King Abdullah Petroleum Studies and Research Center

Electricity Demand Modeling in Saudi Arabia:

Do Regional Differences Matter?

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Key Points

The study finds that income, price and population are the three main drivers of electricity demand in each of Saudi Arabia's regions (central, eastern, southern and western).

Although the impacts vary across the regions, the estimated elasticities are all statistically significant in both the long and short run, and they have the expected signs for all the regions.

The income, price and population elasticities range from 0.10 to 0.93, from -0.61 to -0.06, and from 0.24 to 0.95, respectively, across the regions in the long run. In the short run, these intervals are (0.05, 0.47), (-0.27, -0.01) and (0.13, 1.49), respectively, for income, price and population across the regions.

The relatively low price elasticity in the southern region could be explained by its lower levels of income.

The southern region witnesses significant emigration, and population increases are mainly driven by births, which could explain this region's lower population elasticity.

The southern and eastern regions' lower income elasticities are potentially explained by the economic characteristics of these regions.

The findings reported in this paper may give policymakers insights into the potential regional impact of changes to electricity prices, income and population patterns.

Summary

Energy is a pervasive input to all business and recreational activities. As such, total energy demand is an important indicator that helps explain the pattern of economic development within a country. Identifying and understanding the key determinants of electricity demand is therefore important for the economic prosperity of a country, since the availability of reliable electricity directly affects the prospects of economic development. With mega projects already in the works in Saudi Arabia, and Saudi Vision 2030's National Industrial Development and Logistics Program (NIDLP 2019) being implemented, understanding the Kingdom's existing and projected patterns of electricity demand is arguably more important now than ever before.

While an investigation of the determinants of aggregate electricity demand in the Kingdom is necessary, this topic has already been addressed in the existing literature to some extent (Atalla and Hunt [2016], *inter alia*).

The objective of this research is to understand the determinants that shape electricity consumption over time in Saudi Arabia's central, eastern, southern and western regions, and to provide relevant policy recommendations. These are the Saudi Electricity Company's (SEC's) operating regions, and the sum of these four regions' consumption equals the Kingdom's total electricity consumption.

We were motivated to conduct electricity consumption analysis at the regional level for the following reasons. First, the regional dimension is important because of the differences in weather patterns (and the consequent electricity demand profiles) across the country. Second, the distribution of residential, commercial, and industrial activities differs across the regions, and this may imply different relationships between electricity consumption and its drivers. For example, in the eastern region, electricity consumption is mainly industry-driven, whereas in the western region, home to the holy cities of Makkah and Madinah, electricity consumption is mostly population-driven (SAMA 2019). Third, the implementation of the mega projects mentioned above will also have implications for regional electricity demand. Finally, recent analysis shows that different regions have reacted differently to the electricity price reform, one of the key initiatives in Saudi Vision 2030's Fiscal Balance Program (Alyamani et al. 2019).

Analyzing Saudi Arabia's electricity demand regionally constitutes a novel and significant contribution to the literature in the following ways. First, to the best of our knowledge, very few studies examine the determinants of electricity demand at the regional level in the Kingdom. Alyamani et al. (2019) considered regional aspects of electricity consumption. However, they only considered residential electricity consumption and did just a descriptive analysis. Diabi (1998) examined total electricity consumption for the five operating regions of the SEC from 1980-1992. However, this study was based on a panel analysis, which differs from the time series analysis that we conduct in this research. Additionally, Diabi did not address integration-cointegration and other properties of the data used, such as cross-sectional dependency, which can lead to serious issues such as bias and inconsistencies, and thus provide misleading policy recommendations. Second, this study investigates the demand for electricity at a disaggregated regional level, which takes into account the region-specific features of electricity demand behavior. Third, this paper takes into account the impact of demographic factors that may play significant roles in electricity demand formation. Fourth, it uses recent data, which partially enables us to see the impact of the ongoing energy price

reforms and the consequences of the low oil price environment on electricity demand.

The Kingdom is currently transitioning from a heavily subsidized electricity price environment to a market-based price environment, with the gradual phase-out of subsidies. It is important to consider the impact of this transition from a regional perspective. The findings reported in this study will help facilitate a better understanding of the regional impact of different price policy scenarios and changes in population and income on electricity demand.

The findings presented in this paper could also be useful in determining which regions require transitional support in order to alleviate some of the financial hardships associated with rising electricity prices, and how much support is needed.[1]

This paper employs a cointegration and equilibrium error correction (ECM) methodology to develop long- and short-run price, income and demographic elasticities for regional electricity demand.

The study concludes that income, price and population are the main drivers of electricity demand at a regional level, as theoretically expected.

Although the impacts vary across regions, the estimated elasticities are all statistically significant in both the long and short run and have the expected signs for all the regions. The long-run income, price and population elasticities range from 0.10 to 0.93, from -0.61 to -0.06, and from 0.24 to 0.95, respectively, across the regions.
In the short run, these intervals are (0.05, 0.47), (-0.27, -0.01) and (0.13, 1.49) for income, price and population, respectively, across the regions. The obtained speed of adjustment (SoA) coefficients are significant in all cases, indicating the short-run deviations from the long-run relationship converge back to the equilibrium path. Table 1 summarizes the short- and long-run electricity demand elasticities by region.

The rest of the paper is structured as follows: section 1 reviews the literature on electricity demand modeling for Saudi Arabia; section 2 outlines the theoretical framework; section 3 briefly describes the methodology used, and section 4 presents the data. The estimation results are presented in section 5. In section 6, we discuss our key findings, while section 7 concludes the study and provides the policy implications where we link our findings to the current policy environment.

Table 1. Short-run and long-run elasticities by region.

		Dependent variable: electricity demand by region			
		SEC operating area			
		Central	Eastern	Southern	Western
Income	short run	(0.152, 0.414)	(0.054,0.182)	(0.075, 0.221)	(0.159, 0.471)
	long run	(0.403, 0.931)	(0.102, 0.204)	(0.120, 0.360)	(0.426, 0.470)
Price	short run	(-0.079, -0.013)	(-0.234, -0.088)	(-0.274, -0.150)	(-0.103, -0.029)
	long run	(-0.580, -0.362)	(-0.628, -0.356)	(-0.132, -0.060)	(-0.607, -0.427)
Population	short run	(0.128, 0.616)	(0.168, 0.412)	(0.755, 1.485)	(0.338, 0.600)
	long run	(0.243, 0.661)	(0.771, 0.947)	(0.335, 0.645)	(0.776, 0.840)

Literature Review

In this section, we highlight some of the key trends in the literature on residential, industrial and total electricity consumption in Saudi Arabia. To the best of our knowledge, only two studies have analyzed regional electricity consumption in Saudi Arabia. A recent study by Alyamani et al. (2019) discussed regional aspects of electricity consumption in the Kingdom's residential sector. Diabi (1998) studied total electricity consumption for the five operating regions of the Saudi Electricity Company (SEC), employing data from 1980 to 1992. As the study is quite dated, its findings might not reflect the current electricity demand behavior due to the substantial changes in the country's economic development. Diabi (1998) uses panel estimation techniques without performing integration-cointegration analyses and did not address the potential cross-sectional dependency within regions. These limitations might result in biased estimation results and, consequently, misleading conclusions.

The studies investigating electricity consumption employed a wide range of analytical techniques that are not necessarily quantitative or econometrically sound. We found studies that focused on qualitative analysis, Granger causality analysis, simulations based on optimization models, and a range of econometric estimation methods.

For example, both Jun (2013) (who simply described Saudi Arabia's energy outlook) and Alrashed and Asif (2014), who conducted a survey analysis of residential electricity consumption (REC) in the Kingdom's Eastern Province, provide a qualitative analysis.

Matar (2017) and Matar and Anwer (2017) are examples of studies that adopted a simulation-based approach when investigating electricity consumption. Both studies explored the impact of electricity price changes in the Kingdom on residential electricity consumption in 2011 and 2015. In both studies, the simulations were conducted using an optimization-based partial equilibrium model. They did not explicitly consider income and demographic effects, and no elasticities were reported due to the nature of the studies.

Since this review focuses on econometric studies, reflecting the nature of the research presented in this paper, we will review the existing literature with an emphasis on the type of data used, the econometric methodology and the specifications employed, and the empirical analysis adopted (e.g., whether a study addressed stochastic properties of the data).

We compare the model specifications with the standard specification as dictated by econometric theory, which requires that we account for income, price and demographic effects (Beenstock and Dalziel [1986]; Liddle and Lung [2010]; Hasanov [2019], *inter alia*). This is important because the results from studies that do not account for all factors could potentially contain some omitted variable biases. Some studies, such as Alabbas and Nyangon (2016), have shown that the weather is an important determinant of residential electricity consumption.

Some studies have investigated industrial electricity demand in Saudi Arabia. Al-Sahlawi (1999) utilized aggregate time series data, while Eltony and Mohammad (1993) and Liddle and Lung (2010) utilized country-level panel data but did not report Saudi Arabia-specific estimates. In their specifications, Al-Sahlawi (1999) considered only income, Eltony and Mohammad (1993) considered income and price, and Liddle and Lung (2010) considered only urbanization rates. More recently, Hasanov (2019) studied the determinants of industrial electricity demand for Saudi Arabia by analyzing the core drivers of electricity consumption in the Kingdom's industrial sector.

As mentioned earlier, the results from studies that do not account for income, price and demographic effects might be biased. The four studies mentioned above do not account for these three factors and may contain some biases as a result. Furthermore, Al-Sahlawi (1999) and Eltony and Mohammad (1993) did not consider the integration-cointegration properties of the variables included in their analysis before using ordinary least squares (OLS) estimation. Therefore, their results might be biased from the spurious regression perspective. In addition, both studies are quite old, and recent data might demonstrate relationships differ between the variables of interest.

Next, we turn our attention to key studies on residential electricity demand. Some studies on this subject have a regional focus on the Gulf Cooperation Council (GCC) as a region, without focusing on the regions within Saudi Arabia, as we do in this study. The earliest study we found was Eltony and Mohammad (1993), who examined residential electricity demand for a panel of GCC countries, including Saudi Arabia, finding long-run income and price elasticities of 0.20 and -0.14, respectively. The study did not explicitly account for demographic effects. Al-Sahlawi (1999) estimated the short-run (and long-run) income and price elasticities of residential electricity demand as 0.13 (0.70) and -0.10 (-0.50), respectively. This study did not explicitly account for demographic effects. Both studies used OLS and did not account for the integration-cointegration properties of the variables.

Atalla and Hunt (2016) use a structural time series model (STSM) and data from 1985-2012 to investigate residential electricity consumption in GCC countries. Unlike other studies examined thus far, they account for all three factors required to explain residential electricity consumption. They also used cooling and heating degree day variables as proxies for weather conditions. They found the following long-run elasticities for Saudi Arabia: 0.48 for income, -0.16 for price, and 0.80 for population, which represents the demographic effect. The study also concludes that the short-run price and population elasticities are -0.16 and 4.20, respectively, while income does not affect demand in the short run.

Hasanov et al. (2017) use an error correction model and panel data for a number of oil exporting countries, including Saudi Arabia, to investigate the relationship between GDP, residential electricity consumption, foreign direct investment and employment. One of their key findings was that employment Granger causes residential electricity consumption in the short run.

Several studies model total electricity consumption in Saudi Arabia. Al-Faris (2002) used a vector error correction model (VECM) approach and data from 1970 to 1997 to find long-run (short-run) income and price elasticities for the Kingdom of 0.05 (1.65) and -0.04 (-1.24), respectively. Narayan and Smyth (2009), using data from 1974-2002 and fully modified ordinary least squares (FMOLS), reported long run income elasticity of electricity consumption for the Kingdom of -3.07. In addition, the paper does not explain or interpret its finding of an unusual negative and substantially higher income elasticity.

Liddle and Lung (2010), Karanfil and Li (2015) and Mohammadi and Amin (2015) use ECM and panel data for many countries, including Saudi Arabia, to investigate the causal relationship between total electricity consumption and urbanization. They found that gross domestic product (GDP) per capita and urbanization Granger cause the total electricity consumption per capita. Similarly, Salahuddin et al. (2015), using panel data for GCC countries, found that GDP per capita Granger causes total electricity consumption per capita and reported a long-run income elasticity of 0.41.

Diabi (1998) analyzed regional total electricity consumption in Saudi Arabia based on panel data (1980-1992) for five regions (central, western, eastern, southern and northern). The study compared the results of different estimation methods (OLS, cross-sectionally correlated and timewise autoregressive model [CHTA], cross-sectionally heteroskedastic and timewise autoregressive model [CCTA], fixed effect [FE], random effect [RE] and maximum likelihood estimation [MLE]) and used the urbanization rate to account for income, price and demographic effects. It reported long-run elasticities for the Kingdom of 0.11 to 0.49 for income, -0.14 to 0.00 for price and 0.93 to 1.30 for urbanization. The corresponding short-run elasticities for income, price and urbanization were 0.05 to 0.33, -0.12 to 0.00, and 0.62 to 1.10, respectively.

In summary, a number of studies examine residential, industrial and total electricity consumption in Saudi Arabia. However, to the best of our knowledge, no studies examine total electricity consumption on a regional basis within the Kingdom. Considering this fact, the current study aims to investigate the determinants of electricity demand in Saudi Arabia at the regional level using different cointegration techniques.

Theoretical Framework

We use a standard formulation suggested by the demand-side approach and the stochastic impacts by regression on population, affluence and technology (STIRPAT) framework:

Electricity use = F (price, income, population)

Where ***electricity use*** is the total regional electricity demand, ***income*** is an income proxy, ***population*** is the population size of a given region and ***price*** is the real electricity price.

The functional relationship can be formulated as follows:

$$\textit{Electricity use} = \alpha_0 + \alpha_1 \textit{ income} + \alpha_2 \textit{ population} + \alpha_3 \textit{ price}$$

Increases in income and population, in turn, increase electricity demand, while price increases negatively affect the demand for electricity. As such, the expected signs for the coefficients α_1, and α_2 are positive, while α_3 is expected to be negative.

All the variables are in logarithmic form in the above specification. Hence, the coefficients are elasticities, which capture the percentage change in electricity use as a result of a 1% change in the variable considered.

Methodology

The paper uses cointegration techniques such as dynamic ordinary least squares (DOLS), canonical cointegration regression (CCR) and FMOLS to estimate the long-run relationships between the variables of interest. To estimate the short-run elasticities and speed of adjustment (SoA), we used ECM in the general-to-specific modeling strategy (Gets) framework (Campos, Ericsson, and Hendry 2005; Hendry, Johansen, and Santos 2008; Doornik and Hendry 2009; Doornik 2009; Doornik and Hendry 2018). In addition, because we are using time series data, the variables should be tested for their integration properties; the Dickey-Fuller (1981) unit root test is used for this exercise. For cointegration exercises, we used the Engle-Granger (1987) cointegration test. Because the aforementioned econometric methods and tests are widely used and well known to researchers, we do not describe them here. Interested readers can refer to Saikkonen (1992) and Stock and Watson (1993) for a description of DOLS, Phillips and Hansen (1990) for a description of FMOLS, and Park (1992) for a description of the CCR method.

Data

In this section, we describe the data used in our analysis, including descriptive statistics and the technical properties of the data.

The paper uses annual time series data for the sample from 1990 to 2016, chosen based on the data availability. The data used in the study are described below:

Electricity use represents regional electricity consumption in each of the four regions measured in megawatthours (MWh), taken from the SEC.

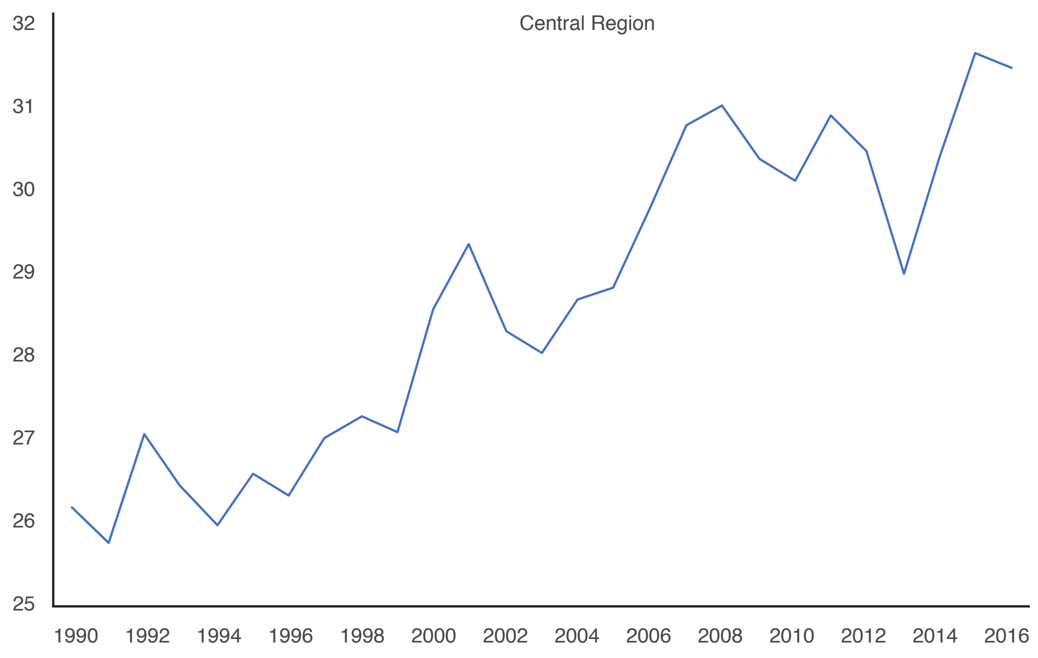
Price is the regional real weighted average electricity price in Saudi riyals (SAR) per tonne of oil equivalent (TOE) (weighted based on the regional consumption types). The consumer price index (CPI) (index 2010=100) and the GDP deflator (PGDP) (2010=100) values are used to convert nominal electricity prices to real values.[2] CPI data is taken from the Saudi Arabian Monetary Authority (SAMA 2017). PGDP data is taken from the General Authority for Statistics (GaStat 2018). Nominal electricity price is the nationwide or aggregate price, as Saudi Arabia does not apply different electricity prices to different regions.

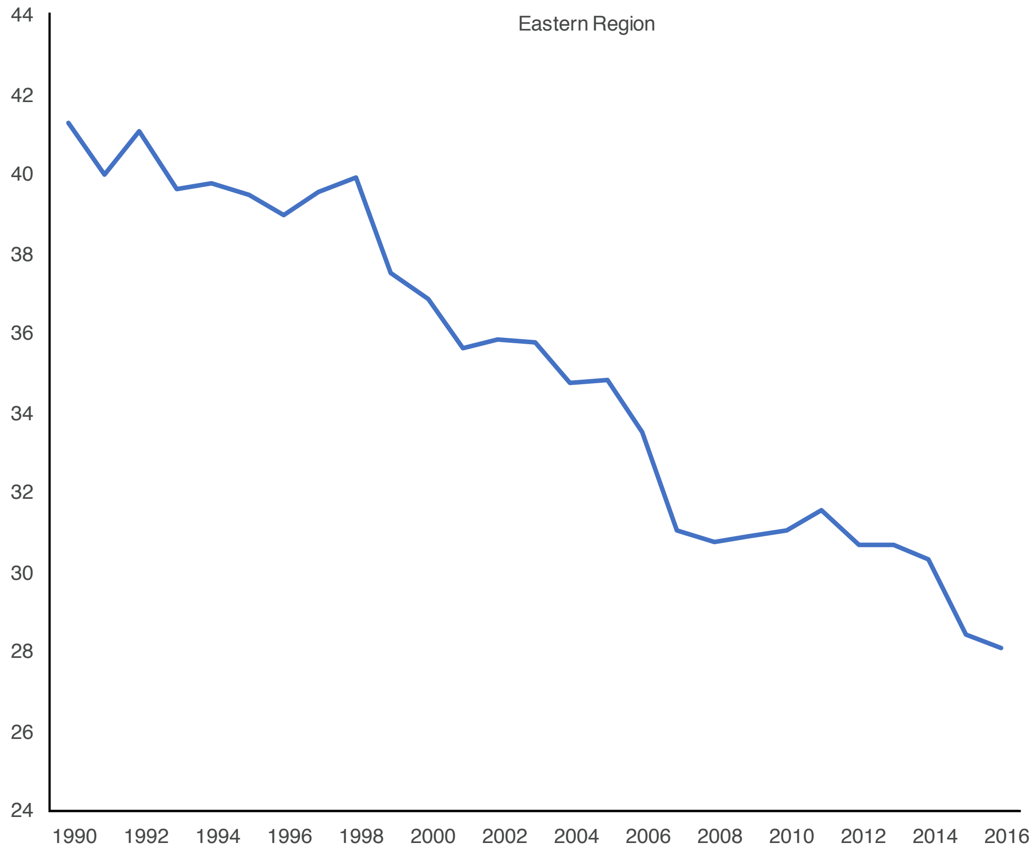
Income is proxied by GDP and disposable income (DI), both in million SAR at 2010 prices. GDP data is taken from GaStat (2018). DI data was calculated by KAPSARC researchers.

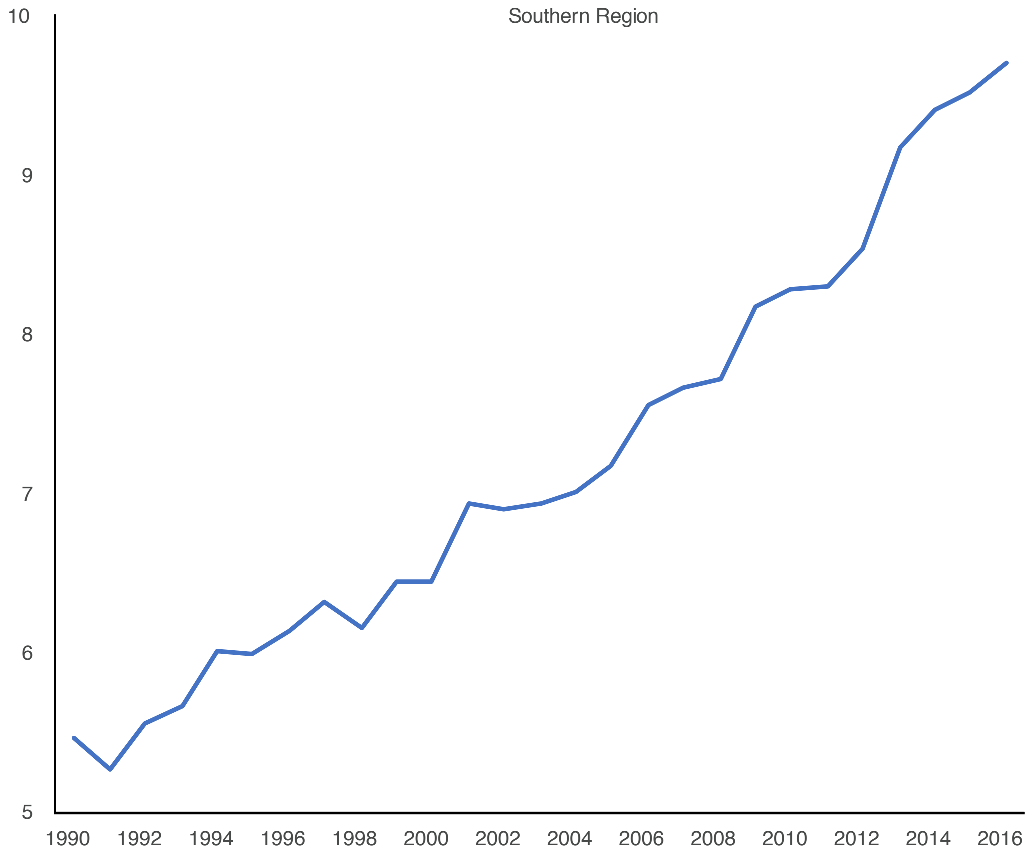
Population is the regional population, in people, as a proxy for the demographic factors. This data was aggregated from the data for Saudi Arabia's 13 provinces provided by SAMA (SAMA 2019).

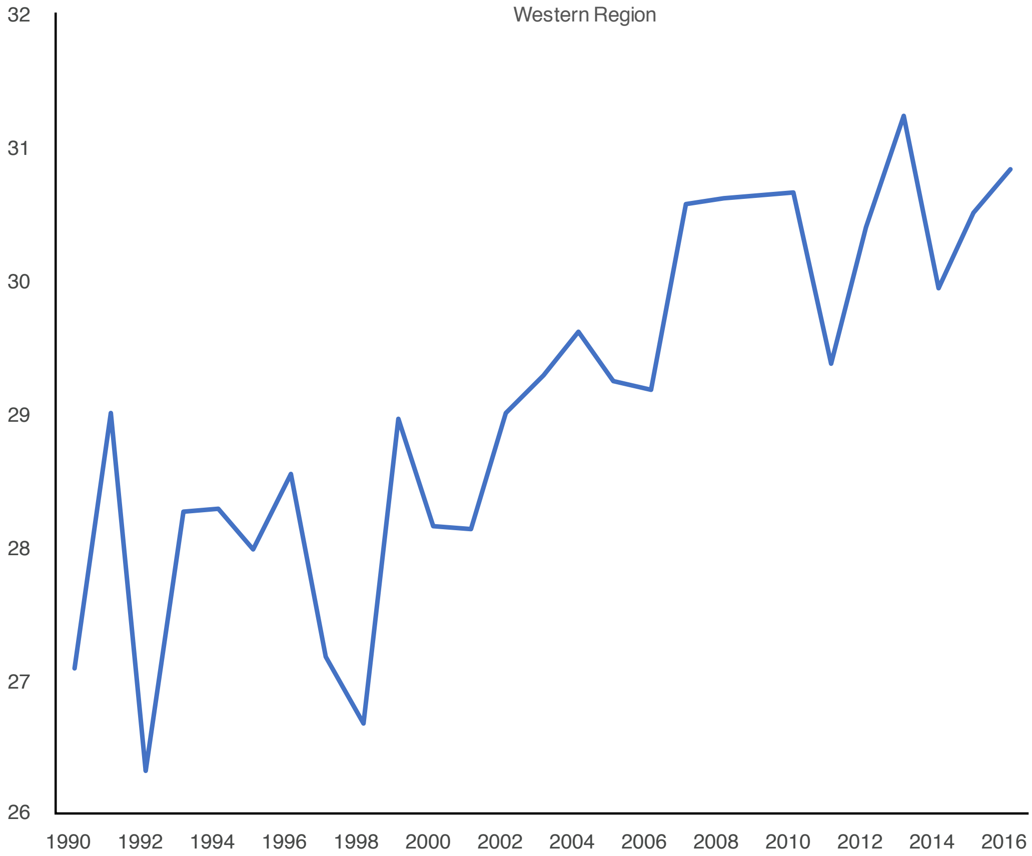
Figure 1 illustrates the national shares of each region's electricity consumption.

Figure 1. Shares of regional electricity demand in total demand (%).




Eastern Region
44
42
40
38
36
34
32
30
28
26
24
1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016


Southern Region
10
9
8
7
6
5
1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016



As can be seen from Figure 1, the share of electricity consumption is significantly higher in the eastern region in early 1990. It decreased over time, approaching the consumption levels of the central and western regions in recent years.

Theoretically, the long-run analysis can be conducted in logs or levels. Here we choose the log-log specification due to its ease of interpretation and compatibility with the existing literature (to allow easier comparisons with previous and future studies).

Empirical Estimation Results

Unit root test results

As is standard practice in the literature, the main concern lies in dealing with the stochastic properties of the variables. Because of this, the Augmented Dickey-Fuller (ADF) unit root test was employed for each variable in levels and first differences. In unit-root testing, the maximum lag length is taken to be two, and the optimal lag is chosen based on the Schwarz information criterion (SIC). Table 2 displays the results of the unit root tests.

Based on the results displayed in Table 2, we can conclude that all variables are integrated of the first order [I(1)], and there is the potential for a cointegration relationship. Hence, we can proceed to the next step and test variables for the common trend. The next section provides the results of the cointegration analyses.

Cointegration test results

To test the existence of a cointegration relationship, i.e., whether the variables share the long-run common trend, we employed the Engle-Granger (EG) cointegration test; the results are given in Table 3.

As the table demonstrates, we found conclusive proof of cointegration for all regions except the eastern region. For the other three regions, all the p-values from the EG tests were below the 5% level. This confirmed the presence of a cointegration relationship

Table 2. ADF unit root test results.

Region	Variable (in logs)	Level	First difference
National	gdp	-0.948	-4.269***
	di	-0.138	-5.147***
Central	dele_coa	-0.976	-4.962***
	pele_coa	-1.274	-4.514***
	pop_coa	-0.271	-5.618***
Eastern	dele_eoa	-1.576	-4.403***
	pele_eoa	-1.782	-4.465***
	pop_eoa	-0.582	-3.806***
Western	dele_woa	-0.903	-6.994***
	pele_woa	-1.898	-4.438***
	pop_woa	-0.139	-4.668***
Southern	dele_soa	-0.444	-5.110***
	pele_soa	-1.327	-4.534***
	pop_soa	-0.670	-4.476***

Note: dele=demand for electricity, COA=central operating region, EOA=eastern operating region, SOA=southern operating region, WOA=western operating region, pop=population, pele=electricity price; ***=Significant at the 1% level; intercept only case is chosen, based on the analyses.

Table 3. Cointegration test results.

	COA		EOA		SOA		WOA	
	Value	P-value	Value	P-value	Value	P-value	Value	P-value
EG tau-statistic								
	-5.413	0.013**	-3.598	0.226	-5.273	0.037**	-4.168	0.040**
EG z-statistic								
	-561.841	0.000***	-18.136	0.189	-60.934	0.000***	-21.866	0.033**

Notes: P-values are MacKinnon (1996) probability values; ** and *** stand for the rejection of the null of no cointegration at 5% and 1% significance levels, respectively.

at the 5% significance level. To further investigate the existence of the long-run relationship in the eastern region, we employed the variable addition test (VAT) for cointegration, proposed by Park (1990), which states the existence of cointegration as a null hypothesis. The test statistic is 4.932 with the p-value of 0.085, concluding the cointegration relationship at an 8.5% significance level. Considering the results of the employed tests, we conclude that there is a long-run relationship for all the regions.

Long-run estimation results

After concluding the cointegration relationship among the variables, the long-run estimation results can be interpreted so they are not spurious. They are provided in Table 4. To give an idea of the impacts in terms of magnitude ranges, we report the 95% confidence intervals for the estimated coefficients/elasticities. The interval estimator provides more information about the representative quality of the estimated coefficient and shows the limits of the impact.

The estimation results presented in Table 4 show that, for all the regions, the impacts of income, price and population are economically meaningful as they take the right signs and are statistically significant at the 1% level. As can be seen from Table 4, the income elasticity of electricity demand varies across regions, demonstrating more stable behavior in the western region and exhibiting wider ranges in the central region. The highest income elasticity is found in the central region, while it is lowest in the eastern region. Overall, the income elasticity ranges from 0.102 to 0.931 across the regions.

Table 4. Long-run estimation results.

	Region			
Regressor	COA	EOA	SOA	WOA
Income*	(0.403, 0.931)	(0.102, 0.204)	(0.120, 0.360)	(0.426, 0.470)
Price	(-0.580, -0.362)	(-0.628, -0.356)	(-0.132, -0.060)	(-0.607, -0.427)
Population	(0.243, 0.661)	(0.771, 0.947)	(0.335, 0.645)	(0.776, 0.840)

Notes: Dependent variable is dele_i and i takes COA, EOA, SOA and WOA, respectively; * for the central and the southern regions, GDP is used as an income measure; for the eastern and western regions, disposable income is used as an income proxy. The numbers in parentheses are 99% confidence intervals for the obtained elasticities.

The price elasticity of electricity demand is found to range from -0.607 to -0.060 across the regions.

The impact of population demonstrates more similarity across regions, with the elasticity ranging from 0.243 to 0.947.

Short-run estimation results

For the short-run analysis, we applied Gets to ECM to determine the relationship for each region. We start with a general ECM specification, which includes the error correction term (ECT), contemporaneous values of all independent variables and two lags of all the variables. We then exclude variables from the analysis based on the test proposed in the methodology and end up with the final short-run specification (Campos, Ericsson, and Hendry [2005], *inter alia*). We are not reporting on the general unrestricted models here to save space, but they are available from the authors upon request. Table 5 documents the final ECM specification and the post-estimation test results.

As Table 5 demonstrates, the short-run final specifications pass all the diagnostic and misspecification tests; hence the results are interpretable. All the remaining regressors in the final ECM have an economically meaningful and a statistically significant impact on electricity consumption in all regions. This is true for the contemporaneous values of all the drivers, i.e., the income, price and population.

The estimated SoA coefficients (coefficient of the ECT term) are statistically significant and negative in all the regions, confirming the existence of a stable long-run relationship among the variables.

Table 5. Short-run estimation results.

	Region							
Independent variables (DLOGs)	Central		Eastern		Western		Southern	
ECT	(-0.293, -0.151)	***	(-0.892, -0.532)	***	(-0.984, -0.746)	***	(-1.318, -0.924)	***
income	(0.152, 0.414)	**	(0.054,0.182)	*	(0.075, 0.221)	*	(0.159, 0.471)	*
price	(-0.079, -0.013)	*	(-0.234, -0.088)	**	(-0.274, -0.150)	***	(-0.103, -0.029)	*
population	(0.128, 0.616)	*	(0.168, 0.412)	**	(0.755, 1.485)	***	(0.338, 0.600)	***
dele (-1)							(0.118, 0.386)	*
income (-1)					(-0.212, -0.078)	**		
price (-1)								
population (-1)	(-0.552, 0.134)				(-1.399, -0.839)	***		
TESTS (p-values)								
Serial correlation LM	0.344		0.062		0.067		0.400	
Normality test (Jarque-Bera)	0.850		0.856		0.522		0.300	
Heteroskedasticity (White)	0.636		0.870		0.484		0.873	
Ramsey RESET test	0.471		0.153		0.133		0.942	

Notes: *Dependent variable is DLOG(DELE_i) and i takes COA, EOA, WOA and SOA;* ***, **, * stand for rejecting a null hypothesis at the 1%, 5% level and 10% significance levels, respectively. All independent variables except ECT are in DLOG.

Discussion of the Results

In this section, we present the key results and insights from our analysis of regional electricity demand. The key results are summarized in Tables 4 and 5. Table 4 displays the estimated long-run elasticities for each region and Table 5 displays the short-run elasticities.

As shown in Table 4, the long-run income elasticities range from 0.10 to 0.93 across the regions, the long-run price elasticities range from -0.61 to -0.06, and the long-run population elasticities range from 0.24 to 0.95. These results are in line with our expectation of positive elasticities for income and population, and negative elasticities for prices that we discussed in the theoretical framework section. Our long-run income elasticities are smaller than the finding of Al-Faris (2002), which is the only study devoted to total electricity demand in the Kingdom after 2000, and seem to be bigger (1.65) than the expected magnitude. In this regard, it makes sense to find that income elasticity is smaller than Al Faris's finding. The long-run price elasticity range is in line with expectations for developing countries. For example, Atalla and Hunt (2016) estimated the long-run price elasticity for residential demand to be -0.16, which is well contained in our interval. In addition, since the previous studies investigated electricity demand modeling at the national level, our results are not directly comparable with theirs. The country-level elasticities are the representative national averages, while the regional naturally take into account region-specific features.

With an income elasticity of 0.93 (the upper bound of the confidence interval), electricity demand in the central region is the most sensitive to changes in income. The eastern region is the most sensitive to changes in population, as the population elasticity of electricity demand is the highest at 0.95 (the upper bound of the confidence interval).

With a price elasticity of -0.61 (the lower bound of the confidence interval), the western region displays the largest sensitivity to changes in prices. We chose the western region because it has a narrower confidence interval in comparison with the eastern region. Comparing the sizes of all the elasticities for each region, income has the largest impact on electricity demand in the central region, population has the largest impact in the eastern region, and price has the highest impact in the western region.

Comparing the elasticities across regions, we observe that, in absolute terms, price elasticity is lowest in the southern region (-0.13, the lower bound of the confidence interval), population elasticity is lower in the central and southern regions, and income elasticity is lowest in the eastern and southern regions. Below we rationalize these findings based on regional characteristics.

We suspect that the low price elasticity in the southern region is a result of the lower levels of income in the south (GaStat 2018). Electricity consumption is already conservative and optimized in the south due to lower income levels, and there is not much scope to further reduce consumption as a result of price increases. This view is reinforced by the lower income elasticity for the southern region.

To explain the regional population elasticities, it is important to highlight that population trends are explained by migration patterns, births and deaths. In the southern region, where adult emigration is prevalent due to the search for better economic opportunities in other regions, and population increases are mainly driven by births, a lower population elasticity could be explained by population growth mainly being driven by births. Compared with adults, young children tend to consume less electricity. Hence, the lower population elasticity in the south is potentially due to population growth being driven by births. The lower income elasticities of the southern and eastern regions could be explained by the economic characteristics of these regions. The eastern region is heavily industrialized, and its low income elasticity makes sense because of its higher levels of income. Changes in income are less likely to impact the level of electricity consumption when income levels are high (Chang et al. [2016], *inter alia*). Unsurprisingly, in the southern region where income levels are lower, the income elasticity is also low. This is potentially explained by the conservative approach to electricity consumption of those at lower income levels. This makes consumers less sensitive to income changes. As Chang (1977, 1980) and Chang and Hsing (1991) discuss, demand for a particular good might be a luxury for those at a certain level of income. At that level of income, income elasticity starts to grow rapidly, and might even become bigger than unity. After a certain level of income, the additional increase in income does not contribute to increased consumption at the same rate. Hence, the income elasticity with respect to that particular good reduces and further increases in income do not change the elasticity significantly. Therefore, for some lower levels of income and some higher levels of income, income elasticities are expected to be low. Income elasticity can be closer, or even bigger, than unity for income levels that fall between the lowest and highest ranges. This point is also concluded by Chang and Hsing (1991) for residential electricity consumption in the United States, and by Chang et al. (2016) for electricity consumption for a panel of countries. In this regard, the lower income elasticities of the eastern and southern regions can be explained by the points mentioned above.

Conclusions and Policy Implications

In this study, we examined the impact of price, income and population (proxies for demographic effects) on electricity demand in the SEC's central, eastern, southern and western operating regions in Saudi Arabia. To the best of our knowledge, this is the first time series study to examine the determinants of regional electricity demand in Saudi Arabia. Our results show that in all regions, electricity is a normal good from a price and income perspective, and population growth positively impacts electricity demand.

The empirical results show the estimates of the regional long-run price elasticities to be around -0.5 in three regions and -0.1 in one region. This leads to the conclusion that changes in electricity prices are an effective market signal that has the potential to impact electricity demand.

The regional differences in elasticities might be useful in helping policymakers understand the potential regional impact of changes in electricity prices. Furthermore, the estimated regional impacts of changes to electricity prices enable policymakers to strike a balance between the desire to encourage efficient electricity consumption (by transitioning to a market-based pricing scheme with higher prices) and the negative impact of the price increase. Striking a balance would require policymakers to determine the appropriate level of household and industrial support required to dampen the negative impact of price changes.

With long-run elasticities that range between 0.24 and 0.95, the strong impact of population on regional electricity demand may require policymakers to pay special attention to policies that impact the total and regional population distribution, which in turn affect the aggregate and regional distribution of electricity demand. This is especially relevant for the effective planning of generation, transmission and distribution networks across the country. The recently implemented expatriate levy is a relevant example of a policy that has the potential to change the existing population dynamics.

Lastly, our results show that an increase in income (GDP and disposable income) leads to an increase in electricity consumption. This result proves that electricity is a normal good from an income perspective. It is important to note that there are big differences in income elasticities across regions. The differences range from approximately 0.7 in the central region to 0.2 in the eastern region. This shows that it is important to account for regional income differences when designing policies for the electricity sector.

In summary, our findings show the characteristics of the regional determinants of electricity demand in Saudi Arabia. The policy implications discussed above represent our contribution to the current policy discussion in Saudi Arabia.

There is room for further research that analyzes regional electricity demand based on consumer type. This would enable policymakers to see which consumer types drive the demand for electricity by region, and give a clearer picture of demand behavior.

Endnotes

[1] Ideally, a regional analysis for each electricity consumer category would provide further insights into the impact of rising electricity prices on different consumer categories and allow for a more targeted support approach, but that is beyond the scope of our analysis. The authors are currently working on this analysis.

[2] The nominal price values were converted to real prices using GDP deflators for the central and southern regions, and CPI for the eastern and western regions, depending on which deflated price produced economically meaningful and statistically significant results.

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About the Project

The objective of the KAPSARC Global Energy Macroeconometric Model (KGEMM) project is to develop a domestic policy analysis tool that examines the impacts of domestic policy measures and global economic and energy shocks on the Kingdom of Saudi Arabia. Commonly available models are typically more focused on the global economy (and the major contributors to global GDP), using an oversimplified representation of major oil and gas exporting economies, including Saudi Arabia, to capture energy flows into the global system.

The project develops and enhances the model described above with the following purposes:

> To provide a better representation of the Saudi economy by taking into account the stylized facts of the Saudi economy.

> To offer KAPSARC's research team and its stakeholders a macroeconometric model that is capable of evaluating the effects of different policy options (for energy price reforms and fiscal policy changes, among others) on the Kingdom's economy. The model is also capable of analyzing the current status and future paths of macroeconomic and energy indicators.

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