across four regions of Saudi Arabia. Mikayilov et al. (2020b, 2022, 2023b) studied the regional electricity demand models for residential, industrial, and commercial sectors, respectively. Hasanov (2021) analyzed the industrial electricity consumption relationship at the aggregate level. Hasanov et al. (2022) modeled government electricity consumption at the aggregate level and did not deal with region-specific relationships. Similarly, Gasim et al. (2023) explored the aggregate sum of government and commercial electricity demand and did not investigate the demand relationships at a regional level.

As evident from the literature survey, no research paper explores the region-specific electricity demand relationships for the government sector. Given the fact that there is a gap in the literature, we are specifically focused on government electricity consumption at the regional level in Saudi Arabia. In addition, more target-oriented policies should be implemented based on sector and region-specific demand responses of drivers of electricity consumption. This, in turn, requires discovering the historical evolution path of demand behavior across regions and estimating the region-specific elasticities of government electricity demand. Considering the abovementioned points, our study aims to address this gap by investigating the determinants of electricity demand across the Central, Eastern, Southern, and Western regions. By focusing on regional analysis of sector-specific regional electricity demand behaviors, we anticipate contributing to understanding electricity consumption relationships in Saudi Arabia and informing targeted policy set-up.

4. MODEL SPECIFICATION AND ECONOMETRIC METHODOLOGY

For modeling the relationships, government sector electricity consumption is considered a function of income, the price of public electricity, and weather conditions. The mathematical expression of the relationship is as follows:

$$demand = f(income, price, temperature)\# \quad (1)$$

In estimations, the demand relationships are modeled in a dynamic form. The model specification is an autoregressive distributed lagged (ADL) form. Considering the sample size, the general model includes all variables with two lags. In other words, the used ADL specification can be expressed as follows:

$$de_t = \alpha_0 + \alpha_1 de_{t-1} + \alpha_2 de_{t-2} + \beta_0 y_t + \beta_1 y_{t-1} + \beta_2 y_{t-2} + \gamma_0 p_t + \gamma_1 p_{t-1} + \gamma_2 p_{t-2} + \theta_0 cdd_t + \theta_1 cdd_{t-1} + \theta_2 cdd_{t-1} + \vartheta_0 hdd_t + \vartheta_1 hdd_{t-1} + \vartheta_2 hdd_{t-2} + interventions_t + \varepsilon_t\# \quad (2)$$

Where, de_t is government sectors electricity consumption, at a regional level, y_t is income, p_t is electricity price, cdd_t and hdd_t are temperature variables standing for cooling and heating degree days. $interventions_t$ stand for region-specific intervention dummies, which the estimation technique will select. In other words, these are interventions impacting the electricity demand exogenously, and need to be captured via different types of dummy variables. For example, launching a government-initiated park or entertainment center might result in a shifting impact on demand. Moreover, postponing an ongoing project financed by the government due to abrupt changes in oil prices might suddenly change the demand behavior. The dummy variables considered and utilized are one-time impulse, the difference of impulse (blip), change in level (step), and break-in trend dummies. ε_t is an error term. All variables in equation (2) are in a logarithmic form.

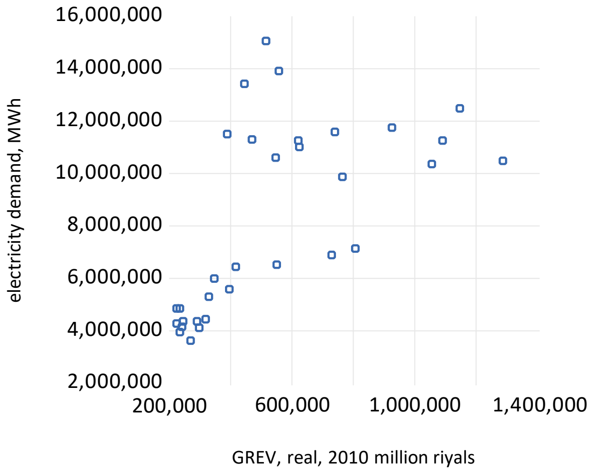
Unit-root properties of the variables are checked utilizing the Augmented Dickey-Fuller (Dickey and Fuller, 1981, ADF) test. The existence of the long-run relationship is tested using the Engle-Granger (Engle & Granger, 1987) cointegration test.

The General to Specific (Gets) modeling strategy (see Hendry and Doornik, 2014; Doornik and Hendry, 2018, inter alia) is employed for empirical estimations. In the Gets approach, starting with the general unrestricted model (specification), the final model has been selected via the Autometrics multipath block search machine-learning algorithm (see Doornik and Hendry, 2018, inter alia). This procedure consists of two steps. The algorithm creates dummy variables for each observation and chooses the intervention dummies in the first step, keeping the theory-related variables. The search goes through the theory-related variables in the second step, fixing the selected intervention dummies. The final model is selected based on the congruency criteria and diagnostic tests (see Hendry and Doornik, 2014; Doornik and Hendry, 2018, inter alia).

5. DATA

The region-specific government sector electricity consumption is modeled using econometric estimation techniques. The data sample used for the econometric estimations ranges from 1990 to 2021. The sample size is selected based on the availability of the electricity demand data for the government sector. Electricity demand is the Regional annual electricity demand by the government sector in megawatt-hours (MWh). The data for the 1990–2004 period is taken from SEC and for 2005-2021 from SAMA (2022). Electricity price is the real price of electricity for the government sector. The nominal price numbers are collected, as discussed in the previous sections. The nominal electricity price is converted to real, using the GDP deflator for the government sector. The GDP deflator data for the government sector is calculated using SAMA's nominal and real GDP data (2022). For the income proxy, we have examined different indicators. Namely, government revenues, public sector gross value added, gross domestic product, non-oil sector gross value added, total government expenditures, and public sector current expenditures have been utilized. These variables are used in total and per capita term relationships. Following the economic rationale, first, the public sector revenues are used. Since, most likely, its relatively volatile behavior, it did not produce promising results. For example, we presented in Figure 6 the scatter plot for the central region's public sector electricity consumption and government revenues. The form of the relationship between the two is blurry.

Figure 6. Scatter plot of public sector electricity consumption and government revenues, Central region.



Source: SAMA (2022)

Then, the other variables were examined. Since the used variables produce different results, we investigated both, which are "better" correlated with the government revenues and produce promising results for all the regions. To save space, only the analyses for the central region are reported. Table 1 presents the results of correlation analyses.

Table 1. Correlation analyses.

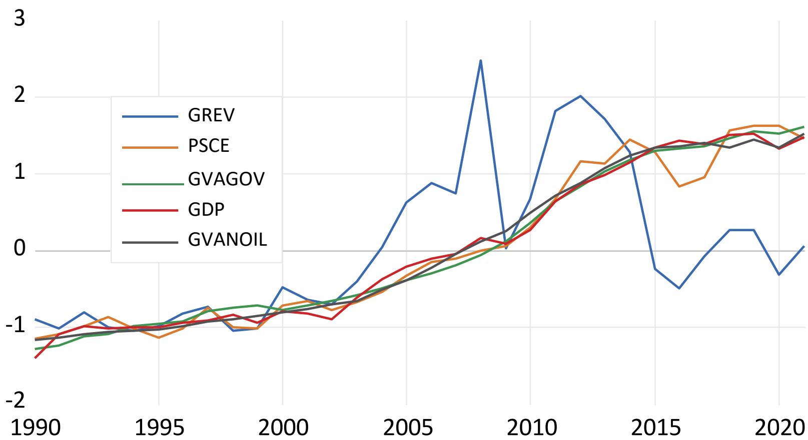
	GREV	PSCE	GVAGOV	GDP	GVANOIL
GREV	1.0000	0.5754	0.5051	0.5496	0.5527
PSCE	0.5754	1.0000	0.9835	0.9816	0.9835
GVAGOV	0.5051	0.9835	1.0000	0.9926	0.9952
GDP	0.5496	0.9816	0.9926	1.0000	0.9947
GVANOIL	0.5527	0.9835	0.9952	0.9947	1.0000

Notes: grev=government revenues, psce= public sector current expenditures, gvagov= gross value added in public administration, gdp=gross domestic product, gvanoil= non-oil sector gross value added.

Source: SAMA (2022).

As can be seen from Table 1, the highest correlation with government revenues is observed for the public sector's current expenditures. In addition, Figure 5 presents the plots of the potential income proxies.

Figure 6. Plots of income proxies, in normalized scale.



Source: SAMA (2022).

As seen in Figure 5, the public sector's current expenditures better "mimic" government revenues. From the modeling side, public sector current expenditures produce models with statistically relevant and economically interpretable outputs for all regions. Moreover, Durand-Lasserve and Karanfil (2023) found that government expenditures and revenues are highly correlated for oil-exporting countries. This finding also rationalizes using public sector current expenditures as an income proxy for the Saudi Arabian case to model government sector electricity consumption.

Therefore, the income variable is proxied with real public sector current expenditures in Millions of riyals. The nominal public sector current expenditures numbers are taken from SAMA (2022) and converted to real values using Consumer Price Index data (SAMA, 2022). The regional CDD and HDD data are updated based on Mikayilov et al. (2020). Table 2 presents the descriptive statistics for the utilized data.

Table 2: Descriptive Statistics

Variable/ region	Central				Eastern				Southern				Western			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
demand	15.823	0.459	15.112	16.526	15.462	0.338	14.469	16.089	14.220	0.841	13.061	15.624	15.435	0.661	13.892	16.650
income	12.819	0.523	12.074	13.550	a	a	a	a	a	a	a	a	a	a	a	a
price	-1.294	0.183	-1.611	-0.804	b	b	b	b	b	b	b	b	b	b	b	b
cdd	7.580	0.084	7.380	7.699	7.675	0.097	7.473	7.849	7.677	0.072	7.551	7.835	8.008	0.097	7.733	8.130

Notes: SD=standard deviation, min=minimum, max=maximum, a=the same income data is used for all the regions, b=price is the same for all regions.

Source: Autors' elaboration based on used data.

6. EMPIRICAL ESTIMATION RESULTS

First, the variables are tested for unit-root properties using the ADF test, and the results are provided in Table 3.

Table 3. Unit root test results.

Variable/region	Central		Eastern		Southern		Western	
	level	differenced	level	differenced	level	differenced	level	differenced
demand	-0.684	-7.716***	-1.628	-6.549***	0.793	-7.569***	-2.227	-6.365***
income	-0.163	-6.989***	a	a	a	a	a	a
price	-1.768	-7.418***	b	b	b	b	b	b
cdd	-1.697	-8.274***	-2.189	-10.811***	-1.847	-7.359***	-2.569	-8.384***

Notes: "***" indicates the rejection of the null hypothesis of "unit root" at a 1% significance level. a=the same income variable is used for all the regions. b=the same price variable is used for all the regions.

Source: Estimation results.

As Table 3 presents, all the variables are found to be stationary in a differenced form. Consequently, the variables are tested for cointegration, and the corresponding test results are presented in Table 4.

Table 4. Cointegration test results.

Region	Central	Eastern	Southern	Western
Test Statistic (EG)	-8.794**	-5.475***	-3.922**	-3.818**

Notes: "**" indicates rejection of the "no cointegration" null hypothesis at a 5% significance level.

Source: Estimation results.

The cointegration tests verified the existence of a long-run relationship for all the regions. Hence, as a next step, the long-run relationships are modeled utilizing specification (2) in the methodology section. The long-run estimation results are given in Table 5.

Table 5. Long-run estimation results.

Variable/region	Central	Eastern	Southern	Western
income	0.206***	0.499***	1.876***	1.001***
price	-	-	-	-
cdd	1.696***	-	-	-
hdd	-	-	-	-

Notes: Selected interventions for COA, DI#2017, SI#2002, TI#2006, TI#2007; for EOA SI#2017, SI#2019; for SOA II#2007; for WOA, no dummy is selected. "*", "**", and "***" indicate the significance of the coefficient at 10%, 5%, and 1% significance level, respectively. "-" = the variable does not have a statistically significant impact on the demand. II#t=impulse dummy, taking 1 at time t, and o otherwise; DI#t=differenced in impulse dummy, taking 1 for year t, and -1 for t+1; SI#t=step dummy taking 1 until year t and 0 after that; TI#t=break in trend dummy, break occurring at time t.

Source: Estimation results.

Table 5 details the results of diagnostic tests' results for the regional government electricity demand models. All the diagnostic results are in line with the assumptions for the residuals. Moreover, as seen in Table 6, the estimated models in sample fitting quality are pretty high.

Table 6. Diagnostics tests' results.

	AR 1-2 test	ARCH 1-1 test	Normality	Hetero test	RESET23 test	RSS	R^2
Central	1.792	0.022	2.464	1.117	1.045	0.038	0.993
Eastern	1.229	1.401	2.500	1.269	1.393	0.206	0.913
Southern	1.285	2.711	0.944	1.902	0.799	0.095	0.995
Western	0.250	1.043	1.971	0.629	0.685	0.724	0.928

Notes: AR = autocorrelation test (Godfrey, 1978); ARCH = autoregressive conditional heteroscedasticity test (Engle, 1982); Normality test = Doornik and Hansen (1994) normality test; Hetero test = heteroscedasticity test (White, 1980); RESET23 = Regression Specification Test (Ramsey James, 1969); RSS=residual sum of squares; R^2=coefficient of determination.

Source: Estimation results by authors

Table 5 shows that the government electricity demand does not respond to price in any region. Moreover, the weather conditions were found to impact only the central region significantly. In line with the theoretical expectations, the signs of income and weather conditions are found to have a positive (increasing) impact on government electricity consumption.

As discussed in the Literature Review section, Mikayilov et al. (2020b, 2022, 2023b) estimated sector-specific electricity demand models for Saudi Arabia at a regional level. Combining their findings with the current study results, Table 6 presents income and price elasticities for four sectors in the short- and long-run.

Table 7. Sectoral long- and short-run electricity demand elasticities at a regional level.

		Central		Eastern		Southern		Western	
		sr	lr	sr	lr	sr	lr	sr	lr
res	price	-0.10	-0.20	-	-0.46	-0.15	-0.25	-0.10	-0.23
	income	-	0.44	0.14	0.27	-	0.54	0.43	1.02
ind	price	-0.10	-0.18	-	-0.02 to -0.06	-	-0.25 to -0.15	-0.12	-0.12
	income	0.45	0.45	0.52	0.52	1.06	1.06	0.56	0.56
comm	price	-	-0.79	-	-0.18	-0.27	-0.56	-0.33	-1.25
	income	1.11	1.11	-	0.54	-	2.68	0.67	1.08
gov	price	-	-	-	-	-	-	-	-
	income	0.21	0.21	-	0.50	-	1.9	0.37	1.00

Notes: res=residential, ind=industrial, comm=commercial, gov=government, sr=short run, lr=long run, - =the elasticity is found statistically insignificant. All the reported elasticities are statistically significant.

Source: Mikayilov et al. (2020b, 2022, 2023b), and current studies estimation results.

7. DISCUSSION OF EMPIRICAL FINDINGS

The estimation results concluded that income statistically impacts government sector electricity demand in all regions. The impact of income is consistent with the regional development characteristics. In more established regions, the central and eastern regions' responses are smaller than the other regions' electricity demand responses to income changes. This finding is sound with the economic reasoning since increased energy needs follow economic well-being. After some level of increasing income-demand coincidence, an increase in income does not increase the demand further, and the response stabilizes (see, for example, Chang et al., 2014; Mikayilov et al., 2020). Therefore, the higher response of government electricity demand to income changes in southern and western regions is in line with this phenomenon. In the government sector, 83% of electricity goes to air conditioning, ventilation, heating, lighting, and refrigeration (Damoom et al., 2018). Considering the Saudi Arabian hot weather conditions, more than half of the electricity consumed by the government sector is used to grant relevant indoor weather conditions (Damoom et al., 2018). In parallel with the desired economic growth, efficient energy use in the government sector is one of the main pillars of achieving a sustainable energy transition (Belaid & Massie, 2023). To achieve this goal, the Saudi government established The National Energy Service Company, which aims to retrofit all government buildings and public utilities considering efficiency requirements. The plan occupies 110,000 governmental buildings and 35,000 public schools. Until recently, almost 9% of the target has been realized (Ministry of Energy, 2022).

The findings indicated no correlation between price changes and government sector electricity demand across all regions. This might be due to the trend of providing high-quality working conditions in line with the increasing economic circumstances. Moreover, the impact of the thought that "what belongs to everyone belongs to no one" (Steensma & Lyles, 2000) is also undeniable. The impact of the temperature conditions is statistically significant only in the central region. In other words, when the weather conditions get hotter in the central region, public consumers increase electricity usage. This might be due to the availability of appliances, such as ACs, in public facilities when needed. In addition, the central region hosting many government institutions in the capital, Riyadh, is the highest electricity consumer in the government sector, with around 36% in 2021.

As seen from Table 7, in line with the conventional economic reasoning, in none of the regions, short-run elasticities are not bigger than the long-run counterparts. Considering the long-run elasticities from Table 7 and shares of sectoral electricity consumption across regions from Mikayilov and Darandary (2023b), we can calculate region-specific weighted elasticities. The calculated weighted income and price elasticities for COA, EOA, SOA, and WOA are 0.51, 0.41, 1.10, and 0.89. The corresponding price elasticities are -0.27, -0.19, -0.23, and -0.33, respectively. These results align with the region's overall development level and support the findings of Mikayilov and Darandary (2023a). The obtained weighted elasticities allow us to conclude that the Southern region is the most responsive region to changes in income. The Western region demonstrates the highest responsiveness to price changes across regions.

8. CONCLUSION AND POLICY SUGGESTIONS

This study has two objectives: First, it investigates the evolution of government electricity prices over time, considering the last three decades.

Then, using the collected data set, explore the relationship between government sector electricity consumption and its drivers. Following the first objective, we have created a comprehensive data set for sectoral electricity prices covering the last three decades. Regarding the second objective, we have estimated relationships between the regional electricity demand for the government sector and its main drivers.

Based on the estimation results, it is evident that income significantly impacts government sector electricity demand across all regions. The income-demand relationship is inelastic in more established regions, such as the central and eastern regions, while it remains higher in the southern and western regions. Most of the electricity consumed in the government sector goes towards air conditioning, ventilation, heating, lighting, and refrigeration, mainly to maintain suitable indoor conditions in the hot Saudi Arabian climate. Additionally, government sector electricity demand does not respond to price changes, possibly due to the desire to maintain high-quality working conditions and the "tragedy of the commons" phenomenon.

Based on the findings of the study, the following policy suggestions can be made:

Consider the region-specific demand responses to income changes in making policy decisions. The higher demand responses to income changes in the two regions should/could be considered in investment decisions. Boost a culture of energy responsibility within the government sector via education and awareness promotions. This can help reduce the "tragedy of the commons" phenomenon and encourage government employees to be more alert to their energy consumption behaviors.

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