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King Abdullah Petroleum Studies and Research Center

The Costs and Gains of Coordinating Electricity Generation in the Gulf Cooperation Council Utilizing the Interconnector

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Key Points

Countries in the Gulf Cooperation Council (GCC) have installed a network of high-voltage transmission lines, known as the GCC Interconnector, which links the member states of Saudi Arabia, Bahrain, Kuwait, Oman, Qatar and the United Arab Emirates (UAE). The Interconnector has successfully provided reliable services to GCC countries but has not yet realized its full potential as a platform to fully integrate individual electricity systems. This paper analyzes the potential costs and gains of electricity exchange among the GCC countries. Given the current political climate, it does not consider electricity exchange with Qatar, except as a sensitivity case. The study finds that:

- Using the Interconnector without restructuring the current fuel subsidy policies increases costs. If subsidies were not removed across the region, other GCC countries would take advantage of lower priced Saudi electricity, and Saudi Arabia would export $2.2 billion (in real 2015 United States dollars) in subsidies-by-wire.

- Subsidy removal delivers the largest economic gain – over $41 billion annually – to the GCC countries. Coupling subsidy removal with electricity exchange increases this economic gain by nearly $1 billion annually. Electricity and water production becomes decoupled and enables a more flexible system. Nearly 33 terawatt hours, or over 5 percent of GCC electricity production, would be exchanged at market prices.

- Substantial investment would accompany these exchanges. Over half of existing capacity (80 gigawatts) would be replaced by more efficient combined-cycle gas turbines and utility-scale photovoltaics, at a cost of $7.3 billion.

- Using a hybrid pricing system to test whether the benefits of electricity coordination could be attained without deregulating fuel prices, subsidies for domestic electricity consumption were retained while opportunity costs were charged for fuels used to produce electricity sent through the Interconnector.

- The hybrid scheme resulted in a net economic loss of $1.4 billion because fuel subsidies still distort the domestic fuel consumption patterns. On average, subsidies still leak across borders.

Executive Summary

Countries in the Gulf Cooperation Council (GCC) have installed a network of high-voltage transmission lines, known as the GCC Interconnector, which links the member states of Saudi Arabia, Bahrain, Kuwait, Oman, Qatar and the United Arab Emirates (UAE). The Interconnector is envisioned as a platform to facilitate coordinated electricity generation among the GCC countries to support the ongoing reform initiatives. The Interconnector was completed in 2011 and has maintained system reliability through enabling the in-kind exchange of electricity among GCC member states.

Given the interest in restructuring domestic electricity sectors and ongoing demand growth, it is useful to examine the potential savings from the greater use of the Interconnector to lower costs and improve the efficiency of electricity generation and transmission in the region. Only countries that benefit from non-emergency transmission have incentives to engage in trades. As such, for the GCC countries to engage in non-emergency transmission, all countries have to benefit.

This paper measures the gains and losses of alternative approaches to trading. It establishes a baseline using the existing policies of each country in 2015 and examines the consequences of transmitting electricity through the Interconnector, using electricity costs based on the existing fuel subsidies. This gives an estimate of the magnitude of fuel subsidies that would be exported through electricity sales. This analysis sets fuel prices equivalent to world prices and runs two scenarios with and without using the Interconnector for non-emergency power flows, to estimate the largest potential economic benefit from using the Interconnector.

This analysis finds that domestic fuel subsidies are the key barrier to economic regional electricity exchanges from which all the member countries benefit. In the absence of subsidy removal across the region, other GCC countries would purchase low-priced electricity generated with subsidized fuels, and Saudi Arabia would export $2.2 billion (in real 2015 United States dollars) annually in subsidies-by-wire.

The bulk of the annual economic benefit results from removing fuel subsidies of $41 billion. The economic gain increases by nearly $1 billion annually when coupling subsidy removal with electricity exchange. Nearly 33 terawatt hours, or over 5 percent, of GCC electricity production would be exchanged at market prices (Table 1).

Table 1. Cross-border electricity transmission with deregulated fuel prices and electricity exchange (excluding Qatar).

	To						
From	**Bahrain**	**Kuwait**	**Oman**	**Qatar**	**Saudi Arabia**	**UAE**	**Gross exports**
Bahrain					5.3		5.3
Kuwait					11.4		11.4
Oman						3.7	3.7
Qatar							
Saudi Arabia	0.51	0.13				0.07	0.7
UAE			0.18		11.6		11.8
Gross imports	0.5	0.1	0.2		28.4	3.7	32.9
Net imports	4.8	11.3	3.5		-27.7	8.1	

Source: KAPSARC analysis.

Substantial investment would accompany these exchanges. More efficient combined-cycle gas turbines and utility-scale photovoltaics would replace over 50 percent of existing capacity at a cost of $7.3 billion. A significant aspect of the capacity shift is the replacement of electricity/water cogeneration plants with water production switching to reverse osmosis. Figure 1 illustrates the change in electricity production by technology.

The thermal cogeneration plants in Figure 1 make the electricity systems inflexible because of the need to produce water. Retiring the cogeneration plants and replacing them with combined-cycle plants and reverse osmosis plants increases the flexibility of the national grids and allows them to take advantage of the interconnection.

These results highlight the potential to increase the efficiency and reduce redundancy in the existing GCC electricity and water systems and achieve substantial gains through increased coordination. Since the GCC countries are unlikely to fully deregulate electricity production, this paper examines scenarios that eliminate cross-border subsidies while maintaining fuel subsidies for domestically consumed electricity. These scenarios balance economic efficiency with social goals. The result is costlier than not having coordination.

As with previous KAPSARC studies, the important lesson is that moving from current highly regulated systems to a more market-based approach on a piecemeal basis can increase costs without the proper sequencing of policy changes. (Matar et al. 2017) The Interconnector can provide substantial economic benefits. However, the conditions must be right for these benefits to be realized.

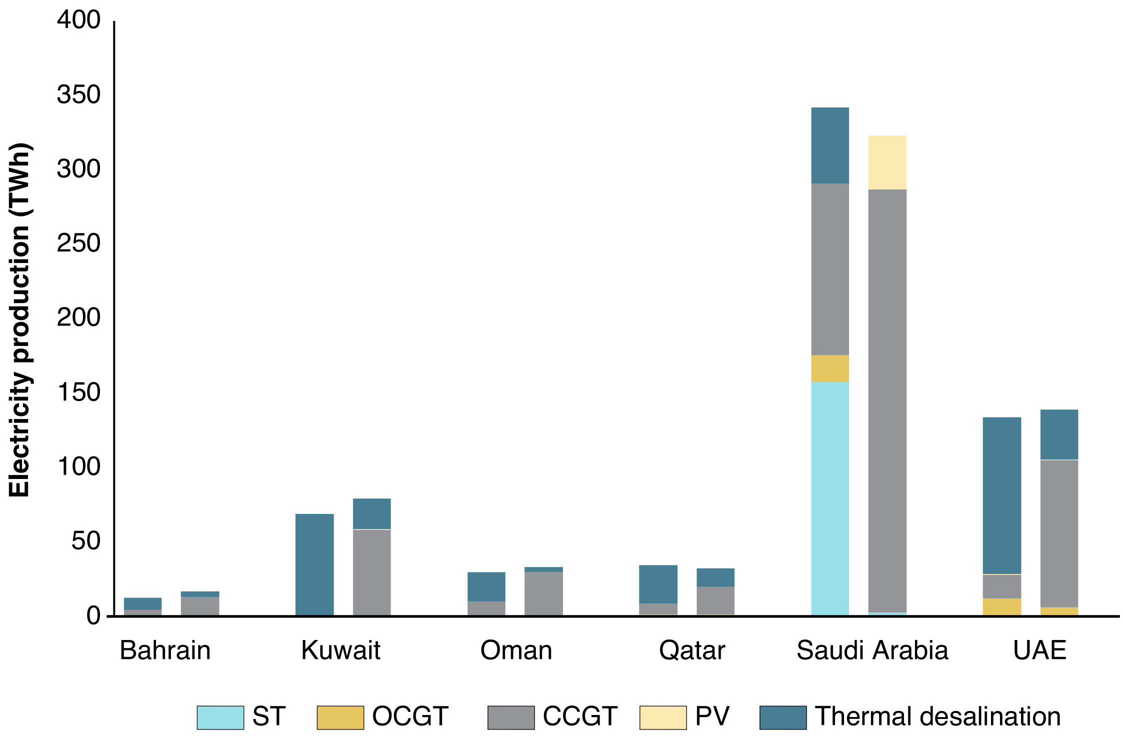

Figure 1. Electricity production by technology in the 'no coordination' scenario (left bar charts) and in the 'deregulated exchange' scenario (right bar charts).

Source: KAPSARC analysis.

Introduction

Countries in the Gulf Cooperation Council (GCC) have installed a network of high-voltage transmission lines, known as the GCC Interconnector, which links the member states of Saudi Arabia, Bahrain, Kuwait, Oman, Qatar and the United Arab Emirates (UAE). The Interconnector was conceived as a tool to "provide the safety and security of the GCC's electrical grids and to avoid power outages by 100 percent", and as a platform to facilitate coordination among countries that would support the ongoing reform initiatives (Gulf Cooperation Council Interconnection Authority 2017).

The Gulf Cooperation Council Interconnection Authority (GCCIA) is the independent system operator and plans to transition the system to a fully operational market, based on the Nord Pool model (Elshurafa et al. 2017). The Authority aims to save an average of $1.3 billion a year over 25 years, through reducing costs from building and operating new power plants and reducing redundant reserve margins (Gulf Cooperation Council Interconnection Authority 2017). The Interconnector was completed in 2011 and has maintained system reliability through enabling in-kind exchange of electricity among member states. The solid black lines in Figure 2 represent the dedicated Interconnector lines. A dedicated Interconnector line was not constructed in the UAE and Oman because the existing national grids were already connected, indicated by the dashed lines.

Figure 2. Map of GCC members and the GCC Interconnector (shown by the thick black lines).

Source: Google Maps, KAPSARC.

The GCC countries could benefit from more coordinated electricity production under the right circumstances, as the countries have non-coincident peaks in electricity demand. However, the Interconnector has not provided the full benefits of integrating the individual grids of the member countries because of the structure of the electricity and water sectors in each country. Since every GCC country subsidizes the fuels consumed and equipment used in electricity generation, any electricity sold across borders means the exporting country subsidizes consumers in the importing countries. Thus, the structures of the domestic markets have inhibited trading electricity.

Currently, with the reduction in government revenues from hydrocarbon exports, all GCC member nations are in the process of reforming their power sectors. Saudi Arabia is currently exploring the option of creating an electricity market such as those in the United States and Europe. That is, they are moving to pricing that is closer to marginal cost. As an intermediate step, on January 1, 2016, Saudi Arabia raised the price of natural gas by 77 percent and crude oil by 50 percent for power and water producers (Wogan 2017). The government of Saudi Arabia has announced future price increases as part of the ongoing reforms of Vision 2030 (Kingdom of Saudi Arabia Vision 2030, 2016).

Given the interest in domestic restructuring and ongoing demand growth, this study examines the potential for savings from the greater use of the Interconnector to lower costs and improve the efficiency of electricity generation and transmission in the region. The paper presents a set of scenarios constructed to examine a range of fuel-subsidy and electricity-exchange policies.

Existing Estimates of Benefits

The GCCIA reported that it "aims to save more than $33 billion" over the next 25 years through avoided capacity investments, reduced operations and maintenance (O&M) costs and operational reserves (Gulf Cooperation Council Interconnection Authority 2017). This estimate is equivalent to average annual savings of $1.3 billion and is in the upper range of publically available estimates. In a 2015 presentation, the CEO of GCCIA reported "$23.6 billion [could be saved through] reduction of fuel and O&M costs for the period between 2014 and 2038," averaging $940 million annually (Al-Ibrahim 2015). The presentation did not report on the methodology used, in particular assumptions about fuel subsidies and prices.

In 2016, the GCCIA launched the Power Trade Pilot Program and saw the highest level of energy exchange in its eight-year history. GCCIA waived an estimated $6.6 million in grid utilization fees to spur trade activities. According to the Authority, total energy exchange utilizing the Interconnector topped 1.3 terawatt hours (TWh) at an estimated value of $160 million. Avoided capital and operating expenditures due to exchanges were $404 million (Gulf Cooperation Council Interconnection Authority 2017; Elshurafa et al. 2017).

The GCC Power and Water System

Background

Energy is the foundation of the modern economies of the GCC. Energy exports represented an average of 78 percent of the four GCC Organization of the Petroleum Exporting Countries (OPEC) members' gross domestic product. However, GCC countries consume fossil fuel resources domestically in substantial quantities for power and water production (OPEC 2017). This study estimates that Saudi Arabia consumes 420 thousand barrels per day (bbl/d) of crude oil domestically for electricity and water production, or roughly 4 percent of its daily production.

The arid desert climate in the GCC and its severe scarcity of freshwater resources mean that cooling and seawater desalination consume large amounts of electricity (Napoli et al. 2018). Total GCC electricity demand was 526 TWh in 2015. Saudi Arabia produced over half of all electricity in the GCC due to its large population and industrial base (Table 2). Saudi Arabia's electricity regulator reported that consumption was 275 TWh in 2015 (ECRA 2014). The UAE has the second largest electricity demand of the GCC, at 111 TWh, and Kuwait and Qatar have the highest electricity demand per capita.

Saudi Arabia had the highest peak demand at 62.3 gigawatts (GW), and Bahrain had the lowest peak at 2.92 GW. Consumption for the UAE and peak load for Bahrain are estimated from previous years. This study estimates that aggregate peak demand is 113.6 GW.

Technology capacities

Over 144 GW of power-generating capacity is installed across all six countries, roughly equivalent to the installed capacity of the Association of Southeast Asian Nations (ASEAN) (International Energy Agency 2015). Around 40 GW of open-cycle gas turbines (OCGTs) and 28 GW of single cycle steam turbines supply nearly half of all power (Figure 3). More efficient combined-cycle gas turbines (CCGTs) represent only 14 percent of capacity (20 GW). Combined power and water plants supply the largest proportion of power in the GCC, at over 56 GW of capacity. This study refers to these plants as 'cogeneration' or 'thermal desalination.'

Table 2. Electricity consumption, consumption per capita and peak load.

Country	Consumption (TWh)	Consumption (per capita)	Peak load (GW)
Bahrain	15.2	11.3	2.9
Kuwait	60.5	15.4	12.8
Oman	31.3	7.6	6.1
Qatar	36.1	14.6	6.7
Saudi Arabia	294.6	9.3	62.3
UAE	126.6	12.2	22.8
Total GCC		10.0	-

Source: UAE Statistical Data for Electricity and Water 2015, Bahrain Information and eGovernment Authority, Electricity and Cogeneration Regulatory Authority, Qatar Electricity and Water Corporation, Kuwait Ministry of Electricity and Water, Oman Power and Water Procurement Company, The World Bank, KAPSARC analysis.

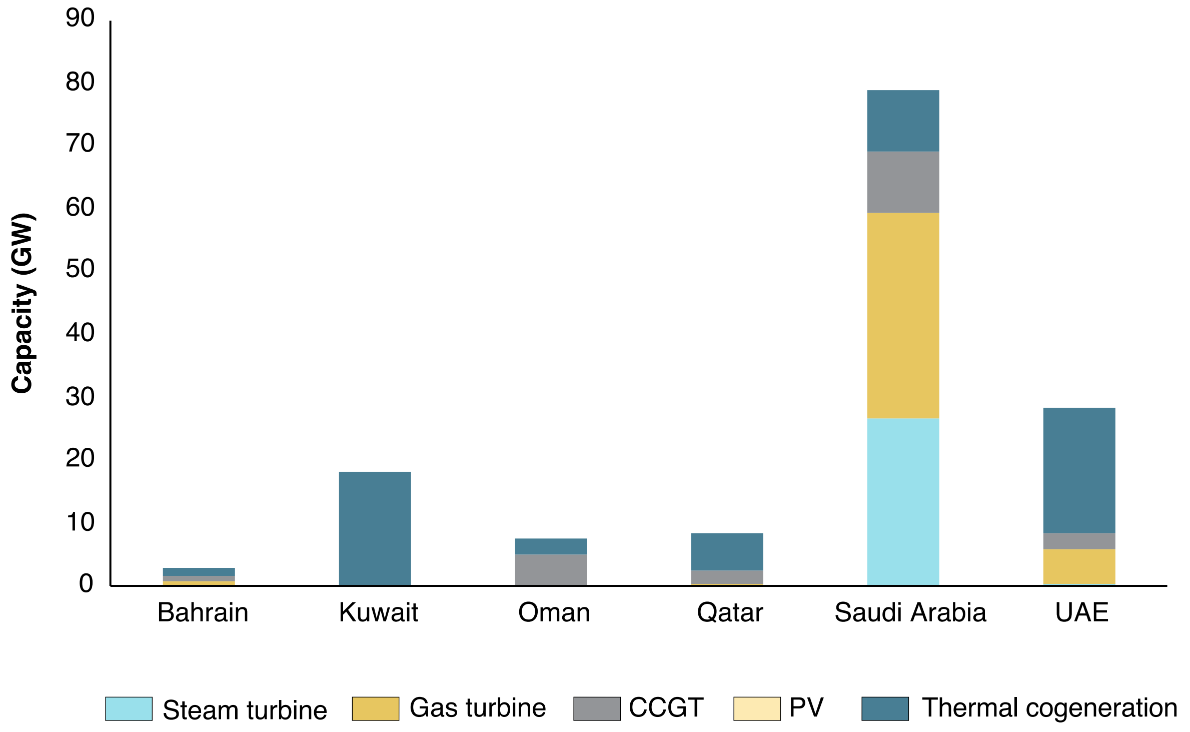

Figure 3. Power capacity by technology type.

Source: UAE Statistical Data for Electricity and Water 2015, Kingdom of Bahrain Water and Electricity Authority, Electricity and Cogeneration Regulatory Authority, Qatar Electricity and Water Corporation, Kuwait Ministry of Electricity and Water, Oman Power and Water Procurement Company, The World Bank, KAPSARC analysis.

Utilities overuse inefficient single-cycle turbines and cogeneration plants because the fuel costs are subsidized. Despite an abundance of solar radiation in the region, only 76 megawatts (MW) of photovoltaics (PV) were installed at the end of 2015 (included but not visible in Figure 3), representing 0.05 percent of all installed capacity.

Fuels

The power and water systems of the GCC member states supplied 6.8 quadrillion British thermal units (QBtu) of fossil fuels in 2015 (annual estimated), with natural gas accounting for 4.6 QBtu annually. Figure 4 presents the consumption of fossil fuel by type in 2015.

As noted above, water and power production in Saudi Arabia, the largest fuel consumer, account for roughly 4 percent of its crude oil production (SEC 2015). Kuwait consumes a combination of natural gas and heavy fuel oil (HFO), and smaller volumes of crude oil and diesel (Kuwait Ministry of Electricity and Water 2015). Natural gas is the primary fuel in Bahrain, Oman and Qatar (OPWP 2015; KAHRAMAA 2014; Kingdom of Bahrain NOGA 2015b). Natural gas is the primary fuel for power and water production in the UAE (UAE Ministry of Energy 2015; DEWA 2014; SEWA 2012; UAE FEWA 2015).

Subsidies

A key feature of the GCC energy system is the prevalence of subsidized fuel prices. Domestic utilities purchase most fuels at highly subsidized prices and pass on the savings in the form of affordable energy services to citizens and industries. This analysis defines subsidies as prices administered by the government below export (market) value. The low price of fuels has induced investment in inefficient steam and open-cycle turbines and remains a key impediment to exchanging energy. Table 3 details the fuel prices used throughout this study for scenarios with administered fuel prices (Wogan 2017).

Natural gas prices for Oman and Qatar are estimated. This analysis assumes Bahrain, Oman, Qatar and the UAE pay the international price for crude oil, assumed here to be $55 per bbl.

Linkage with water sector

A key feature of the electricity sector in all GCC countries is the tight linkage between the electricity system and the water sector (Napoli et al. 2018). The water utilities consume electricity in reverse osmosis (RO) plants, which use membranes to separate desalinated water from saltwater. They also generate electricity with the multi-stage-flash technology, which generates electricity and then uses the remaining heat to distill water from seawater. Most of the multi-stage-flash plants have little flexibility in the mix of electricity and water produced. The range of water to electricity ratios in the more flexible plants is limited, and at times these plants produce excess electricity or water (Wogan 2017). Figure 5 details seawater desalination plant capacities.

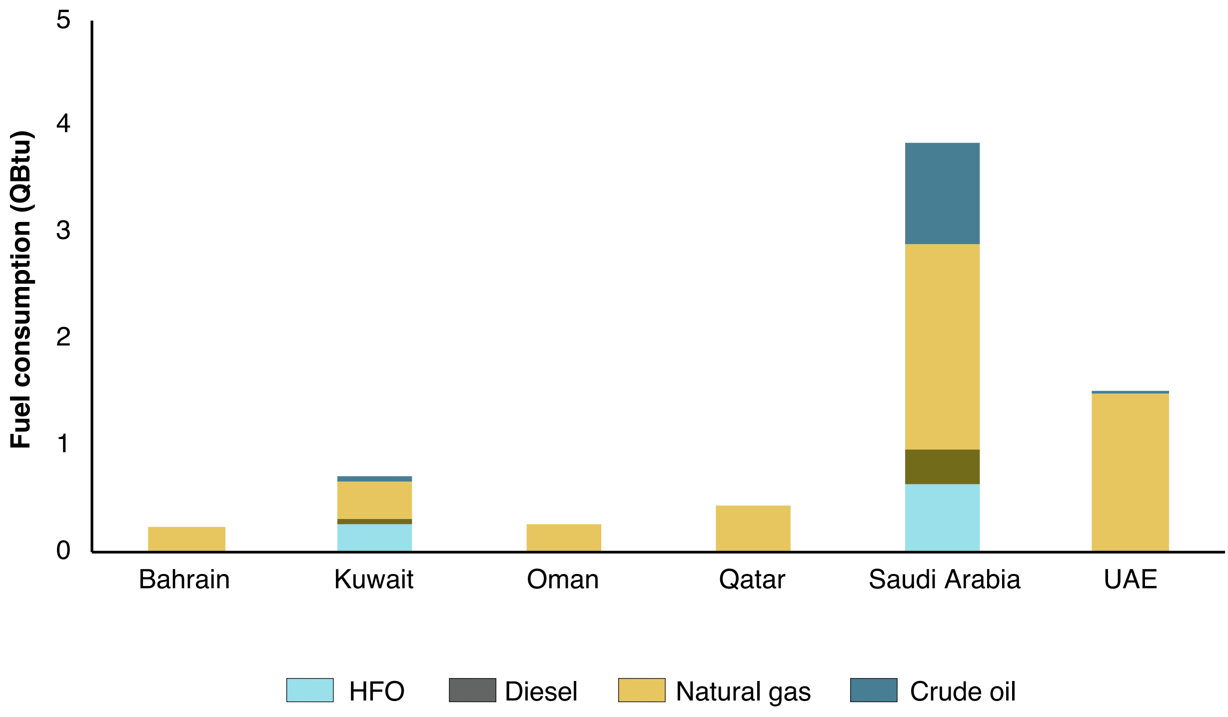

Figure 4. Estimated fuel mix for power and water sectors by GCC member state.

Source: Kingdom of Bahrain National Oil and Gas Authority, Kuwait Ministry of Electricity and Water, Oman Power and Water Procurement Company, KAHRAMAA, UAE Ministry of Energy, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, KAPSARC analysis.

Table 3. Administered fuel prices observed 2015.

	Natural gas ($/MMBtu)	Crude oil ($/bbl)	HFO ($/bbl)	Diesel ($/bbl)
Bahrain	2.75	55.00	N/A	N/A
Kuwait	3.53	42.10	44.43	62.73
Oman	2.00	55.00	N/A	N/A
Qatar	1.50	55.00	N/A	N/A
Saudi Arabia	0.75	4.24	2.26	3.75
UAE	2.00	55.00	N/A	N/A

Source: KAPSARC analysis.

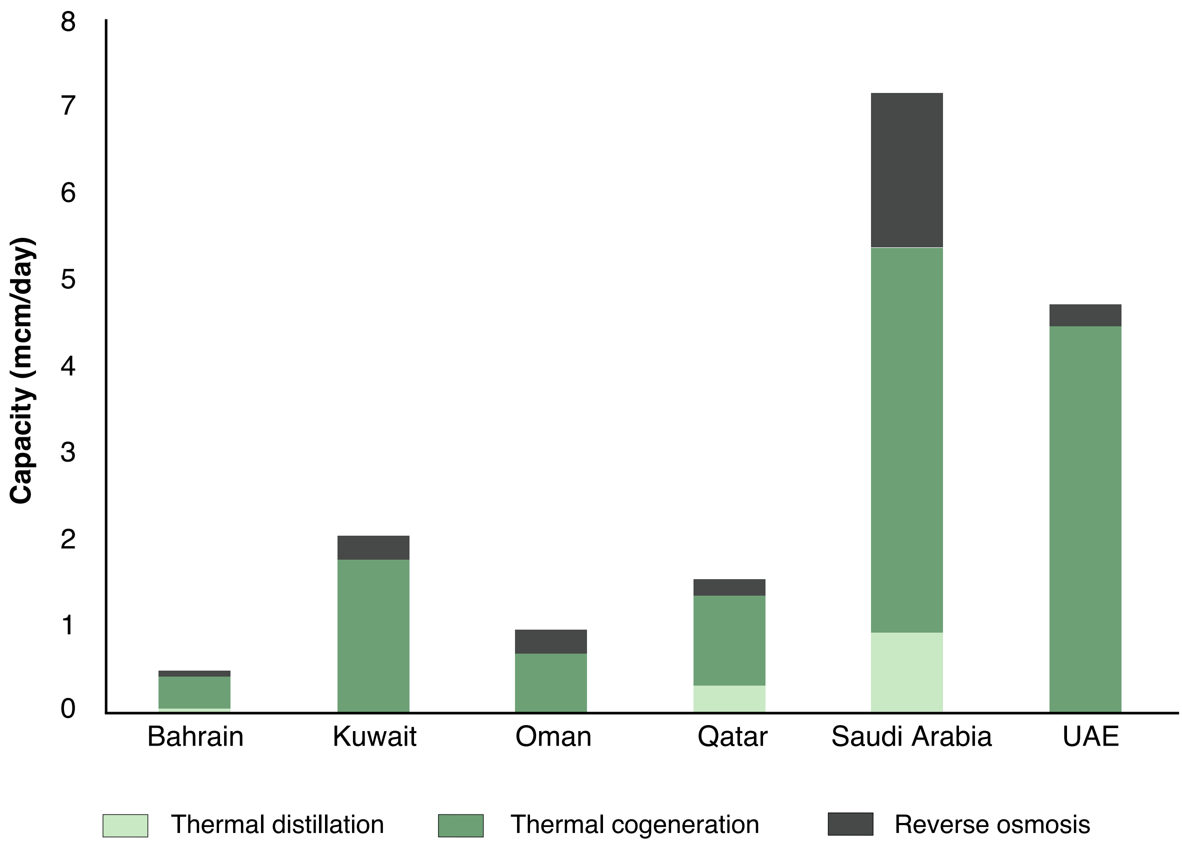

Figure 5. Water production by technology in million cubic meters (m^3) per day.

Source: KAPSARC analysis.

Aggregate GCC capacity for water production is nearly 17 million cubic meters (m^3) per day; 42 percent of this is in Saudi Arabia alone (ECRA 2015). Nearly two-thirds of GCC water production is produced in conjunction with power. Many of these plants operate as base-load units that produce water and electricity mainly in fixed proportions. Saudi Arabia currently has some cogeneration plants that can control the ratio of power and water produced. More efficient RO plants are less than one-fifth of desalination capacity, with most found in Saudi Arabia. As RO technologies consume electricity instead of producing it, more power generation capacity is needed to meet electricity demand.

GCC Interconnector

The Interconnector consists of a main corridor with feed lines to the individual country systems (Figure 6). Capacities of the linkages are 1200 MW for Kuwait, Qatar and Saudi Arabia and 600 MW for Bahrain. The Interconnector backbone does not physically run through the UAE to connect Oman to the system. Instead, the UAE's national grid acts as a bridge to Oman's national grid (Gulf Cooperation Council Interconnection Authority 2017).

There are multiple connection points in Saudi Arabia, but they are modeled as one connection point in the Eastern Province.

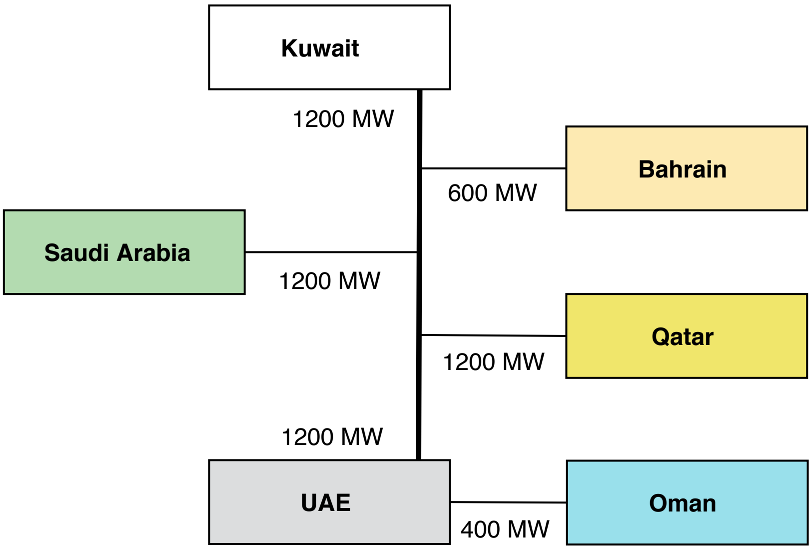

Figure 6. The GCC Interconnector and capacities.

Source: GCCIA 2016, KAPSARC.

Country Overviews

Bahrain

The Kingdom of Bahrain is the smallest member of the GCC in terms of area, population and energy demand. In 2015, it produced a little over 15 TWh of electricity from a mix of thermal cogeneration and power-only plants (Bahrain Information & eGovernment Authority 2018). The energy and water sectors are vertically integrated within the Electricity and Water Authority (Kingdom of Bahrain Electricity and Water Authority 2016). The country has a 600 MW connection to the Interconnector.

The power and water sectors represent 31 percent of the country's natural gas consumption; the industrial sector, which includes aluminum production, represents over 70 percent of national fuel consumption (Kingdom of Bahrain NOGA 2015a). The National Oil and Gas Authority is responsible for setting fuel prices in the Kingdom. Starting in April 2015, the Authority has unified the prices of natural gas to all consumers, set at $2.5 per million British thermal units (MMBtu). The price is set to increase by $0.25 per MMBtu annually until 2021 (Kingdom of Bahrain EWA 2016). Bahrain does not presently import natural gas but has started construction on a liquefied natural gas receiving and regasification terminal to meet future demand.

Kuwait

Kuwait is the third largest electricity producer in the GCC. The Kuwaiti generation fleet is a mix of steam turbines (9.0 GW), OCGTs (7 GW), and CCGTs (2.3 GW) (Kuwait MEW 2015). All plants co-produce desalinated water using multi-stage flash distillers (Wood and AlSayegh 2012). The Kuwaiti connection to the Interconnector has a capacity of 1.2 GW (Figure 6).

Kuwait has the capacity to produce about 2 million m^3 per day of drinking water from thermal cogeneration units and 270 thousand m^3 per day from RO (Kuwait MEW 2016; Wood and AlSayegh 2010). The Ministry of Electricity and Water is responsible for all aspects of the production and delivery of electricity and water, while the fuel prices are set by Kuwait Petroleum Company. Like Saudi Arabia, it consumes a mix of natural gas and Heavy fuel oil (HFO), and small volumes of diesel and crude oil (Kuwait MEW 2016).

Kuwait does not export natural gas and has become increasingly reliant on Liquefied natural gas (LNG) imports to meet domestic demand. Kuwait takes LNG delivery at Mina al-Ahmadi GasPort, which has a baseload capacity of 500 million cubic feet per day (mcfd) and peak capacity of 600 mcfd. Kuwait imported 136 billion cubic feet (bcf) of LNG in 2015 (Excelerate Energy 2016). The price of natural gas seen by the utility varies over time and seems to be priced at the average of the controlled domestic price and the import price.

Oman

Oman's electricity sector has been unbundled for over a decade. The Oman Power and Water Procurement Company is the single buyer of electricity from independent power and water producers (IPWPs) and is responsible for regulating fuel prices and fuel use (OPWP 2015).

Nearly all power-generating plants in Oman are CCGTs. Two-thirds of the capacity is power-only plants while one-third is thermal cogeneration facilities. Natural gas is the only fuel consumed. Oman has the capacity to produce around 950 thousand m^3 per day of water, with three RO plants capable of delivering over a quarter of the production (Oman PAEW 2015; OPWP 2016).

In 2015, Oman produced 358 million bbl/d of crude oil and exported 287 million bbl/d. Natural gas production has grown to 3.1 bcfd (NCSI Oman 2016). One-third of the gas is supplied to power stations and desalination plants, over one-quarter to the Oman LNG liquefaction plant, 10 percent to oil fields for enhanced oil recovery and the remainder to households and industries. Oman is both an importer and exporter of natural gas. In 2015, according to the Oman LNG annual report, the country exported 376 bcf of LNG and imported 69 bcf of natural gas from Qatar via the Dolphin Pipeline. It has been reported that Oman is considering importing LNG to meet domestic demand (Oman LNG 2015; Dolphin Energy Ltd. n.d.).

Oman was the last country to join the Interconnector. It is not directly connected to the main corridor but links with the UAE's national grid, which provides it with 400 MW of capacity (Figure 6) (Fraser and Al-Assad 2008).

Qatar

The power sector in Qatar was reformed in 2000 by separating power generation and water production from transmission and distribution. Currently, the Qatar Electricity and Water Company (QEWC) and independent power and water producers carry out power generation and water production. The QEWC holds shares in these IPWPs, in most cases at more than 50 percent (QEWC 2015). It is responsible for nearly all electricity generation and water supply. The generation mix reflects the availability of low-cost natural gas; the QEWC operates over 8.6 GW of CCGT plants, of which two-thirds are thermal cogeneration units. As of the end of 2015, total water desalination capacity stood at 1.37 million m^3 per day (QEWC 2015). The high penetration of thermal desalination plants means that a significant proportion of Qatar's power capacity must operate to produce drinking water. This constraint limits the flexibility of the system to ramp power production up and down in response to demand.

A 1.2 GW line (Figure 6) connects Qatar to the Interconnector.

Natural gas is the main fuel in Qatar (oil provides a backup) due to its abundance in the country. Power and water producers consumed approximately 1.2 billion cubic feet per day (bcfd) in 2015 (KAHRAMAA 2014). The price paid for natural gas depends on when plant operators signed contracts with Qatar Petroleum. In general, power and water producers pay between $1 to $2 per MMBtu for fuel (Wogan 2017).

Natural gas production and exports dominate Qatar's hydrocarbon output. Production was reported to be 17.3 bcfd in 2015 (OPEC 2016). Liquefaction plants process the natural gas, which is then exported through Dolphin Energy's subsea pipeline, connecting Qatar to the UAE via the Taweelah receiving facilities in Abu Dhabi. Natural gas exports totaled 4.6 tcf in 2015, with nearly 700 bcf delivered by the pipeline (OPEC 2016). Of that amount, Abu Dhabi consumed 360 bcf, Dubai took 260 bcf and Oman the remaining 69 bcf (Dolphin Energy Ltd. n.d.). More than 3.9 tcf was sold as LNG on long-term and spot contracts. Qatar produced 230 million bbl/d of crude oil and exported 170 million bbl/d (OPEC 2016).

Saudi Arabia

Saudi Arabia is the largest member of the GCC geographically and has the highest population and electricity demand. Because of its size, transmitted electricity can travel long distances and the regional distribution of production and consumption is important. Saudi Arabia is connected to the Interconnector via a 1.2 GW line from the Eastern Province (Figure 6).

Its generation mix, skewed toward steam plants, with oil and gas the primary fuels, reflects its fuel subsidies. Some plants consume crude oil directly while others burn residual oil or distillate. The newest plants tend to be combined-cycle, natural-gas plants. The government sets the fuel prices for diesel at $3.60 per bbl, residual oil at $2.08 per bbl whether desulfurized or not, crude oil at $4.25 per bbl, and natural gas at $0.75 per MMBtu (in 2015) (Wogan 2017; Elshurafa et al. 2017).

Saudi Arabia has over 81 GW of power-only capacity installed, with gas turbines accounting for nearly half, and steam turbines and combined cycle units making up the remainder. A significant amount of thermal desalination capacity (9.4 GW) exists in the three regions adjacent to the Red Sea and the Arabian Gulf, with a combined capacity to desalinate over 7.2 million m^3 per day. The water consumed in the central region comes from a large aquifer and desalination plants. The eastern region mainly consumes desalinated water. Thermal-based cogeneration accounts for three-quarters of water production, with the remaining quarter coming from RO (ECRA 2015).

Saudi Arabia is the largest crude oil producer in the GCC, with production reaching 3.7 billion bbl/d in 2015 (Saudi Aramco 2015). Crude oil exports amounted to 2.6 billion bbl/d in 2015 (OPEC 2016). Currently, nearly all 2.9 tcf of natural gas production in the country is associated with oil, and there is minimal non-associated gas production. A critical issue is that the price it sets for natural gas is below the cost of developing non-associated gas reserves, supplies are limited, and the available natural gas is rationed to a range of users. The allocation limits the use of natural gas for electricity generation, which leads to increased oil consumption. Currently, the production of associated gas is profitable. Under World Trade Organization rules, Saudi Arabia can charge its current price because it does not subsidize the gas. However, if the country were to import gas at the world price, it would have to become the market price. Because of this Saudi Arabia cannot import gas and keep it below-market prices; the country has chosen rationing over imports.

United Arab Emirates

The UAE power sector comprises regional autonomous entities that independently manage their power. Most of these regional entities have a vertically integrated power structure. Abu Dhabi is the exception in that generation, transmission and distribution function separately under an independent regulator (Abu Dhabi RSB 2013). Independent power producers (IPPs), which are partially owned by the government, generate nearly 96 percent of Abu Dhabi's power. The Abu Dhabi Water and Electricity Company purchases through bidding processes under power purchase agreements. Transmission of electricity and water is carried out by the Abu Dhabi Transmission and Dispatch Company.

The UAE connects to the GCC Interconnector through a 1.2 GW line to Saudi Arabia and provides a 400 MW line to Oman (Figure 6). Like Oman, the UAE does not have dedicated Interconnector infrastructure among its states. Instead, it transmits power through its national grid (Fraser and Al-Assad 2008).

Of nearly 29 GW of power generation capacity in the UAE, around 90 percent is cogeneration capacity used to desalinate seawater. Most of the power and water capacity is in Abu Dhabi and Dubai, including 60 MW of solar PV. Sharjah and the Federal Electricity and Water Authority purchase electricity from the Emirates National Grid as they have limited power generation capacity. Combined cycle cogeneration technology accounts for nearly 73 percent of capacity, followed by steam cogeneration (19 percent) (United Arab Emirates Ministry of Energy and Industry 2017). RO makes up 5 percent of the UAE's water production capacity (UAE FEWA 2015).

It is difficult to ascertain the fuel prices paid by the utility sector in the UAE as they are not publicly available. Abu Dhabi produces natural gas and receives deliveries from the Dolphin pipeline – reportedly at $1.30/MMBtu (Neuhof 2013). Dubai draws gas from the Dolphin pipeline and receives LNG deliveries at the Jebel Ali terminal. The price paid by utilities might be an average cost from all sources, or it might be that the low price is maintained, and the upstream sector takes a financial loss when selling fuel. Boersma and Griffiths report that the Abu Dhabi National Oil Company calculates the production cost of associated gas at $1/MMBtu (Boersma and Griffiths 2016). A recent study by Lahn estimated natural gas prices at between $1/MMBtu and $2/MMBtu (Lahn 2016).

The UAE is the second-largest GCC energy producer after Saudi Arabia. The emirate of Abu Dhabi leads energy production, accounting for nearly all the UAE's production and exports. In 2015, Abu Dhabi produced 1.07 billion bbl/d of crude oil and exported 0.89 billion bbl/d. The emirate produced 2.8 tcf of natural gas in 2015, which was used to supply industrial sectors, produce liquefied fuels and products for export, and supply liquefaction trains (ADWEC 2014). Gas exports reached 4.4 tcf in 2015, with 720 bcf transiting through the Dolphin pipeline (Dolphin Energy Ltd. n.d.; OPEC 2016).

The emirate of Dubai, by contrast, is not well-endowed with hydrocarbon resources. Dubai produced small volumes of crude oil (0.01 billion bbl/d) and natural gas (39 bcf) in 2013. The Jebel Ali LNG Import Terminal receives natural gas (350 bcf) (Excelerate Energy 2016).

Methodology

This analysis employs the KAPSARC Energy Model for the GCC (KEM-GCC) to explore the potential benefits and costs of using the Interconnector for economic exchanges of electricity. KEM-GCC is an extension of the KAPSARC Energy Model for Saudi Arabia, developed to study the energy-intensive sectors of Saudi Arabia. KEM-GCC has been used to study the role of subsidy reforms (Matar et al. 2017). A key feature of KEM-GCC is its ability to represent a range of regulations, allowing an estimation of the consequences of government policies and interventions in energy markets (Murphy, Pierru and Smeers 2016).

This study calibrated the model to reproduce the fuel mix and technology utilization reported in 2015. The following technologies are available for deployment in the model: steam turbines, OCGTs, CCGTs, PV, concentrated solar power (CSP), nuclear, wind, and thermal desalination. OCGTs can be converted to CCGTs. Technology costs from the U.S. Energy Information Administration (EIA) are used for thermal technologies, and International Energy Agency (IEA) costs for renewable technologies (presented in Appendix A, Table A1) (U.S. Energy Information Administration 2017).

To capture the geographic dispersion of electricity and water production and consumption, the study disaggregated the six GCC states into 12 regions. Bahrain, Kuwait and Qatar are each represented as individual regions due to their small size. For simplicity, Oman was also considered as a single region even though it has three electricity systems: the Main Interconnected System, which includes Muscat; the Dhofar Power System, which includes Salalah; and the Rural Areas System. Saudi Arabia was divided into four regions (east, west, south and central) that correspond to the service area definitions of the Saudi Electricity Company. The UAE was represented as four regions: Abu Dhabi, Dubai, Sharjah and the Federal Electricity and Water Authority, which encompasses the remaining emirates.

Electricity transmission is represented between regions using a transshipment formulation. An optimal power flow representation was studied for Saudi Arabia and resulted in substantial impacts based on physics and operation of transmission (Matar and Elshurafa 2017). Formulating KEM-GCC as a transmission model could represent the physics and operation of transmission more accurately and is a possible avenue for further research.

At the time of publication, Saudi Arabia and Qatar have ceased diplomatic relations. For this reason, this study did not consider electricity exchange with Qatar except as a sensitivity analysis.

Scenarios

The study first established a baseline using the current policies of each country. It then compared the economic surplus with current policies with complete fuel price deregulation. Economic surplus was defined as the gain in revenue from additional fuel exports and the savings from reduced fuel consumption and avoided capacity investments. Economic surplus generally includes a measure of consumer benefits. However, this study presumed the prices of electricity are fixed and consumer surplus is constant. Deregulation provides an estimate of the largest possible economic surplus. Since complete deregulation is unlikely, this study examined alternative regulations and estimated surplus measures, providing trade-offs between economic efficiency and the degree of government control:

> No coordination: The baseline scenario where the Interconnector is not used and the GCC countries implement all current pricing and rationing policies.

Subsidy exports: An investigation of the magnitude of fuel subsidies that would be exported. The GCC countries implement all current pricing and rationing policies and electricity can flow through the Interconnector.

Fuel price deregulation: An examination of efficiency gains by setting all fuel prices to marginal costs (or world market prices). Electricity does not flow through the Interconnector.

Deregulated exchange: An estimation of the gains by setting all prices to marginal costs (or world market prices) and letting electricity flow through the Interconnector.

Renewable exports: A scenario that prevents exports of subsidies-by-wire, by using current fuel prices and allowing only renewable energy to flow through the Interconnector.

Hybrid pricing: Increasing the quantity of energy that can be exchanged by introducing different prices for domestic consumption and exports. It keeps current prices for domestic consumption and charges marginal costs for fuels and equipment used to produce electricity sent through the Interconnector. The electricity a country sends to the Interconnector does not exceed the electricity they generate from unsubsidized fuels.

In all scenarios, Interconnector capacity and energy and water demand were kept at 2015 levels (see Tables 2 and 3). The baseline and all alternative scenarios policies reflect a long-run equilibrium where new, more efficient capacity can replace existing inefficient capacity (there are no lead times for technology deployment). Nuclear and coal plants were not considered as alternatives because none were deployed in 2015.

This study used the annualized capital cost of newly built capacity to calculate the estimated benefits or costs of a policy. It measured the value of fuel savings and added consumption using opportunity costs. For fuels that are imported or exported, the cost is the border price, while the cost for fuels not imported, or exported, is the shadow price (determined endogenously). Table 3 contains the administered prices for fuels by country. A price of $55 per bbl is assumed for international oil. LNG can be imported for $9 per MMBtu and exported at a netback price of $7 per MMBtu.

Analysis

No coordination: Establishing a baseline

In this scenario, the utilities do not send electricity through the Interconnector.

Modest capacity expansion occurs in this scenario. Saudi Arabia converts 3.4 GW of OCGTs to CCGTs. Kuwait deploys 2 GW of new thermal desalination capacity. Because fuel prices are kept low, renewables are uneconomical and no capacity is added. Electricity production, particularly in Saudi Arabia and the UAE, utilizes steam and OCGTs with substantial thermal desalination (Figure 7).

The counterfactual scenarios are assessed against this scenario.

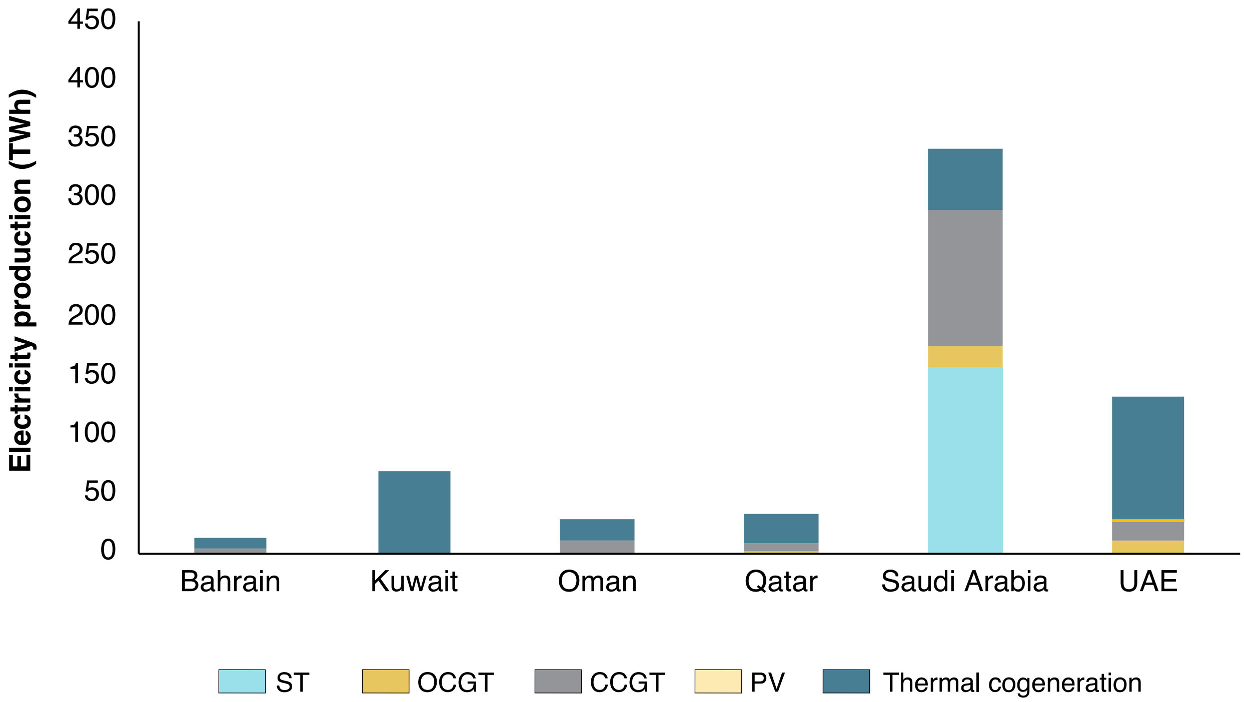

Figure 7. Electricity production by technology in the ‘no coordination’ scenario.

Source: KAPSARC analysis.

Subsidy exports: The consequences of using the connector without price reform

In the absence of full energy price reform, electricity exports would transfer subsidies from one country to another through production using subsidized fuels. This is a key barrier to market-based electricity trade in the GCC. To estimate the magnitude of subsidy transfers by wire, the 'no coordination' scenario was modified by allowing electricity flows between countries with electricity produced at administered fuel prices.

This study estimates that over 31 TWh of electricity would cross borders (Table 4). In this scenario, Saudi Arabia is the largest net exporter of electricity (24.1 TWh), a consequence of having the lowest fuel prices in the GCC (Table 3). Kuwait is the largest recipient of Saudi Arabian electricity (11.7 TWh), decreasing its consumption of HFO by 40 percent. The UAE cuts LNG imports by 75 percent by importing electricity.

The value of fuel subsidies in the exported electricity is calculated by multiplying the incremental fuel consumption in Saudi Arabia by the difference between the international fuel price and the administered price. This study estimates the outflow of subsidies from Saudi Arabia at $2.2 billion. This amount is equivalent to the estimate of the amount spent on Saudi Arabian fuel consumption in the 'no coordination' scenario. Saudi Arabian crude oil consumption increased by 115 thousand bbl/d over 'no coordination'.

The loss in economic surplus for Saudi Arabia is $4.4 billion. Consequently, restricting the Interconnector to emergencies makes economic sense with current fuel pricing. For trading to be economical, the study now looks at alternative scenarios for fuel pricing. Fuel price deregulation with trading offered the largest gain in economic surplus. The study first estimates the economic gains with fuel price deregulation but no trading, to understand the value of economic trading separately from fuel price deregulation.

Table 4. Cross-border electricity flows with subsidy leakage.

	To						
From	**Bahrain**	**Kuwait**	**Oman**	**Qatar**	**Saudi Arabia**	**UAE**	**Gross exports**
Bahrain					0.05		0.1
Kuwait							0.0
Oman						2.44	2.4
Qatar							
Saudi Arabia	5.8	11.7				8.3	25.8
UAE			1.44		1.58		3.0
Gross imports	5.8	11.7	1.4		1.6	10.8	31.3
Net imports	-5.7	-11.7	1.0		24.1	-7.7	

Source: KAPSARC analysis.

Fuel price deregulation without trading

For this scenario, fuel prices are no longer administered and instead reach values determined by supply and demand. The system, representing all GCC countries, gains $41 billion in economic surplus from efficiencies induced by higher fuel prices.

Higher fuel prices drive the deployment of almost 67 GW of CCGTs and 7.8 thousand cubic meters per day (mcmpd) of RO desalination (Table 5). Higher fuel prices make PV cost-effective for Saudi Arabia. The economic benefit for Saudi Arabia is $31 billion.

CCGTs supply 80 percent of electricity production (Figure 8). Steam turbines and open-cycle gas turbines are used during peak load segments. CCGTs replaced nearly 50 percent of the existing capacity. This result reveals the amount of inefficiency in the existing electricity system, where substantial steam and open-cycle turbine capacity become too costly to operate due to higher heat rates and higher fuel costs.

The power system becomes more flexible with the introduction of RO capacity, which decouples power and water production. This change allows power production to ramp up without an increase in water production. RO capacity can increase or decrease output to meet water demand without requiring power production to follow.

Electricity production becomes more efficient. Total GCC fuel consumption decreases by 29 percent, driven by the deployment of CCGTs and the substitution of natural gas for oil and oil products. Fuel savings translate directly to an increase in exports for Oman, Qatar and Saudi Arabia (Table 6).

Kuwait offsets HFO consumption by increasing LNG imports. With the removal of fuel quotas in Saudi Arabia, natural gas consumption increases. In the UAE, fuel savings eliminate the need for LNG imports. Saudi Arabia consumes 38 percent less energy while producing the same quantity of electricity as before.

Table 5. Capacity additions in the ‘fuel price deregulation scenario’ for power plants (GW) and RO plants (mcmpd).

	OCGT conversion	CCGT new build	PV	Total power	RO
Bahrain					0.1
Kuwait		7.5		7.5	0.8
Oman		3.5		3.5	0.2
Qatar	0.1	1.7		1.8	0.7
Saudi Arabia	3.4	40.2	13.2	56.8	3.6
UAE	0.1	10.5		10.6	2.3
Total	3.5	63.4		80.2	7.8

Source: KAPSARC analysis.

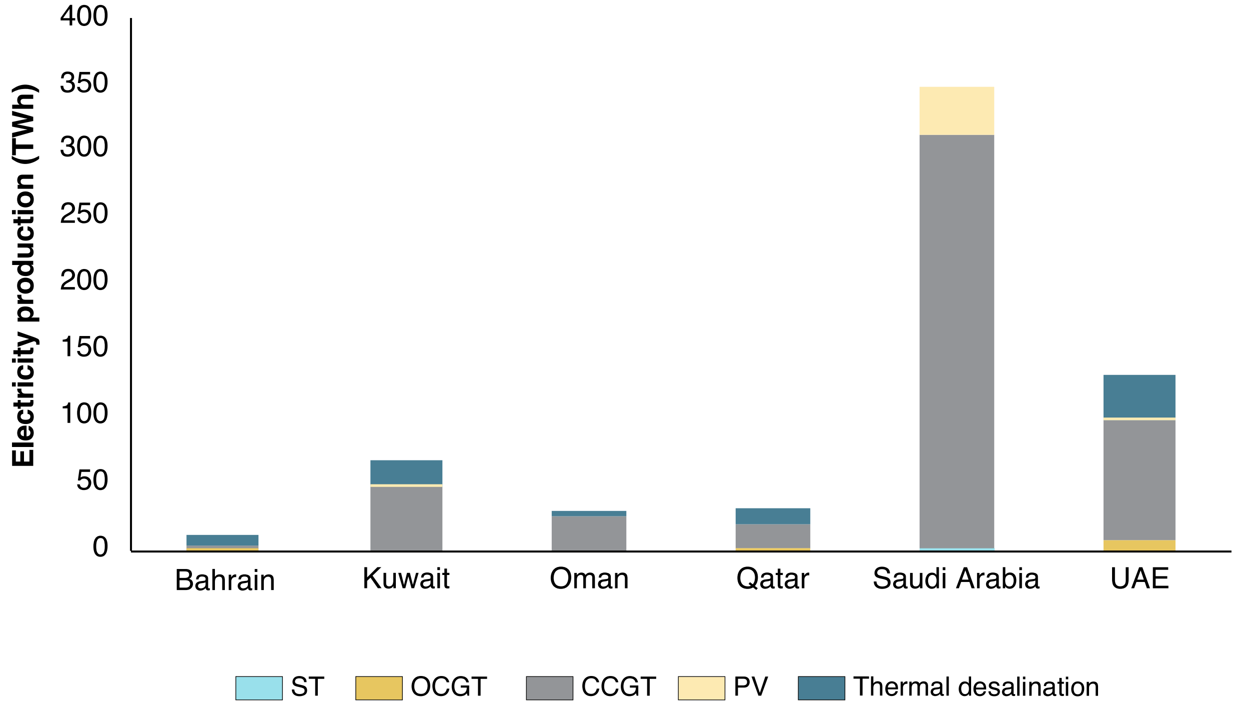

Figure 8. Electricity production by technology in the 'fuel price deregulation' scenario (TWh).
Source: KAPSARC analysis.

Table 6. Change in natural gas and crude oil in 'fuel price deregulation' relative to the 'no coordination' scenario.

	Natural gas (bcf)			Crude oil (MM bbl)	
	Consumption	**Imports**	**Exports**	**Consumption**	**Exports**
Bahrain	-0.1				
Kuwait	65.5	66.2		-0.1	0.1
Oman	-51.7		52.3		
Qatar	-40.9		41.3		
Saudi Arabia	11.8			-78.3	78.3
UAE	-208.8	-210.9			
Total	-224.3	-144.8	93.5	-78.4	78.4
Change	-7%	-34%	2%	-7%	1%

Source: KAPSARC analysis.

Deregulated exchange: Estimating the potential for using the Interconnector with fuels priced at market

Coupling electricity exchange and fuel subsidy removals adds an incremental benefit of $560 million annually for an overall economic gain of $42 billion. This scenario is the technically and economically optimal market outcome. The five independent energy systems effectively become one integrated system that meets demand in each region at least cost by coordinating investment decisions and electricity transmission through pricing signals.

This study observed that roughly the same quantity of electricity could be exchanged when treating the GCC as a single integrated system of five members, excluding Qatar, with deregulated fuel prices as in the ‘subsidy export’ scenario (Table 7). The flows reversed, with Saudi Arabia becoming a net importer of electricity (27.7 TWh), while Kuwait and Qatar became net exporters.

Desalination via RO plants increases electricity demand in Saudi Arabia. CCGTs and 13 GW of newly deployed PV combined with electricity imports meet this demand (Table 8 and Figure 9). As seen in the ‘fuel price deregulation’ scenario, the deployment of CCGTs and subsequent electricity production creates a more flexible power system by decoupling power and water production. The capacity additions in Qatar are the result of deregulation without electricity exchange.

For Saudi Arabia, importing electricity offsets crude oil consumption, freeing 296 thousand bbl/d for export. From a GCC system perspective, revenue from exporting more crude outweighs the opportunity costs of consuming gas.

Table 7. Cross-border electricity transmission (TWh) in the ‘deregulated exchange’ scenario

	To						
From	**Bahrain**	**Kuwait**	**Oman**	**Qatar**	**Saudi Arabia**	**UAE**	**Gross exports**
Bahrain					5.3		5.3
Kuwait					11.4		11.4
Oman						3.7	3.7
Qatar							
Saudi Arabia	0.5	0.1				0.1	0.7
UAE			0.2		11.6		11.8
Gross imports	0.5	0.1	0.2		28.4	3.7	32.9
Net imports	4.8	11.3	3.5		-27.7	8.1	

Source: KAPSARC analysis.

Table 8. Capacity additions in the 'deregulated exchange' scenario for power plants (GW) and RO plants (bcm).

	OCGT conversion	CCGT new build	PV	Total (GW)	RO (bcm)
Bahrain		0.9		0.9	0.2
Kuwait		8.5		8.5	0.8
Oman		3.8		3.8	0.2
Qatar	0.1	1.7		1.8	0.7
Saudi Arabia	3.4	37.1	13.3	53.8	3.6
UAE	0.1	11.7		11.8	2.3
Total	3.5	63.8	13.3	80.6	7.9

Source: KAPSARC analysis.

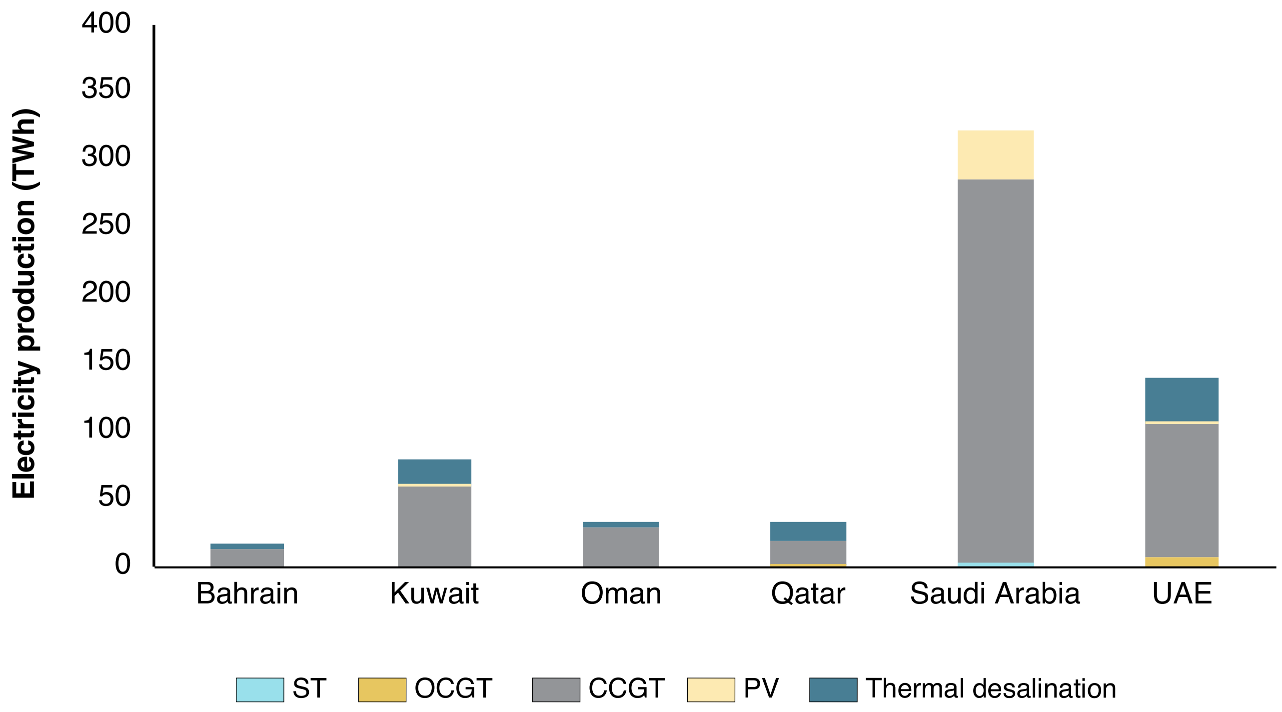

Figure 9. Electricity production by technology in the 'deregulated exchange' scenario (TWh).
Source: KAPSARC analysis.

Table 9. Change in natural gas and crude oil use between the 'no coordination' and 'deregulated exchange' scenarios.

	Natural gas (bcf)			Crude oil (MM bbl)	
	Consumption	Imports	Exports	Consumption	Exports
Bahrain	1.9			2.7	-2.7
Kuwait	128.8	130.1		-0.1	0.1
Oman	-32.1		32.4		
Qatar	-40.9		41.3		
Saudi Arabia	10.1			-108.3	108.3
UAE	-168.0	-169.7			
Total	-100.1	-39.5	73.7	-105.8	105.8
Change	-3%	-9%	1%	-10%	2%

Source: KAPSARC analysis.

Deregulated exchange including Qatar

This analysis considered electricity trade including Qatar. Total exchange increases to over 44 TWh – an increase of 35 percent from deregulated exchange without Qatar. Saudi Arabia is a net importer of electricity (39 TWh), while Kuwait, Qatar and the UAE become net exporters. Qatar sent 11.7 TWh of gas-by-wire to Saudi Arabia (Table 10).

Table 10. Change in natural gas and crude oil use between the 'no coordination' and 'deregulated exchange' scenarios.

	To						
From	Bahrain	Kuwait	Oman	Qatar	Saudi Arabia	UAE	Gross exports
Bahrain					5.3		5.3
Kuwait					11.4		11.4
Oman						3.7	3.7
Qatar					11.7		11.7
Saudi Arabia	0.5	0.1		0.0		0.1	0.7
UAE			0.2		11.6		11.8
Gross imports	0.5	0.1	0.2	0.0	40.1	3.7	44.6
Net imports	4.8	11.3	3.5	11.7	-39.3	8.1	

Source: KAPSARC analysis.

Table 11. Change in natural gas and crude oil use when Qatar participates in electricity exchange.

	Natural gas (bcf)			Crude oil (MM bbl)	
	Consumption	Imports	Exports	Consumption	Exports
Bahrain	1.9			2.7	-2.7
Kuwait	128.8	130.1		-0.1	0.1
Oman	-32.1		32.4		
Qatar	22.4		-22.7		
Saudi Arabia	9.0			-120.9	120.9
UAE	-168.0	-169.7			
Total	-37.9	-39.5	9.8	-118.3	118.3
Change	-1%	-10%		-11%	2%

Source: KAPSARC analysis.

Saudi Arabia exports an additional 331 thousand bbl/d when Qatar participates in the GCC exchange (Table 11).

Total economic gain increases by an additional $240 million with Qatar included, to $810 million relative to the 'no coordination' scenario. This figure is proximate to the estimate reported by the GCCIA of around $1.3 billion in annual savings from electricity trade (Gulf Cooperation Council Interconnection Authority 2017).

These results suggest that including Qatar in electricity exchanges would deliver net economic gains for all countries.

Enable GCC transmission at deregulated prices while retaining the administered prices for domestic sales

The GCC countries might want to maintain low domestic energy prices while exporting electricity to each other. Electricity exports maintain reliability (Gulf Cooperation Council Interconnection Authority 2017). This paper now explores two options. The first permits exporting electricity produced just from renewable sources. The second introduces a two-tiered fuel price regime, where electricity is produced for domestic consumption at administered prices and electricity for export is produced at market prices. Electricity is then exported with prices set to marginal costs. This hybrid approach is a compromise between retaining the rent transfers from state to citizenry in the form of low-cost energy services and finding higher value uses for fuel resources through electricity exports.

The quantity of cross-border transmission is limited to the quantity of electricity produced from renewable sources and/or fuels at market value.

This prevents subsidized electricity from being exported. It is impossible to track or manage individual electrons, but this mechanism is sufficient to distinguish production at different fuel prices and by renewables.

Renewable electricity exports

Saudi Arabia exports 4.4 TWh of renewable energy to Kuwait annually. Saudi Arabia invests in 1.3 GW of large-scale PV, but subsidized fuel prices dampen the economic prospects of additional renewable energy deployment. Investment costs lead to an economic loss of $1.5 billion. The impact on fuel consumption and imports is marginal.

Hybrid pricing

Again, Saudi Arabia is the only significant net exporter of electricity, with 11.7 TWh of exports (out of 11.8 TWh total). Kuwait is the largest recipient (11.7 TWh). The hybrid pricing scheme reduces total electricity exports by over one-third compared to the ‘subsidy leakage’ scenario (Table 11).

Renewable capacity is not deployed, given the low price of domestic electricity. No significant decoupling of the power and water sectors occurs because thermal desalination plants are still economical when consuming subsidized fuels.

Table 11. Cross-border electricity flows with hybrid pricing.

	To						
From	**Bahrain**	**Kuwait**	**Oman**	**Qatar**	**Saudi Arabia**	**UAE**	**Gross exports**
Bahrain							
Kuwait							
Oman							
Qatar							
Saudi Arabia		11.7				0.1	11.8
UAE					0.04		
Gross imports		11.7				0.1	11.8
Net imports		-11.7			11.7	-0.1	

Source: KAPSARC analysis.

This scenario reveals that even with two pricing tiers, subsidies are exported indirectly as electricity. In Saudi Arabia, gas and crude oil consumption increase. CCGTs consume marginally priced natural gas for electricity export. CCGT capacity and gas supply become fully utilized. Crude oil consumption increases to meet domestic electricity demand and is used on the margin in less-efficient steam and OCGTs (Table 12). Electricity imports substitute the consumption of HFO and diesel in Kuwait. LNG imports also increase.

Economic surplus decreases by $1.4 billion relative to the no ‘coordination’ scenario – an economic surplus $100 million greater than the renewable-only exchanges.

Table 12. Change in natural gas and crude oil use between the ‘hybrid pricing’ and ‘no coordination’ scenarios.

	Natural gas (bcf)			Crude oil (MM bbl)	
	Consumption	Imports	Exports	Consumption	Exports
Bahrain					
Kuwait	73.6	74.3		-0.1	0.1
Oman					
Qatar					
Saudi Arabia	3.8			21.1	-21.1
UAE	-0.2	-0.2		0.0	0.0
Total	77.1	74.1		21.0	-21.0

Source: KAPSARC analysis.

Expanding the Interconnector

Based on this study's modeling, only 5 percent of total GCC electricity demand would be exchanged with the current Interconnector capacity in the 'deregulated exchange' scenario. This quantity increases to 27 percent (168 TWh) when capacity expansion is allowed (assuming deregulated fuel prices and incorporating Qatar). The deregulated gas price paid by Qatari generators is greater than the netback price of $7 per MMBtu. Saudi Arabia becomes the largest importer of gas-by-wire from Qatar (126 TWh), which requires an additional 11.9 GW of capacity between Qatar and Saudi Arabia (Figure 10), or ten times the existing capacity.

Electricity imports substitute for Saudi Arabian electricity production using HFO, diesel and crude oil. As a result, oil exports increase by 600 million bbl/d. While the link between the UAE and Oman is not a dedicated GCCIA line, an additional 1.9 GW of capacity could be added.

Adding Interconnector capacity and export of Qatari gas-by-wire enables the largest economic gain to the GCC: $42.5 billion.

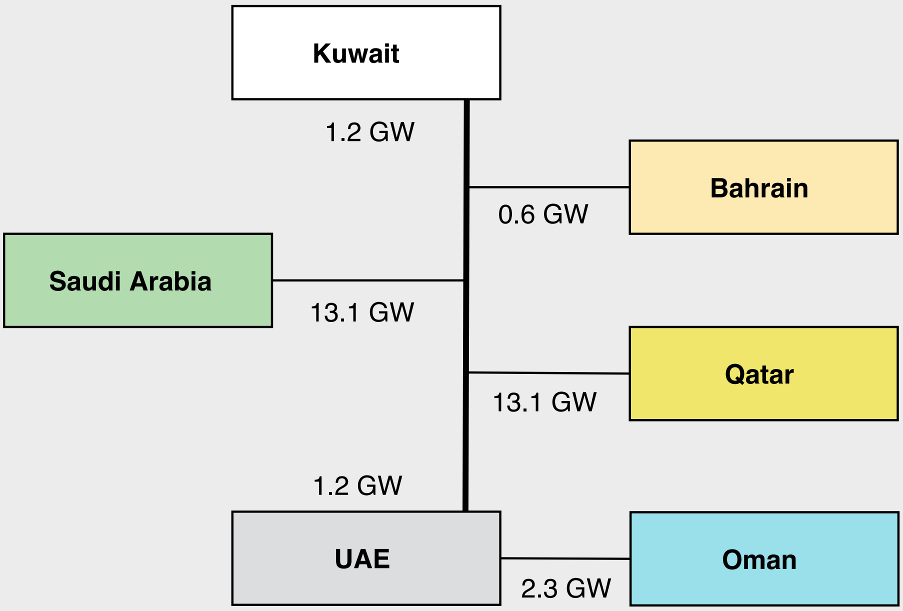

Figure 10. Interconnector capacities after expansion (in GW).

Source: KAPSARC analysis.

Total System Costs

As seen in the results above, some countries gain economically from the export or import of electricity. This analysis computes the costs and gains for each country in each scenario. The net gain is calculated as the revenue from fuel exports net of capital investment, less fuel imports and operation and maintenance costs. Capital costs are discounted over the lifetime of the equipment. The revenue and costs of exporting and importing electricity are included in the calculation. The net effect is observed at a country level and netted out at a regional system level. Table 13 details the incremental gains of each scenario relative to the 'no coordination' scenario.

The bulk of the gains ($41.4 billion) are the result of subsidy removal, which induces investment in and the operation of more efficient technologies. The incremental gain of adding electricity exchange on top of fuel price deregulation is $810 million (when including Qatar), for a total of $42 billion in annual economic surplus. Saudi Arabia realizes the largest gain because it substitutes expensive electricity production from crude oil (in terms of opportunity cost) with electricity imports and more efficient utilization of natural gas. The UAE also exports electricity, and the newly deployed CCGTs provide efficiency gains that lower its production costs and contribute to higher export revenues.

For comparison, the estimated total economic gain is much larger than the value published by the GCCIA, which expects an estimated annual average saving of $1.3 billion over the next 25 years. One possible explanation is that the GCCIA estimates do not fully capture the gains from subsidy removal, which are substantial, as shown in this analysis. This analysis considers the structural shifts induced by fuel subsidy removal, and specifically includes the opportunity cost of fuels in its calculation.

The incremental change is positive, which suggests the value of a policy package that couples fuel price deregulation with coordination. Each country sees a positive change, key for the feasibility of a regional policy. Given that the results are for single year static counterfactuals, larger gains are possible over a multi-year horizon.

Table 13. Incremental gains relative to the 'no coordination' scenario (in billion 2015 U.S. dollars).

	Subsidy export	Fuel price deregulation	Deregulated exchange	Renewable exports	Hybrid pricing
Bahrain	0.1	0.4	0.4		
Kuwait	0.5	1.4	1.5	0.2	0.4
Oman	-0.1	1.3	1.3	31.9	
Qatar	0.0	1.6	1.6	-31.9	
Saudi Arabia	-4.3	30.6	31.0	-1.7	-1.8
UAE	1.0	6.0	6.1		
Total system	-2.8	41.4	42.0	-1.5	-1.4

Source: KAPSARC analysis.

Conclusion

This analysis explored the potential utilization of energy exchanges using the Interconnector, and quantified costs and benefits to the GCC as a whole, and individual GCC member states. The expected benefits of coordinating electricity production and distribution among member states are lower system costs through avoided capacity investment, reduced fuel consumption and greater fuel exports.

Fuel subsidies are the key barrier to regional electricity exchanges. Without full energy price reform, electricity exports would transfer subsidies from one country to another in the form of subsidized fuels. This is a key barrier to market-based electricity trade in the GCC. This study estimates that Saudi Arabia exports nearly eight times as much electricity as Oman or the UAE (26 TWh) since it charges its utility the lowest fuel prices in the GCC.

This study finds that removing fuel subsidies delivers the largest economic gains in the GCC – over $41 billion annually – through investment in more efficient capacity. Coupling electricity exchange with subsidy removals would lift the annual economic gain to $42 billion. Over 32 TWh, or 5 percent, of GCC electricity production would be exchanged at market prices. The UAE, Kuwait, and Qatar are the largest net exporters, while Saudi Arabia becomes the largest net importer of electricity (28 TWh) – equivalent to 8 percent of its demand.

Substantial investment would accompany an integrated regional electricity system. More efficient CCGTs and utility-scale PV would replace nearly 50 percent of existing capacity at a cost of $7.3 billion. Foregone subsidies can be applied to consumer bills, making the same income transfer while achieving the benefits of trade.

Given that the results are for single-year static counterfactuals, larger gains are possible over a multi-year horizon. The next phase of this analysis will explore the potential for electricity exchange over multiple years. This will provide insight into the evolution of the GCC power system by considering technology lead times and growth in energy and water demand. The study will incorporate the 5.6 GW nuclear capacity under construction in Abu Dhabi, and the planned nuclear deployments in Saudi Arabia and their roles in an interconnected regional electricity system.

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Appendix A: Technology Costs

Table A1. Technology costs used in KEM-GCC. Source: EIA, IEA.

Technology	Capital cost ($/GW)	Variable O&M ($/GWh)	Fixed O&M ($/GW)
Steam turbine	1026	3420	17.2
OCGT	1026	4430	17.2
CCGT (new build)	911	3420	10.7
CCGT (converted)	180	3420	10.7
Nuclear	5288	2250	98.1
PV	2360		24
CSP	5250		210
Wind	2020		50

Source: KAPSARC analysis.

Appendix B: Electricity Production By Technology

Table B1. Electricity production in the ‘no coordination’ scenario.

	ST	OCGT	CCGT	PV	Thermal desalination	Total
Bahrain		0.3	4.1		8.1	12.4
Kuwait					69.0	69.0
Oman			10.1		19.4	29.5
Qatar		1.2	7.5		25.8	34.4
Saudi Arabia	157.6	17.7	115.3		51.3	341.9
UAE		12.3	15.8	0.1	105.6	133.8
Total	157.6	31.4	152.8	0.1	279.1	621.1

Source: KAPSARC analysis.

Table B2. Electricity production in the ‘subsidy exports’ scenario.

	ST	OCGT	CCGT	PV	Thermal cogeneration	Total
Bahrain		0.1	3.5		3.6	7.3
Kuwait					58.4	58.4
Oman			11.3		19.1	30.4
Qatar		1.2	7.5		25.8	34.4
Saudi Arabia	172.9	24.2	115.3		51.3	363.7
UAE		7.8	16.7	0.1	99.8	124.5
Total	172.9	33.4	154.3	0.1	258.1	618.7

Source: KAPSARC analysis.

Table B3. Electricity production in the 'fuel price deregulation' scenario.

	ST	OCGT	CCGT	PV	Thermal cogeneration	Total
Bahrain		0.3	4.2		8.0	12.4
Kuwait			48.8		20.2	69.0
Oman			26.7		3.3	30.0
Qatar		1.2	18.6		12.4	32.1
Saudi Arabia	2.6		309.1	36.1		347.9
UAE		7.0	90.5	0.1	33.9	131.6
Total	2.6	8.5	497.8	36.3	77.8	623.0

Source: KAPSARC analysis.

Table B4. Electricity production in the 'deregulated exchange' scenario.

	ST	OCGT	CCGT	PV	Thermal cogeneration	Total
Bahrain			13.1		3.6	16.8
Kuwait			58.3		20.8	79.1
Oman			29.8		3.3	33.1
Qatar		1.2	18.6		12.4	32.1
Saudi Arabia	2.6		284.1	36.2		323.0
UAE		6.3	98.5	0.1	33.9	138.9
Total	2.6	7.5	502.4	36.4	74.1	623.0

Source: KAPSARC analysis.

Table B5. Electricity production in the ‘renewable exports’ scenario.

	ST	OCGT	CCGT	PV	Thermal cogeneration	Total
Bahrain		0.3	4.1		8.1	12.4
Kuwait					65.1	65.1
Oman			10.1		19.4	29.5
Qatar		1.2	7.5		25.8	34.4
Saudi Arabia	157.6	17.7	115.3	3.9	51.3	345.8
UAE		12.5	16.0	0.1	105.1	133.8
Total	157.6	31.6	152.9	4.0	274.8	621.0

Source: KAPSARC analysis.

Table B6. Electricity production in the ‘hybrid pricing’ scenario.

	ST	OCGT	CCGT	PV	Thermal cogeneration	Total
Bahrain		0.3	4.1		8.1	12.4
Kuwait			12.2		46.2	58.4
Oman			10.1		19.4	29.5
Qatar		1.2	7.5		25.8	34.4
Saudi Arabia	163.4	19.5	115.3		53.8	352.1
UAE		13.6	16.6	0.1	103.3	133.7
Total	163.4	34.6	165.8	0.1	256.7	620.6

Source: KAPSARC analysis.

Appendix C: Fuel Consumption By Scenario

Table C1. Fuel consumption in the 'no coordination' scenario.

	HFO (MM tons)	Diesel (MM tons)	Natural gas (bcf)	Crude oil (MM bbl)
Bahrain			92.3	
Kuwait	4.0		396.0	0.1
Oman			245.1	
Qatar			265.7	
Saudi Arabia	9.4	10.7	1298.9	203.9
UAE			1111.0	
Total	13.4	10.7	3408.9	204.0

Source: KAPSARC analysis.

Table C2. Fuel consumption in the 'subsidy exports' scenario.

	HFO (MM tons)	Diesel (MM tons)	Natural gas (bcf)	Crude oil (MM bbl)
Bahrain			51.5	
Kuwait	2.4		396.0	
Oman			253.2	
Qatar			265.7	
Saudi Arabia	9.4	10.8	1298.9	246.1
UAE			1021.4	
Total	11.8	10.8	3286.6	246.1

Source: KAPSARC analysis.

Appendix C: Fuel Consumption by Scenario

Table C3. Fuel consumption in the 'fuel price deregulation' scenario.

	HFO (MM tons)	Diesel (MM tons)	Natural gas (bcf)	Crude oil (MM bbl)
Bahrain			92.2	
Kuwait			461.5	
Oman			193.3	
Qatar			224.8	
Saudi Arabia			1310.7	124.8
UAE			902.2	
Total	0	0	3184.6	124.8

Source: KAPSARC analysis.

Table C4. Fuel consumption in the 'deregulated exchange' scenario.

	HFO (MM tons)	Diesel (MM tons)	Natural gas (bcf)	Crude oil (MM bbl)
Bahrain			94.2	2.7
Kuwait			524.8	
Oman			213.0	
Qatar			224.8	
Saudi Arabia			1309.0	94.8
UAE			943.0	0.0
Total	0	0	3308.8	97.4

Source: KAPSARC analysis.

Table C5. Fuel consumption in the 'renewable exports' scenario.

	HFO (MM tons)	Diesel (MM tons)	Natural gas (bcf)	Crude oil (MM bbl)
Bahrain			92.3	
Kuwait	3.3		396.0	
Oman			244.9	
Qatar			265.7	
Saudi Arabia	9.4	10.7	1200.0	223.0
UAE			1111.1	
Total	12.7	10.7	3310.0	223.0

Source: KAPSARC analysis.

Table C6. Fuel consumption in the 'hybrid pricing' scenario.

	HFO (MM tons)	Diesel (MM tons)	Natural gas (bcf)	Crude oil (MM bbl)
Bahrain			92.3	
Kuwait			469.6	
Oman			245.1	
Qatar			265.7	
Saudi Arabia	9.4	10.7	1302.7	224.2
UAE			1110.8	
Total	9.4	10.7	3486.0	224.2

Source: KAPSARC analysis.

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About the Project

This project adopts a regional view of the power and water sectors to answer the following research question: What are the potential economic, technical and environmental impacts of regional electricity system coordination? The KAPSARC Energy Model for GCC (KEM-GCC) has been developed to answer these questions. It is a model of the power and water sectors of all six GCC countries represented as 12 sub-regions with the capability to trade electricity and fuels.

Notes

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