THE INTERACTIONS BETWEEN RESIDENTIAL ELECTRICITY CONSUMPTION AND THE POWER SECTOR WITHIN AN ECONOMIC EQUILIBRIUM FRAMEWORK: A LOOK AT ENERGY EFFICIENCY IN SAUDI ARABIA

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Overview

In light of rapidly increasing domestic demand for fossil fuels, Saudi Arabia has been studying various options to lower its energy use. The residential sector is responsible for around half of total electricity sales in Saudi Arabia, making it an attractive target for lowering overall consumption. The government has placed emphasis on efficiency as an alternative to price reform for households, as has been shown with the efforts of the Saudi Energy Efficiency Center (SEEC) and the Ministry of Water and Electricity. Public awareness campaigns have complemented the recent introduction of more stringent standards for air conditioners and the requirement for new residences to have thermal insulation. This study investigates the system effects of the wide adoption of these efficiency measures.

We explore the role of residential electricity consumption in the Saudi energy system and in particular its interaction with the power sector. The objectives of this analysis are twofold: One is to calculate the potential shifts in the intraday system-level power demand resulting from more efficient households. The other is to quantify the impact of the new load curves on the operations of the electricity sector. To accomplish this, we interface an engineering residential electricity consumption model with a bottom-up economic equilibrium model. The economic equilibrium component is our recently-developed KAPSARC Energy Model, or KEM.

The paper is structured as follows: The next section provides an overview of electricity demand and the make-up of the residential sector in Saudi Arabia. The modeling approach and the integration with KEM are then detailed, followed by a discussion of the data used for the calibration of the residential model. The paper is concluded with the presentation and discussion of the results.

Methods

A residential electricity demand model has been integrated with KEM for Saudi Arabia. An engineering-based approach was adopted to capture the physical and technological factors that impact electricity use in residences. The model's hourly resolution allows the simulation to quantify the intraday effects of any load-altering measure. The model also consists of four sub-regions within Saudi Arabia to consider climate differences. This is especially useful when observing the interaction between any load shifting and the operating decisions of the power sector.

Due to the significance of heating, ventilating, and air conditioning (HVAC) on the demand for electricity, the residential model constructs power load curves using the electricity consumption of HVAC systems as the foundation upon which other end uses are added. The model simulates the conductive, convective, and radiative heat gains that take place in residential enclosures by taking into account outdoor conditions and residence characteristics. The required operating level of the HVAC system to achieve some desired indoor air conditions is also calculated.

KEM is a partial equilibrium model that represents six of Saudi Arabia's energy intensive sectors. Matar et al. (2014) provide a detailed description of the first version of KEM. Any changes observed in household electricity use may have cascading implications on other sectors in KEM.

Results

We test the effects of higher air-conditioner energy efficiency ratio (EER) and the greater penetration of thermal insulation in residences. The findings reflect the resulting economic equilibrium for each scenario in the year 2011. Increasing the EER of the residential air conditioner stock and the prevalence of thermal insulation in homes reduce crude oil consumption and cost for the power sector. The peaks of oil consumption for power generation are alleviated during the summer months as the efficiency measures target the demand for space cooling. Compared to a baseline scenario calibrated to 2011 residential electricity consumption, increasing the average EER to 11

BTU/(W·hr) would have resulted in a 225-thousand-barrels-per-day annual reduction in the amount of crude oil burned for electricity generation. Increasing the 2011 share of insulated homes from 27% to 64% would have allowed the power sector to lower its yearly use of the fuel by 158 thousand barrels per day. Combining the features of both scenarios yields incremental yet not additive fuel savings, as both measures have interacting physical effects. Table 1 below shows a more detailed set of results.

Table 1 – Simulation results at the national level for a reference and alternative scenarios in a 2011 setting

		Reference	**Higher Prevalence of Thermal Insulation**	**Increased EER to 11 BTU/(W·hour)**	**Combined EER and Insulation**
National residential electricity consumption (TWh)		111.44	93.55	86.03	74.05
Reduction in total cost to power sector (million USD)		-	428.50	607.62	880.46
Reduction in oil consumption by power sector (thousand barrels per day)	Summer	-	233.5	339.2	376.0
	Spring and Fall		169.3	228.9	271.6
	Winter		58.4	97.6	147.4
	Yearly Average		158.3	224.6	267.6
Average thermal efficiency of electricity generation		34.0%	35.0%	35.5%	36.3%

Moreover, the results show more efficient use of the power generation capacity. The least efficient equipment, which is put off to only be used during the highest load periods, is forgone due to the lowered electricity demand during the peak segments. Thus, our methodology is able to capture the presence of two effects that influence the amount of fuels burned for power generation. Firstly, there is a direct reduction in fuel use caused by lower electricity production. Secondly, the more efficient utilization of the generation capacity leads to less fuel consumed per unit of electricity produced. The fuel-saving benefits for the power sector when peaking equipment would be ramped up are greater than those realized if the electricity reduction takes place during low demand periods.

Conclusions

The widespread adoption of residential efficiency measures introduces profound effects on the overall energy system. Different types of efficiency measures, even if they yield the same reduction of electricity consumption, do not uniformly shift the electricity load curves and hence may affect the energy system differently. This is demonstrated by incorporating the simulated load curves for scenarios that explore the increased penetration of thermal insulation materials and a more efficient air conditioner stock in counterfactual analyses. Measures reducing heat gains into the residential enclosures have a delayed impact on the system-level hourly load profile whereas the effect of measures mitigating the direct use of electricity is instantaneous. Regional climate differences also influence how the load curves respond to higher efficiency. Our analysis also shows how improved efficiency in end-use may cause other sectors in an economy to also become more efficient.

References

Matar, M., Murphy, F., Pierru, A., and Rioux, B., 2014. Modeling the Saudi Energy Economy and Its Administered Components: The KAPSARC Energy Model. USAEE Working Paper No. 13-150. <http://ssrn.com/abstract=2343342>.