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King Abdullah Petroleum Studies and Research Center

Commentary

Saving Costs and Emissions by Reforming Electricity Prices in Saudi Arabia:
A Counterfactual Assessment

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Motivation and objective of the study

Electricity price reforms are generally regarded as a mechanism to reduce distortions in energy markets, improve energy efficiency, and increase government revenue. However, an additional co-benefit of such policy measures is lowering greenhouse gas (GHG) emissions.

This commentary aims to assess the unobserved contribution of such policy measures to mitigating emissions through rationalizing the use of domestic energy

What would carbon dioxide (CO_2) emissions and fuel costs have been if Saudi Arabia had not implemented residential electricity price reforms in 2016 and 2018? This commentary aims to assess the unobserved contribution of such policy measures to mitigating emissions through rationalizing the use of domestic energy. Moreover, Saudi Arabia's updated 2021 National Determined Contribution (NDC) has set a path for the Kingdom to be net-zero by 2060, including fully displacing liquid fuels from the country's power sector. It aims to generate 50% of its electricity from natural gas and 50% from renewables by 2030 and to reduce, avoid, and remove 278 million tonnes of CO_2 annually by 2030 (Kingdom of Saudi Arabia 2021). The NDC considers 2019 as the base year for the emissions. This paper quantifies the emissions mitigated before 2019 due to the country's electricity price reforms.

This commentary leverages a pervious KAPSARC study, "Regional Heterogeneous Drivers of Electricity Demand in Saudi Arabia," published in *Energy Policy* (Mikayilov et al. 2020). The study developed a partial equilibrium model to estimate how drivers of residential electricity demand differ by region within the country. This commentary expands that paper's analysis by conducting a counterfactual assessment where no price changes occur in residential electricity prices for the years 2016-2018 (see Figure 1). This scenario is used to examine the difference between regional residential electricity demand without price-adjusting measures and actual demand to measure the difference between the associated fuel costs and CO_2 emissions of the two scenarios.

Brief overview

Conventional energy sources impose an opportunity cost on the government and has a unique carbon footprint

Between 1990 and 2015, residential electricity in Saudi Arabia grew rapidly at an average rate of 4.2% per year (SAMA 2019). Residential electricity demand represents 50% of the Kingdom's total electricity (SAMA 2020), and total electricity generation contributes to around 40% of Saudi Arabia's total emissions (Oreggioni et. al 2019). In 2016 and 2018, the government implemented two waves of electricity price reforms (EPR) to motivate efficient energy consumption. Electricity generation in Saudi Arabia uses four conventional energy sources: crude oil, diesel, heavy fuel oil, and natural gas, and renewable sources such as solar and wind. Each of the conventional energy sources impose an opportunity cost on the government and has a unique carbon footprint. The reforms could also be viewed implicitly as a prudent carbon policy; in essence, an increase in the price of carbon-based energy (Edenhofer et al. [2017] *inter alia*). Research shows that implicit carbon policies, such as removing fossil fuel energy incentives or rationalizing energy prices, are more useful for developing countries (see Klenert et al. [2018], inter alia) than explicit carbon policies. The rationale behind this is that implicit carbon policies allow emissions mitigation without negatively affecting the international competitiveness of a country. In addition, they are easy to implement, have features that are unique to a specific country, without additional concerns such as the establishment of a relevant market, the introduction of fair legislation, or the need to establish infrastructure.

Moreover, rationalizing energy-use policies can improve the Kingdom's environmental quality and contribute to reducing its carbon emissions. Energy price reforms can thus be viewed as a complement to the Circular Carbon Economy (CCE) framework, which was launched by Saudi Arabia and endorsed by G20 members in 2020. The CCE approach consists of four pillars: reduce, reuse, recycle, and remove. It is a sustainable approach for managing emissions (SV2030 2017) and is considered one of the main frameworks for achieving the Saudi Green Initiative (SGI 2021) targets.

Rationalizing energy-use policies can improve the Kingdom's environmental quality and contribute to reducing its carbon emissions

Modeling framework

Our estimates are based on those of Mikayilov et al. (2020), which found that regional heterogeneity plays a significant role in explaining the response of each region's residential electricity demand to price reforms. This is evident when examining some of the regional differences of the Saudi Electricity Company's four operating regions in Saudi Arabia (see Table 1). Only the price of electricity, which is administered by the government, was a homogenous input in all regions.

Regional heterogeneity plays a significant role

Table 1. Descriptive statistics for regional heterogeneity.

Region	Real per capita GDP in 2018, $	Weather 1990-2018, degrees Celsius		Population (% of total) in 2018	Average share of residential electricity consumption (% of total), 1990-2018	Average per capita residential electricity consumption growth rates		Population density (person/ square km)
		Mean	Std. dev			1990-2018	2015-2018	2016
Central	21,591	24.23	8.00	32%	30%	3.6%	-6.1%	2,025
East	33,584	24.29	8.87	18%	20%	4.3%	-5.6%	2,180
West	13,267	28.36	6.16	35%	40%	3.6%	-6.1%	3,423
South	23,284	25.40	5.06	15%	10%	5.7%	-3.6%	1,871

Sources: SAMA; NCEI-NOAA; Lopez et al. (2019); KAPSARC WebGIS Portal (2019).

Electricity consumption is driven by income levels, electricity prices, weather conditions, and population (see Beenstock and Dalziel [1986], and Atalla and Hunt [2016], *inter alia*).

$$\boldsymbol{De_{t,r} = f(Y_{t,r}, P_t, CDD_{t,r}, HDD_{t,r}, UEDT_{t,r})} \qquad (1)$$

Where $\boldsymbol{De_{t,r}}$ is per capita residential electricity consumption for region $\boldsymbol{r}$ at $\boldsymbol{t}$, $\boldsymbol{Y_{t,r}}$ is per capita income in real terms, $\boldsymbol{P_t}$ is the weighted average residential electricity price in real terms, $\boldsymbol{CDD_{t,r}}$ is annual cooling degree days, $\boldsymbol{HDD_{t,r}}$ is annual heating degree days, and $\boldsymbol{UEDT_{t,r}}$ is the underlying energy demand trend for residential electricity consumption. It can be interpreted as the stochastic trend of the effects of technological improvements, among other unmodeled factors (Hunt et al. 2003).

Our empirical long-run estimations used the specification[1] as in Mikayilov et al. (2020):

$$\boldsymbol{De_{t,r} = a_0 + b_1 y_{t,r} + b_2 P_t + b_3 CDD_{t,r} + b_4 HDD_{t,r} + UEDT_{t,r}} \qquad (2)$$

Therefore, demand for residential electricity in each region is positively impacted by an increase in income, cooling degree days, and heating degree days, but it is negatively affected by price.

Counterfactual exercise

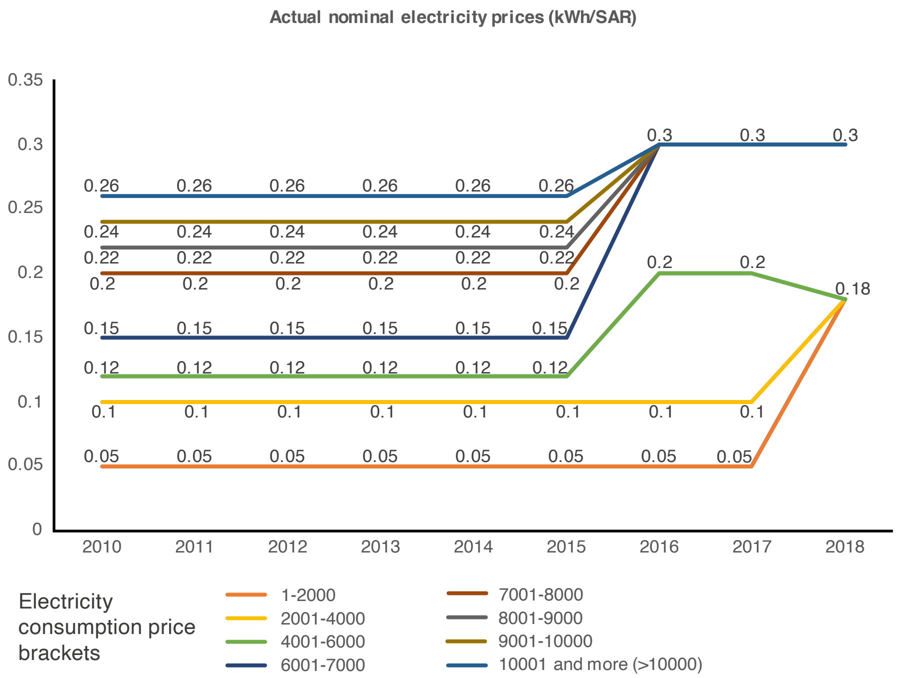
Using the long-run unique specification for each region, we calculate the counterfactual residential electricity demand for 2016-2018, while holding electricity prices constant at the 2015 level (see Figure 1). We calculate the counterfactual using the estimated parameters that consider observed price variation of electricity price reforms to be consistent with the regionally observed responses. Additionally, in a typical counterfactual exercise (i.e., a partial equilibrium setting), it is impossible to observe how all influencing factors would behave. For example, what would gross domestic product (GDP) values be if EPR did not materialize? In other words, we do not consider the change in demand for electricity if GDP figures, or other factors, were impacted by the change in electricity prices.[2]

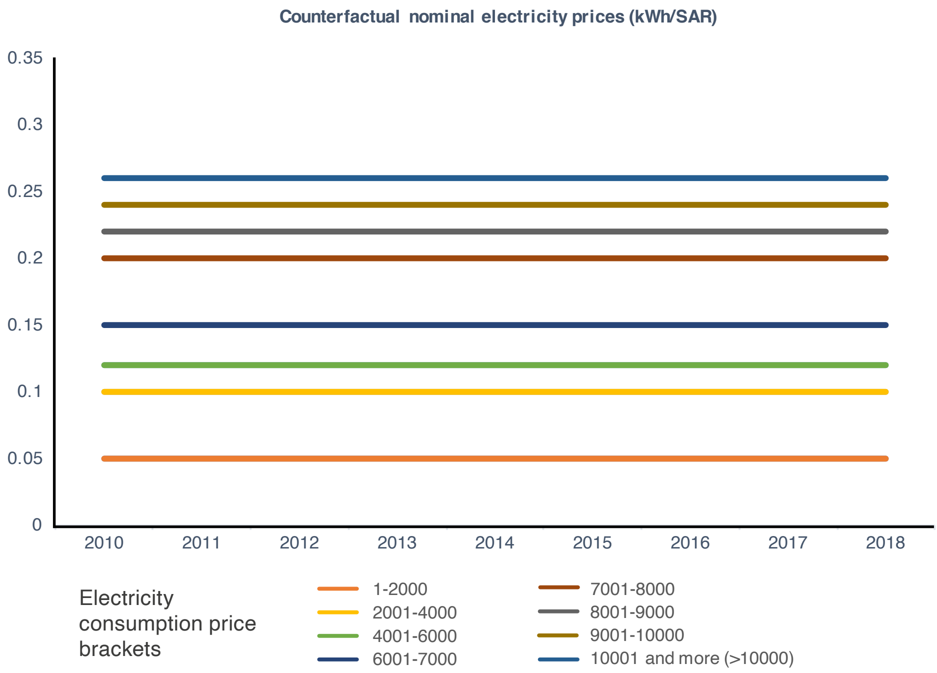
Using the long-run unique specification for each region, we calculate the counterfactual residential electricity demand for 2016-2018, while holding electricity prices constant at the 2015 level

[1] Transformed into the long-run specification from its dynamic counterpart.

[2] Intuitively, we are potentially underestimating the true impact of EPR, since demand most likely would have been higher through the income channel.

Figure 1. Realized and counterfactual nominal residential electricity prices.

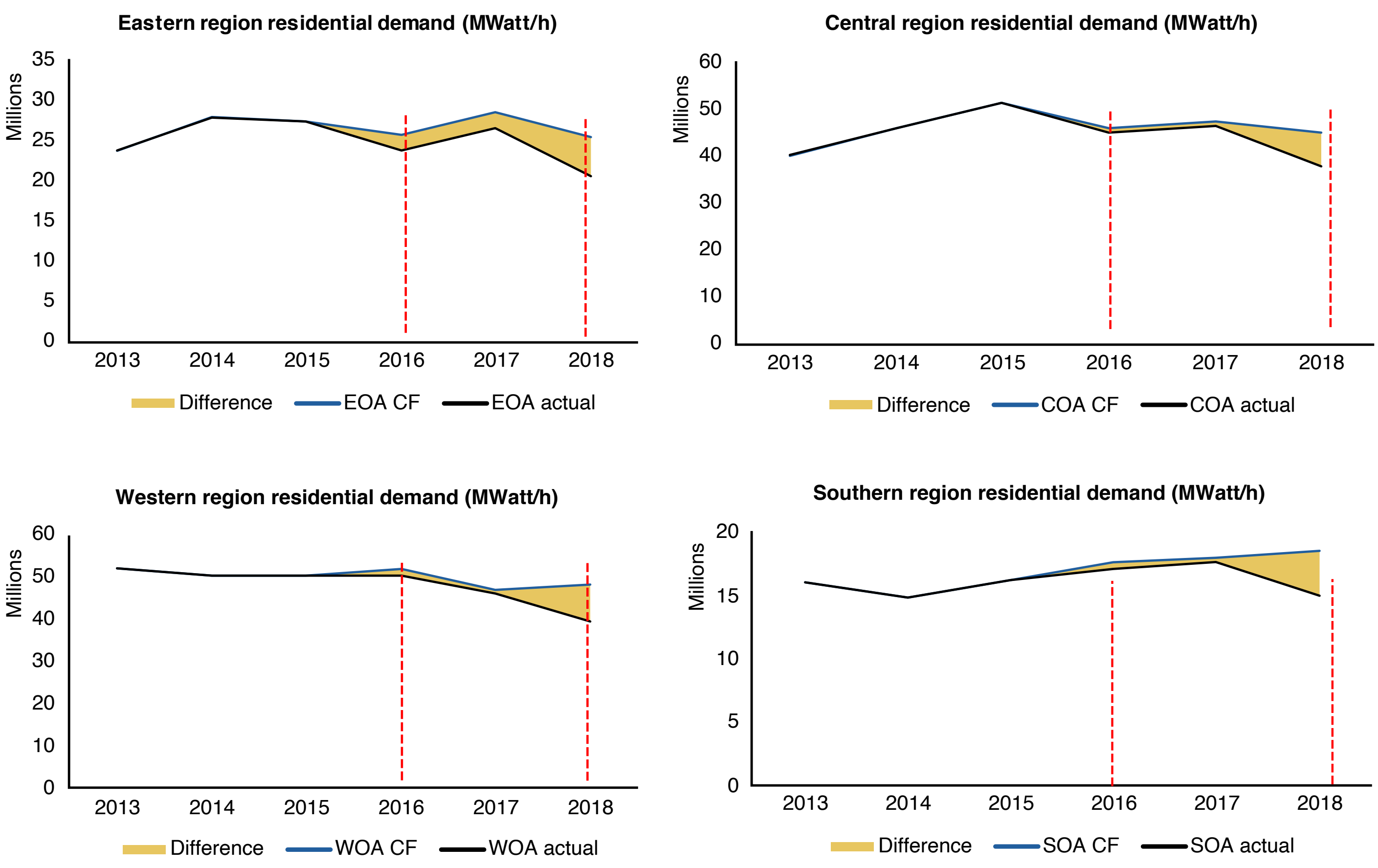




Source: Authors' assumptions; AlGhamdi (2019).

Figure 2 displays the results of the counterfactual against the actual regional electricity consumption. The orange line is the *actual* energy demand, and the blue line represents the counterfactual energy demand. The shade in yellow is the difference in electricity consumption between the two. This difference illustrates the impact of the role of electricity prices on electricity demand, while keeping everything else constant. Thus, it can be assumed that if prices remain constant at the 2015 level, different demand patterns emerge in all regions due to their unique demand responses, with higher electricity consumption overall.

Figure 2. Regional electricity demand for actual and counterfactual scenarios (CF) (2010-2018).



Source: Authors' calculations.

To estimate the impact of the counterfactual scenario in terms of its associated fuel costs and CO_2 emissions, we use the difference between actual and counterfactual electricity demand to scale up a power system model specifically built for Saudi Arabia. The KAPSARC Power Model (KPM) uses the commercially available software package PLEXOS 4. It is a cost-minimization model of electricity production, which considers fuel access, costs and other constraints for the year 2018. For more information on the detailed representation of the generation fleet, fuels, and heat rates, see Elshurafa et al. (2021).

Total fuel costs

According to the KPM[3] results, the price reforms avoided approximately $500 million worth of fuel costs needed to generate the additional electricity demand for the counterfactual scenario when compared to the actual generation (with price reforms) for the 2016-2018 period. While these results are consistent, KPM assumes that the electricity fuel generation mix in 2016 and 2017 was the same as 2018. This may suggest that the savings might have been higher, as stated by the Saudi Electricity Company's (SEC's) yearly earnings report that a 15% decrease in fuel costs resulted from improved thermal efficiency and improvements in the fuel mix from 2017 (SEC 2018).

With regards to carbon emissions, KPM4 uses precise conversions for each energy source needed for electricity generation. For 2018, the results show that Saudi Arabia avoided an electricity consumption trajectory of approximately 24 million tonnes more carbon in 2018, 4.5 million more tonnes in 2017, and 7.6 million more tonnes in 2016. In total, the electricity price reforms helped avoid increased CO_2 emissions of approximately 36 million tonnes. The corresponding region-specific CO_2 emission numbers are reported in Table 4.

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Table 2. Carbon emissions[4] for each SEC operating region (tonnes of carbon).

	Carbon emission (Tonnes)								
	2016			2017			2018		
	Actual	Counterfactual	Reduction	Actual	Counterfactual	Reduction	Actual	Counterfactual	Reduction
Central region	65,865,545	68,635,935	-4%	67,256,820	68,768,516	-2%	58,427,119	63,751,735	-9%
Eastern region	68,506,601	71,117,464	-4%	70,275,484	72,159,794	-3%	59,519,740	66,754,876	-12%
Western region	96,502,294	98,441,172	-2%	91,487,073	92,649,186	-1%	82,034,038	91,390,789	-11%
Southern region	20,203,256	20,566,795	-2%	19,399,823	19,660,127	-1%	17,702,139	19,384,553	-10%
Regional emission	251,077,697	258,761,366		248,419,199	253,237,623		217,683,037	241,281,953	
Total emissions avoided per year	7,683,670			4,818,424			23,598,917		
Total emissions avoided 2016-2018	36,101,009,97								

Source: KPM, PLEXOS. Author's calculations.

Note: Reductions refer to the percentage of the difference between counterfactual and actual, relative to actual.

[3] PLEXOS is calibrated to 2018 data. Therefore, generation costs and emissions for 2017 and 2016 are derived by scaling the model to reflect actual consumption.

Conclusion

This assessment finds, through a partial equilibrium framework, that Saudi Arabia's electricity price reforms saved the consumption of approximately $500 million worth of fuels. This figure was used to generate the counterfactual electricity demand for the 2016-2018 period. The largest mitigation of CO_2 emissions occurred during the second wave of price reforms in 2018, where the price adjustments targeted the largest portion of electricity consumers. In total, the two phases of residential electricity price reforms managed to avoid an additional 36 million tonnes of CO_2 emissions. This number represents only the residential sector, and, as mentioned previously, it potentially underestimates the true impact by disregarding the demand response through the income effect.

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The findings of this commentary provide a perspective on the effectiveness of previous energy policies that predate, yet complement, the recent targets and goals set by the Saudi Green Initiative (SGI) and the CCE framework. The SGI outlines a path for the Kingdom of Saudi Arabia to help protect the planet. It aims to deliver sustainable change, outlined by six pillars: 1) grow the clean energy sector, 2) reduce carbon emissions, 3) protect oceans, 4) defend wildlife, 5) prevent desertification, and 6) increase recycling. During the launch of the SGI, the Saudi government announced it aimed to achieve net-zero CO_2 emissions by 2060. To that end, further analysis is essential to understand how to achieve a lower emissions path while also ensuring sustainable economic growth.

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About the project

The Modeling Energy Consumption and its Impacts in Saudi Arabia project aims to conduct advisory and applied research activities focused on modeling and forecasting indicators of energy consumption and their impacts in Saudi Arabia. In line with the ongoing energy policies the Kingdom is implementing, the project focuses on three main areas:

- Modeling and forecasting energy consumption indicators.
- Modeling and forecasting the environmental impacts of energy consumption.
- Investigating the trajectories and potential of energy efficiency.

About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

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