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King Abdullah Petroleum Studies and Research Center

GCC Energy System Overview – 2017

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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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Summary

This paper presents datasets that support economic and policy analyses of countries in the Gulf Cooperation Council (GCC). The objective is to provide an overview of the GCC energy systems and serve as a reference for researchers performing quantitative modeling and analysis. The following data have been collected from public sources, using the most recent complete datasets available.

We begin by describing the GCC in terms of electricity systems specific to each country. For each system, we compile and present information about how electricity and water are supplied in terms of technologies and fuels. A key point is the linkage of electricity and water production in the GCC. Power plants typically produce a combination of electricity and water, primarily through desalinating seawater using waste heat. This linkage must be considered when analyzing how energy is transformed in the GCC.

An assessment of fossil and renewable resources follows in the third section. The GCC states are well endowed with fossil and renewable resources. To date, fossil energy has been exploited for export and domestic consumption while the use of renewable resources has been negligible in terms of total primary energy supply.

The fourth section presents government administered fuel prices and electricity tariffs. These provide a context for understanding the composition of the energy and water sectors. Regulated energy prices are a characteristic of the GCC. Administered prices on the supply (electricity production) and demand side (electricity consumption) have been, and continue to be, a key barrier to electricity trade and greater penetration of renewable technologies in the power and water sectors. Ongoing price reforms are expected to improve the prospects of electricity trade and cost-effectiveness of renewables.

Existing energy policies, future targets and power sector reforms are covered in the fifth section. GCC countries have announced plans to both diversify electricity production (by deploying renewables and nuclear capacity) and to reduce demand (through efficiency measures). Recently announced targets in all six GCC states suggest that renewable resources and nuclear energy will be a prominent component of the region's future energy systems. Almost 80 GW of renewables will be installed, around four times the amount of nuclear power that is planned in the region.

The accompanying datasets are available on the OpenKAPSARC data portal and will be updated as new data are available.

The GCC Energy System

Founded in 1981, the Cooperation Council for the Arab States of the Gulf, colloquially known as the Gulf Cooperation Council (GCC), is a union of six states in the Arabian Peninsula: Bahrain, Kuwait, Oman, Qatar, the Kingdom of Saudi Arabia (KSA) and the United Arab Emirates (UAE) (GCC General Secretariat 2016). To capture the geographic variation of electricity and water production and consumption, this analysis disaggregates the six GCC states into 12 regions (Figure 1).

Bahrain, Kuwait and Qatar are each represented as individual regions due to their small size. For simplicity, Oman is 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 is considered as four regions (east, west, south and central) that correspond to the service area definitions defined by the Saudi Electricity Company (SEC). The UAE is represented as four regions: Abu Dhabi, Dubai, Sharjah and the Federal Electricity and Water Authority (FEWA), which corresponds to the regulatory authorities for the remaining four emirates.

Figure 1. The GCC member states and disaggregation into regions (GCC Interconnector shown in red).

Source: GCC Interconnection Authority, KAPSARC.

Energy demand and growth

Within the GCC, substantial differences can be noted in the growth of total primary energy consumption from 1972 to 2012 for Kuwait, Qatar, Saudi Arabia and the UAE (Figure 2) (BP 2017). All countries follow a similar trend, but magnitudes are different due to several factors, including population, economic development and urbanization.

The industrial sector accounts for the largest share of total final energy consumption in the GCC, representing half of all demand. The transport sector accounts for the second-largest share (32 percent), followed by residential (10 percent), commercial (5 percent) and other sectors (2 percent) (IRENA 2016).

In terms of energy consumption, the residential sector accounts for most of demand in almost all GCC countries (Figure 3) (OPWP 2015; Kuwait CSB 2015; Bahrain CIO 2012; ECRA 2014). The exceptions are Qatar, where industry is the largest consumer (67 percent), and the UAE, where the commercial sector is highest (43 percent) (UAE Ministry of Energy 2015; KAHRAMAA 2014; OPWP 2015; Kuwait CSB 2015; Bahrain CIO 2012; ECRA 2014). Between 2003 and 2013, electricity

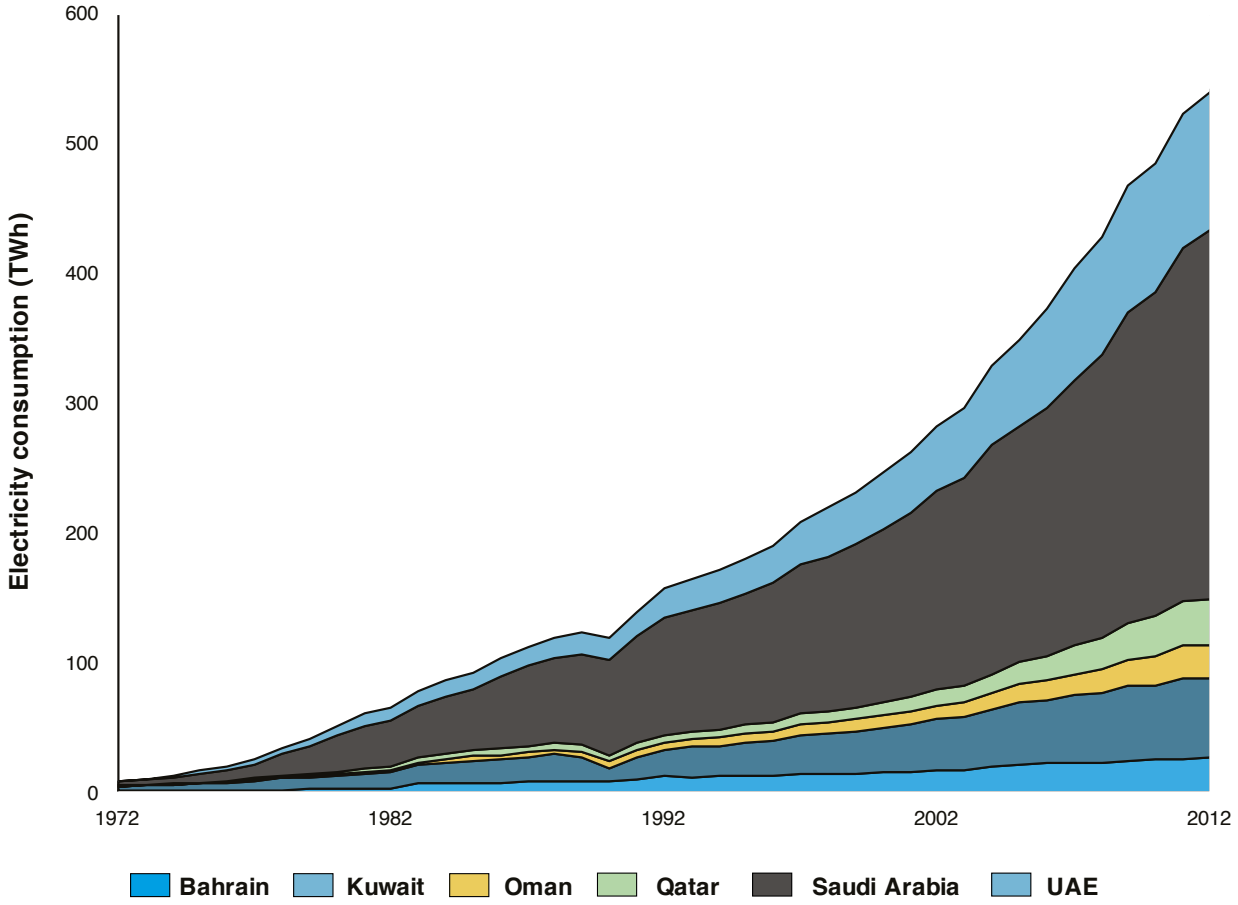

Figure 2. Total primary energy consumption from 1972-2012, million tons of oil equivalent (Mtoe).

Source: British Petroleum, KAPSARC.

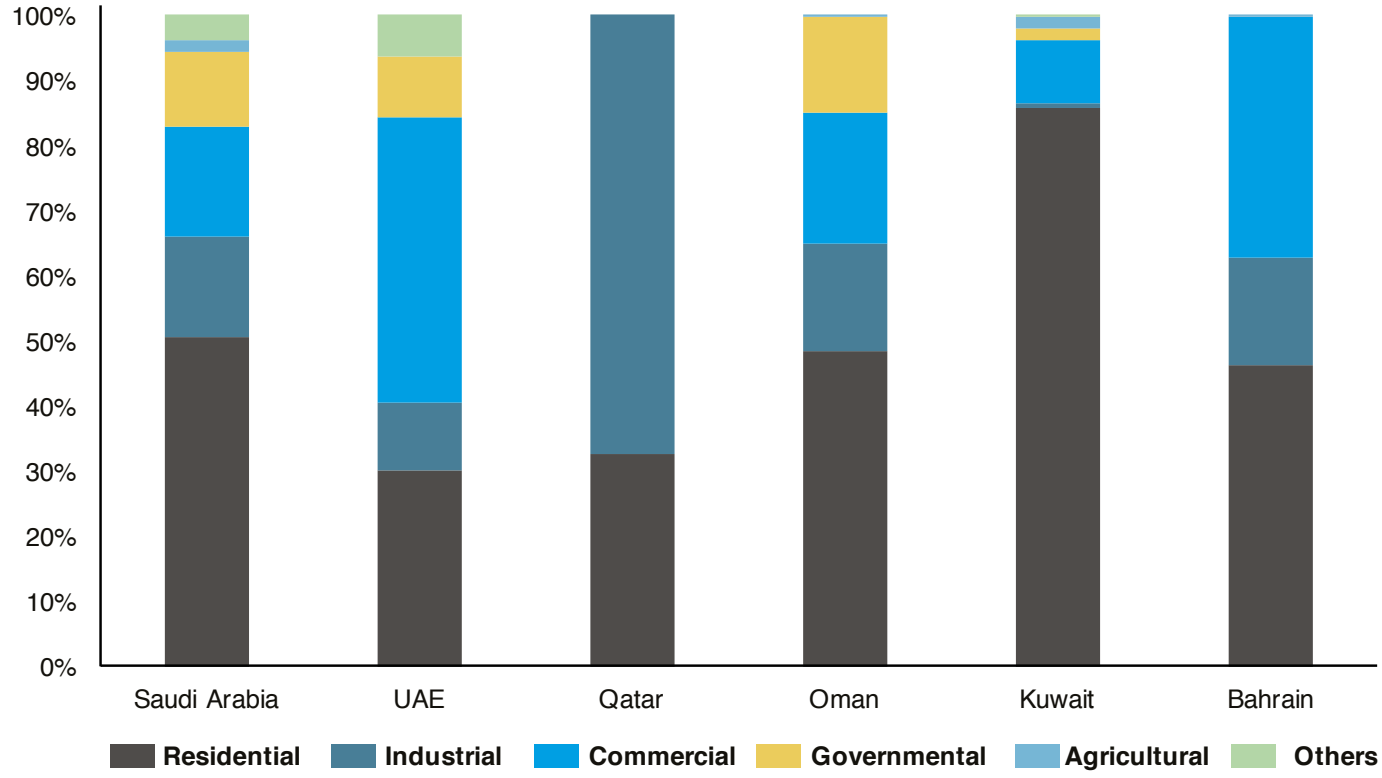

Figure 3. Sectoral energy consumption, 2015.

Source: IRENA.

consumption across the GCC region showed an average annual growth rate (AAGR) of 6 percent to 7 percent, largely driven by the residential sector, which accounts for about 44 percent of the region's total consumption (IRENA 2016).

Energy Pricing

For the most part, governments control the energy assets underpinning GCC economic development. With dual aims of ensuring energy access and supporting economic development, governments have followed a long-held policy of supplying domestic energy to citizens/residents and industries at very low prices.

At present, electricity tariffs in the GCC, which are regulated, are among the lowest in the world with substantial subsidies offered to both utilities and end-consumers. In Saudi Arabia, for example, the state-owned SEC has long-term contracts with the government to purchase fuel for generation from state-owned Saudi Aramco at a fixed price. While slightly above marginal production costs, these tariffs are well below market price. Electricity is then sold to consumers at subsidized prices. Subsidies and low prices currently cost GCC governments more than $160 billion annually in foregone revenues (World Bank 2014). This pricing scheme leads to high per-capita consumption by fostering an environment characterized by low energy efficiency and lack of conservation.

Energy subsidies in the power and water sectors are discussed in detail in the section on barriers to coordination.

Carbon Dioxide (CO_2) emissions

The GCC produced 1.17 billion tons of CO_2-equivalent in 2012. The bulk of CO_2-equivalent emissions in GCC are related to energy production and consumption. On average, across the member states, 95 percent of emissions are energy related, with agriculture, waste and land-use changes making up the remainder (WRI 2015). Of this amount, the power and water sectors emitted 438 million tons of CO_2-equivalent. A breakdown of the energy sub-sector emissions is presented in Figure 4.

The power and water sectors produce on average 43 percent of emissions. Oman has the lowest share of emissions from the power sector (22 percent) while Bahrain has the highest (76 percent). There is a potential for the GCC to realize aggregate greenhouse gas (GHG) emission reductions by improving the efficiency of the power and water fleet or by purchasing power from each other using the GCC Interconnector.

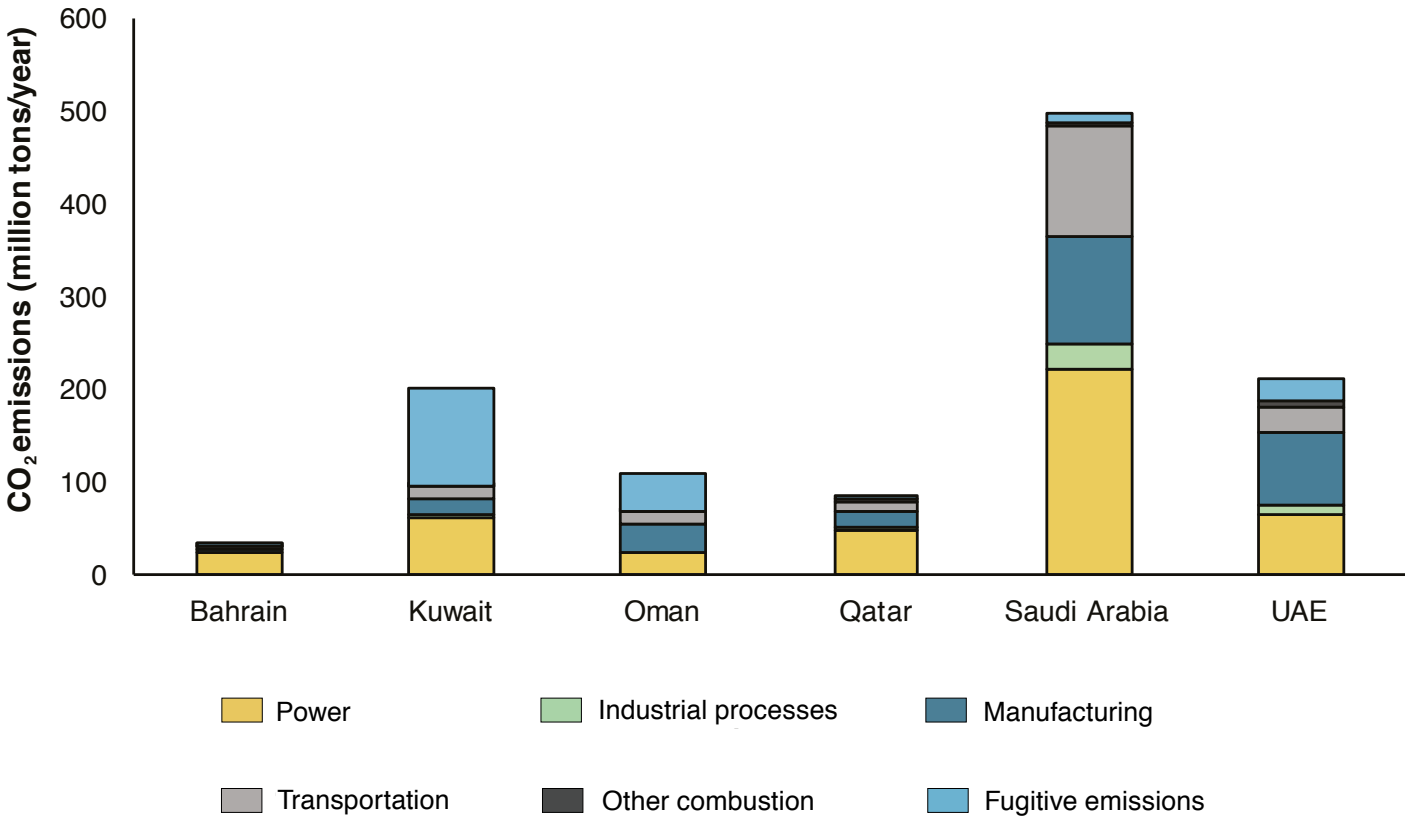

Figure 4. Breakdown of GHG emissions by energy sub-sectors in 2012.

Source: World Resources Institute.

Energy Transformation in the Power and Water Sectors

Electricity and water production are inextricably linked in the GCC. Power plants typically produce a combination of power and desalinated water, with fossil fuels providing nearly all the input fuels. This linkage must be considered when analyzing how energy is transformed in the GCC.

Power and water capacities by technology

Two types of thermal power generation capacity are used in the GCC: power-only units and cogeneration units, which produce power and use waste heat to desalinate seawater. Cogeneration uses steam, gas or combined-cycle turbines coupled with various distillation techniques, i.e., multi-effect distillation (MED), multistage flash (MSF) units or heat recovery steam generators (HRSG).

All GCC member states have a mix of power and water desalination capacity. Saudi Arabia, with more than 80.5 GW of power generation, has the biggest installed capacity (including desalination). Collectively, the UAE has the second-largest (almost 29 GW), with more than half (15.5 GW) in the emirate of Abu Dhabi. The other countries have smaller capacities: Kuwait (18.3 GW), Qatar (8.6 GW), Oman (7.8 GW) and Bahrain (2.8 GW). The technology mix for each country is shown in Figure 5.

At the end of 2015, total installed power capacity (including cogeneration) was 149 GW, of which 90 GW is thermal power-only. Single-cycle gas turbines — at 47 GW — have the largest share by technology type, while combined-cycle units represent 21 GW. More than 44 GW of cogeneration capacity is installed in the region, with Kuwait, Qatar and the UAE relying predominantly on this technology to meet their power demand. Despite an abundance of solar radiation in the region, at the end of 2015 only 76 MW of photovoltaics (PV) were installed (included but not visible in Figure 5). PV capacity represented 0.05 percent of all installed capacity.

Some 82 percent of cogeneration capacity is in the form of thermal cogeneration units, while more efficient reverse osmosis (RO) plants account for only 14 percent. A key distinction between thermal cogeneration and RO plants is that the latter consume electricity to pump seawater through a membrane. Notably, Bahrain, Oman and the three coastal regions of Saudi Arabia utilize RO technology. Kuwait and Qatar do not have any RO plants. A small number of thermal water-only plants, utilizing MED or MSF processes, exist in Kuwait and in the southern region of Saudi Arabia. Figure 6 presents desalination capacity (measured in cubic meters per day [m^3/day]) in terms of thermal-only, cogeneration and RO technologies.

States that have coupled power and water production almost exclusively use thermal cogeneration. Many of these plants operate as base-load units that produce a fixed amount of water and electricity to meet demand. Saudi Arabia currently has variable cogeneration plants, in which the ratio of power and water produced can be controlled. Bahrain, Saudi Arabia and Oman have RO and thermal desalination capacity; as these technologies do not produce electricity, more electricity generation capacity is needed to meet power demand independent of water production. This coupling of the power and water sectors must be considered when integrating renewables into the electricity mix. If renewable capacity replaces thermal cogeneration plants, RO plants — which consume electricity — would be needed to produce desalinated water.

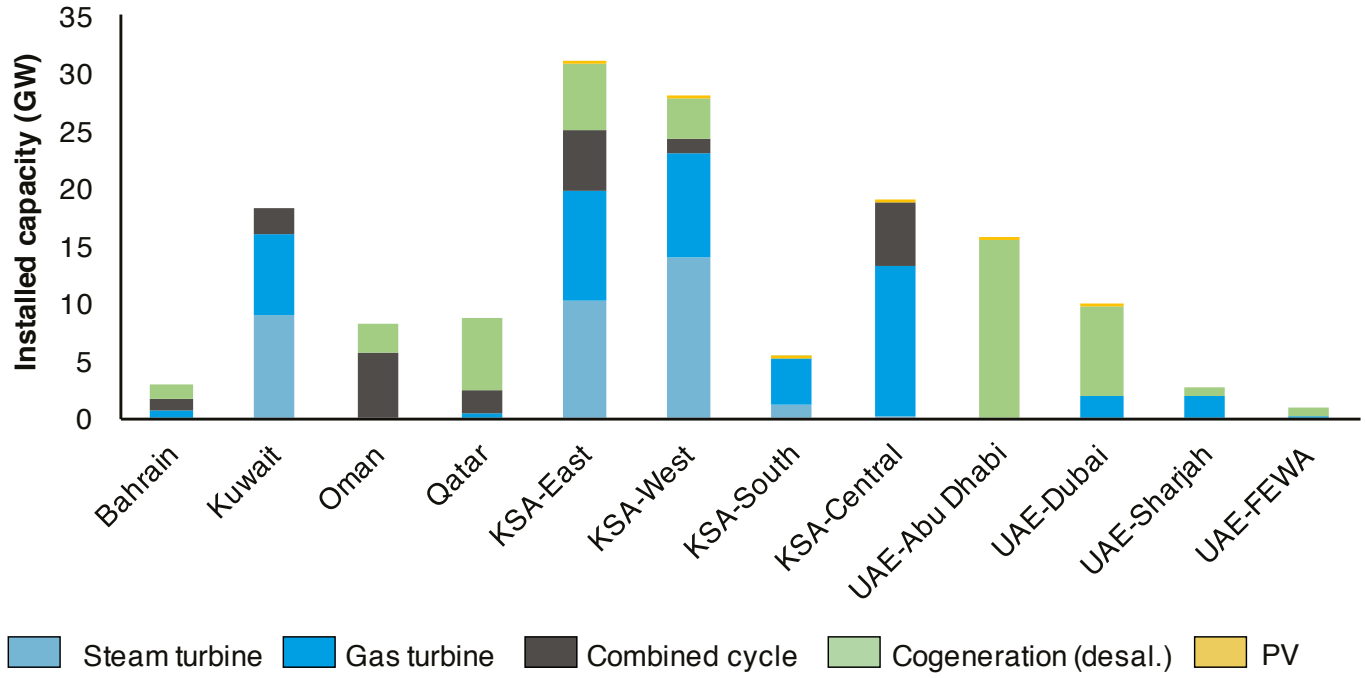

Figure 5. Power and water capacity by technology type.

Source: Kingdom of Bahrain Electricity & Water Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Saudi Electricity Company, Electricity & Cogeneration Regulatory Authority, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

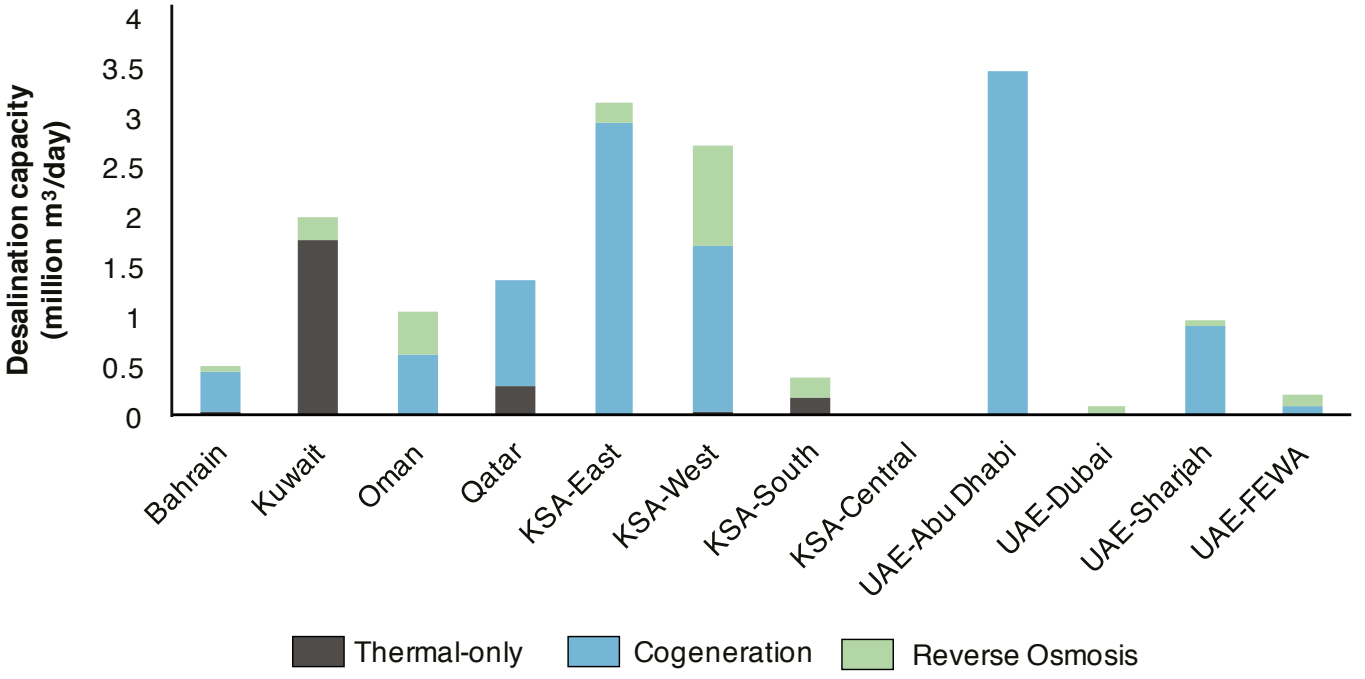

Figure 6. Installed desalination capacity by type (million m^3/day).

Source: Kingdom of Bahrain Electricity & Water Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Saudi Electricity Company, Electricity & Cogeneration Regulatory Authority, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

Fuel mix for power and water

The power and water systems of the GCC states rely almost exclusively on fossil fuels. Natural gas is the most consumed fuel at almost 2.8 quadrillion British thermal units (QBtu), while crude oil, heavy fuel oil (HFO) and diesel cover the remaining 1.9 QBtu per annum. This breakdown is not surprising given the abundance of fossil fuel resources, described in greater detail in Section 3. The relative consumption of fossil fuel by type is presented for each country in Figure 7.

Water and power production in Saudi Arabia, the largest fuel consumer, account for a significant amount of crude oil and oil products (diesel and heavy fuel oil) (SEC 2015). Kuwait consumes a mix of natural gas and heavy fuel oil, with trace quantities of crude oil and diesel (Kuwait Ministry of Electricity and Water 2016a). In Oman and Qatar, natural gas is the primary fuel (OPWP 2015; KAHRAMAA 2014). Bahrain mostly consumes natural gas and some diesel (Bahrain NOGA 2015). The data for Figure 7 are presented in Tables A1 (energy units) and A2 (physical units) in the Appendix.

For the UAE, natural gas is the primary fuel for power and water production. In Abu Dhabi, the more than 689 trillion Btu of natural gas consumed

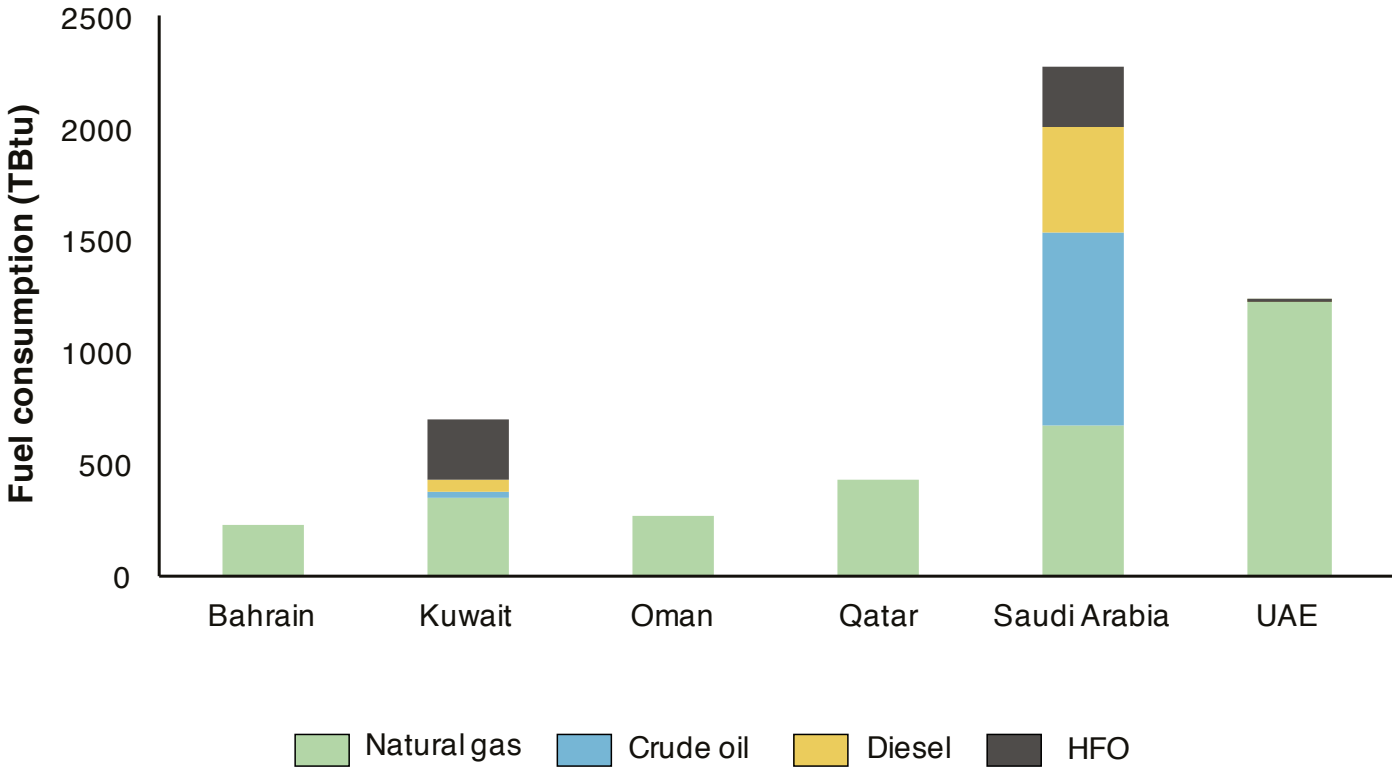

Figure 7. Estimated fuel mix for power and water sectors by GCC member state.

Source: Kingdom of Bahrain National Oil & Gas Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Electricity & Cogeneration Regulatory Authority, UAE Ministry of Energy, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

account for over 99 percent of all fuels consumed in 2015 (SCAD 2015). The fuel mix is essentially 100 percent natural gas in Dubai, although an extremely small amount of diesel is used for testing and commissioning, according to the Dubai Electricity and Water Authority (DEWA) (2014). The Sharjah region uses natural gas and a mix of heavy and light fuel oil (aggregated as HFO in Table 2.1) (SEWA 2012). FEWA consumes natural gas and a small volume of heavy fuel oil (UAE FEWA 2015; UAE Ministry of Energy 2015).

Capacities by individual technology are presented in Appendix B (See Tables B1-B3). A brief discussion of the power and water capital stock in each member state follows:

Bahrain: Power is supplied by 1.7 GW of gas turbines and combined cycle units, along with 1.1 GW of cogeneration capacity for a total of 2.8 GW. These units, along with the Ras Abu Jarjur RO plant, have the capacity to supply 498,000 m^3/day of water. Natural gas is the primary fuel source. The industrial sector consumes nearly 90 percent of all natural gas (estimated from capacity of power plants) (Bahrain CIO 2012; "Rifaa II Plant Upgrade, Bahrain" 2016; Power Engineering International 2004; Hidd Power Company 2016; Bahrain NOGA 2015).

Kuwait: Power in Kuwait is produced by steam turbines, gas turbines, and combined cycle gas turbines (CCGTs). Natural gas and heavy fuel oil are the main fuels consumed by the power sector. Thermal desalination plants consume natural gas exclusively. Kuwait has capacity to produce over 1.99 million m^3/day of drinking water (Kuwait Ministry of Electricity & Water 2016).

Oman: Nearly all power generating plants in Oman are combined-cycle gas turbines (CCGTs). Two-thirds of the capacity are power-only plants (5.8 GW) while one-third is thermal cogeneration (2.4 GW). The fuel mix is exclusively natural gas (OPWP 2015). Oman has capacity to produce over 1.1 million m^3/day of water, with three RO plants capable of delivering 0.44 million m^3/day.

Qatar: The Qatar Electricity and Water Company operates over 8.6 GW of power capacity, of which 72 percent is thermal cogeneration with the ability to produce up to 1.37 million m^3/day of drinking water. All plants run on natural gas, with oil as a backup fuel. Approximately 433.6 trillion Btu of natural gas is consumed by power and water producers (KAHRAMAA 2014). More than 1 GW of power capacity operates in the upstream, fertilizer, vinyl and liquefied natural gas (LNG) industries (QEWC 2015).

Saudi Arabia: Saudi Arabia has over 82 GW of power-only capacity installed, with gas turbines accounting for nearly half, and steam turbines and combined cycle units making up the remainder (ECRA 2014). 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 combined capacity to desalinate over 6.2 million m^3/day. Most of the water capacity (78 percent) is thermal-based cogeneration; the remaining 22 percent is RO (SWCC 2014).

UAE: Of nearly 29 GW of power generation capacity in the UAE, 24.9 GW is used to desalinate seawater. Most of the power and water capacity is in Abu Dhabi and Dubai, including 60 MW of solar PV (ADWEC 2014). Both Sharjah and FEWA have limited power generation capacity, and thus purchase electricity from the Emirates National Grid. Combined cycle cogeneration technology accounts for nearly 73 percent of capacity, followed by steam cogeneration (19 percent) and RO (5 percent).

Electricity production and consumption

For the most part, GCC member states produce and consume electricity generated within national borders. The magnitude of production, consumption and peak loads are tabulated below.

Saudi Arabia produces over half of all electricity in the GCC. ECRA reported that 304 TWh were produced in 2015, while 274.5 TWh were delivered to customers (ECRA 2014). In the UAE, Abu Dhabi produces over 70 TWh of electricity, roughly 18 TWh of which exceeds domestic demand and is sold to Sharjah and FEWA. Sharjah imports nearly half of its power demand from the Emirates National Grid (SEWA 2012). Similarly, with less than 1 GW of capacity, FEWA consumes nearly 25 times more electricity than it produces (UAE FEWA 2015). Qatar produced more than 38 TWh in 2014 (KAHRAMAA 2014). In Oman, total electricity production is reported at 31.3 TWh (OPWP 2015). (In the last two cases, consumption data are not available.)

Aggregate peak electricity demand in the GCC topped 104 GW in 2015, with Saudi Arabia (56.6 GW) representing over half of the demand and Bahrain having the smallest share at 2.92 GW (Bahrain CIO 2012; ECRA 2014). To date, the GCC Interconnector has been used primarily for reliability purposes, transferring power to meet peak load demands in Kuwait, for example. The GCC Interconnection Authority reported nearly 1 TWh in unscheduled exchanges in 2014 (Al-Ibrahim 2015).

Table 1. Electricity production in terawatt-hours (TWh), consumption (TWh) and peak load (GW).

Country	Production	Consumption	Peak load
Bahrain	14.1	12.6	2.9
Kuwait	68.3	60.5	12.8
Oman	31.3	31.3	6.1
Qatar	38.7	36.1	6.7
Saudi Arabia	304.2	274.5	56.6
UAE – Abu Dhabi	70.9	52.8	9.0
UAE – Dubai	39.6	38.4	7.2
UAE – Sharjah	5.7	10.2	2.2
UAE – FEWA	0.40	10.3	2.2
Total GCC	573.2	526.7	-

Source: Kingdom of Bahrain Electricity & Water Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Saudi Electricity Company, Electricity & Cogeneration Regulatory Authority, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

Water production and consumption

The importance of water and power production in the GCC is crucial to strategies that aim to integrate more renewable energy. While cogeneration plants are an efficient use of waste heat, combining renewable electricity and RO plants could reduce hydrocarbon consumption.

The region has one of the highest levels of water-scarcity in the world. Surface water resources are very limited, existing only along the east and west coasts. In terms of renewable water supply, the region has the world's lowest availability, with only about 60 m^3 to 370 m^3 of annual freshwater available per capita. According to the United Nations World Water Development Report 2016, a country experiences 'water stress' when annual renewable water resources fall below 1,700 m^3 per person per year. Rapid population growth and urbanization are putting pressure on the limited water resources, as is high per-capita consumption, which ranges between 0.3 m^3 per day and 0.75 m^3 per day. Furthermore, about 84 percent of the water used in Saudi Arabia goes to agriculture making it the main reason for the high water per-capita use in this region.

Thus, the use of treated wastewater has become a means for increasing water availability. Currently, 84 percent of all wastewater collected in the region go through tertiary treatment, and 44 percent of this safely treated wastewater was subsequently used.

Most GCC countries and regions are self-sufficient in terms of the production and consumption of water resources, except for FEWA, which consumes nearly 24 million m^3 per year more than it produces. A majority (83 percent) of Sharjah's water production is from desalination, of which only 10 percent uses RO with the remainder from thermal cogeneration (SEWA 2012). Table 2 summarizes water production and consumption for GCC member states.

Table 2. Annual desalinated water production and consumption (million m^3).

Country	Production (million m^3)	Consumption (million m^3)
Bahrain	174.9	174.4
Kuwait	562.1	533.2
Oman	228.6	222
Qatar	495.0	495.0
Saudi Arabia	2,269.6	1,600
UAE – Abu Dhabi	1,170.5	1,154
UAE – Dubai	404.1	358.6
UAE – Sharjah	115.3	90.2
UAE – FEWA	66.5	90.5
Total GCC	5,486.6	4,717.9

Source: Kingdom of Bahrain Electricity & Water Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Saudi Electricity Company, Electricity & Cogeneration Regulatory Authority, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

Resources

The GCC is endowed with abundant fossil and renewable resources. To date, states have mainly exploited their oil and gas resources but have plans to utilize more solar irradiation and wind. This section begins with an overview of oil and gas production and trade; ending with a brief assessment of solar and wind resources.

Oil and gas

Most oil and gas production in the GCC is concentrated in Saudi Arabia's eastern province, Qatar, Abu Dhabi and Kuwait. Saudi Arabia is the largest crude producer (3.7 billion barrels [bbls] in 2015) and the second-largest gas producer (4.2 QBtu raw gas) after Qatar, which produced nearly 6.4 QBtu (OPEC 2016; Saudi Aramco 2015). Kuwait produces over 1 billion bbls of crude oil. In the UAE, Abu Dhabi is the primary source of domestic hydrocarbons. In recent years, Dubai's oil production has been declining and the other two regions of the UAE have negligible oil and gas production. Figure 8 shows the balance of domestic production, imports, and exports for crude oil and natural gas.

Each country is discussed in more detail below:

Bahrain: Bahrain produced 73.6 million bbls of crude oil in 2015. The country imported more oil

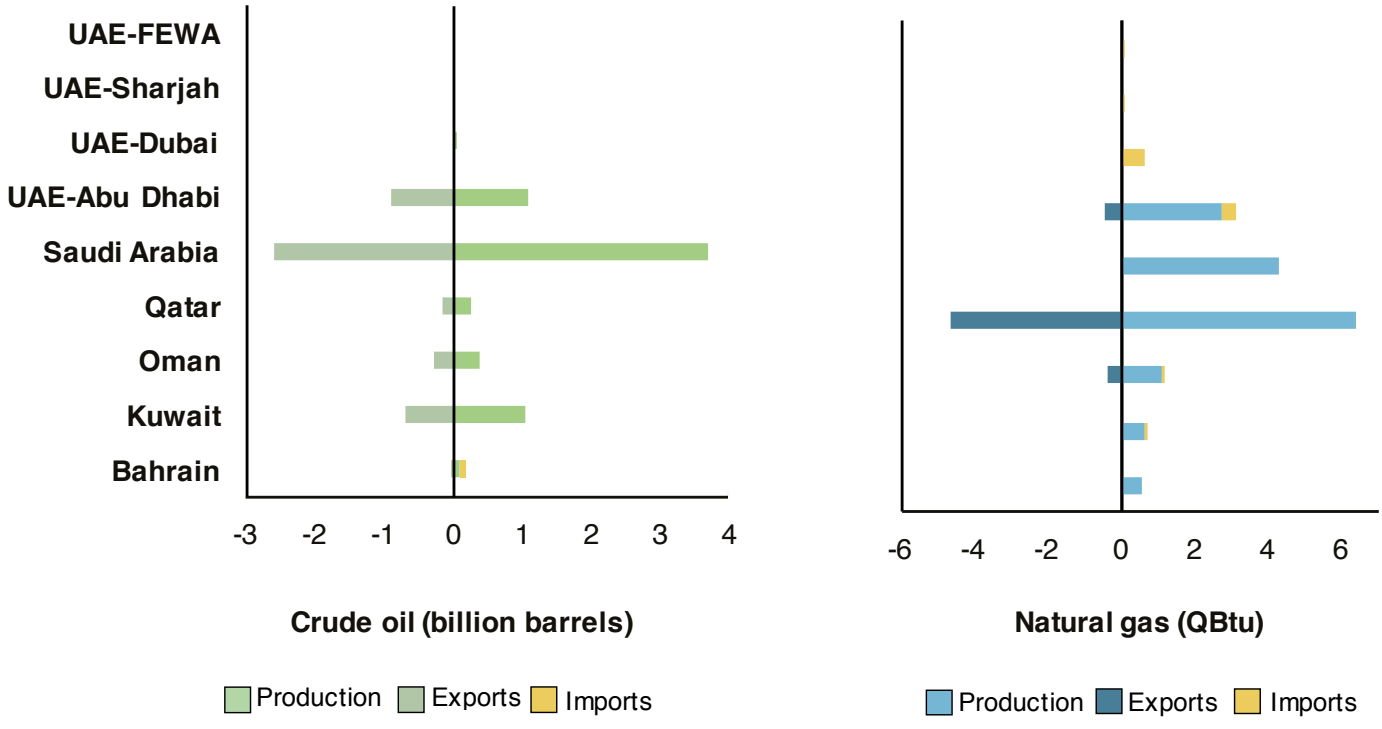

Figure 8. Crude oil and gas production and exports.

Source: OPEC.

from Saudi Arabia (78.7 million bbls) than it produced, for a total supply of 152.3 million bbls. Bahrain used some of the crude oil in domestic refineries and exported 54.8 billion bbls in 2015. Gross natural gas production was reported as 0.76 QBtu in 2015, of which 28 percent is reinjected for enhanced oil recovery and reservoir maintenance, leaving 0.55 QBtu of sales gas production (Bahrain NOGA 2015).

Kuwait: Kuwait produced 1.05 billion bbls of crude oil in 2015. The country produces a range of light to heavy crudes, which are blended into a single grade. Kuwait exports crude with an American Petroleum Institute gravity (API) of 31, typical of medium grade Middle Eastern crude (Strategies et Politiques Energetiques 2015). In 2015, Kuwait exported 0.72 billion bbls of crude oil, up from 0.69 billion bbls in 2013 (OPEC 2016).

Natural gas production in Kuwait is reported as 0.64 QBtu in 2015 (KOC 2015), of which around 1 percent was flared or reinjected, leaving 0.60 QBtu of sales gas production (OPEC 2016). Kuwait does not export natural gas and has become increasingly reliant on LNG imports to meet domestic demand. Kuwait takes LNG delivery at Mina al-Ahmadi GasPort, which has a baseload capacity of 0.505 QBTU/day and peak capacity of 0.606 QBtu/day (Excelerate Energy 2016). In 2015, Kuwait imported 0.137 QBtu of LNG (OPEC 2016).

Oman: In 2015, Oman produced 358 million bbls of crude oil and exported 0.287 billion bbls (NCSI Oman 2016; OPEC 2016). Natural gas production has grown to 1.13 QBtu, of which 0.38 QBtu was exported (OPEC 2016; PDO 2015). 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 (Strategies et Politiques Energetiques 2015). Oman is both an importer and exporter of natural gas. In 2015, according to the Oman LNG annual report, the country exported 0.38 QBtu of LNG while also importing 0.07 QBtu of natural gas from Qatar via the Dolphin pipeline (Oman LNG 2015; Dolphin Energy Ltd 2016). It has been reported that Oman is considering LNG imports to shore up domestic demand (Sergie and Dipaola 2015).

Qatar: Natural gas production and exports dominate Qatar's hydrocarbon output. Sales gas production was reported to be 6.4 QBtu in 2015. Natural gas is exported through liquefaction plants and the Dolphin pipeline, which connects to the UAE via the Taweelah receiving facility in Abu Dhabi. Natural gas exports totaled 4.6 QBtu in 2015, with 0.7 QBtu delivered by the pipeline (OPEC 2016). Of that amount, Abu Dhabi lifted 0.36 QBtu, Dubai took 0.26 QBtu and Oman the remaining 0.07 QBtu (Dolphin Energy Ltd 2016). More than 3.9 QBtu was sold as LNG on long-term and spot contracts. Qatar produced 0.23 billion bbls of crude oil in 2015, exporting 0.17 billion bbls (OPEC 2016).

Saudi Arabia: With production reaching 3.7 billion bbls in 2015, Saudi Arabia is the largest crude oil producer in the GCC. Crude oil exports amounted to 2.6 billion bbls in 2015. Currently, Saudi Arabia does not export or import natural gas: the entirety of the 2.9 QBtu produced is either reinjected into oil fields or consumed by industrial sectors such as power, water and petrochemicals (Saudi Aramco 2015).

UAE: The second-largest energy producer in the GCC (after Saudi Arabia), UAE energy production

is led by the emirate of Abu Dhabi, which accounts for nearly all the production and exports. In 2015, Abu Dhabi produced 1.07 billion bbls of crude oil of which 0.89 billion bbls was exported. The emirate produced 2.8 QBtu 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 0.47 QBtu in 2015, with 0.36 QBtu transiting through the Dolphin pipeline (Dolphin Energy Ltd 2016; OPEC 2016).

Dubai, by contrast, is not well-endowed with hydrocarbon resources. Small volumes, 0.01 billion bbls of crude oil and 0.04 QBtu of natural gas, were produced in Dubai in 2013. The entirety of Dubai's crude production is exported as a medium gravity grade (Strategies et Politiques Energetiques 2015). LNG is received at the Jebel Ali LNG Import Terminal (0.35 QBtu) (Excelerate Energy 2016).

The other two regions of the UAE, SEWA and FEWA, do not produce crude but do import natural gas.

The six member states produce electricity and plan investments in the energy sector independent of each other. This practice has proved adequate for many years. However, the region is facing key challenges with increasing domestic energy and water demand amid tighter national budgets. The utilities for the most part are owned and operated by the government, and a significant amount of government expenditures are for subsidizing fuel or energy products. The strain of these subsidies on national finances is amplified in a low oil price environment.

Cooperation and integration among the individual member states is a potential area to help overcome some of the challenges facing the domestic energy sectors. The GCC Interconnection has been proposed as a platform for integrating the electricity systems of the member states. Despite the completion of the interconnector in 2011, only small transfers have taken place mostly to maintain the reliability of the system (Wogan and Cote 2016). Optimal utilization of the interconnector could enable member states to produce power at lower cost, introduce economic efficiencies and better utilize renewable resources.

Renewables

The GCC is also well-endowed with renewable resources, making technologies such as solar PV, concentrated solar power (CSP) and wind turbines as attractive options for power generation. To date, the penetration of renewables has been marginal (see Power and Water Sectors for discussion on power technologies). Despite the small installed capacity of renewables, many member states have announced plans to expand renewable investments in the coming years (as discussed in Policies, Targets and Reforms). The following section presents selected data for solar and wind resources to illustrate the potential of renewables.

Solar insolation and wind data for Saudi Arabia and the UAE have been collected to illustrate the temporal and geographic variation in these two resources. Data were collected from the National Renewable Energy Laboratory (NREL) database and are available for the four regions in Saudi Arabia, and Abu Dhabi.

Solar

To simplify analysis of the solar resource, hourly data were aggregated into eight discrete segments for three representative seasons. A more detailed discussion on the rationale behind this discretization is presented in Matar et al (2017).

GCC energy trade

Natural gas, and oil to a lesser extent, are traded among GCC member states. The largest trade is between Qatar and Kuwait, UAE and Oman. Since 2004, Qatar has been supplying the northern emirates of the UAE with gas via the Dolphin pipeline. A tie-in line between Fujairah and Oman supplied gas to Oman. The Dolphin pipeline can now transport up to 2 billion cubic feet per day (0.75 QBtu per year). Abu Dhabi lifts the most gas at 0.99 billion cubic feet per day (0.36 QBtu per year), followed by Dubai with 0.73 billion cubic feet per day (0.26 QBtu per year) and Oman with 0.2 billion cubic feet per day (0.07 QBtu per year) (figure 9).

The only crude oil trade within the GCC occurs between Saudi Arabia and Bahrain. Bahrain imports 0.07 billion bbls of crude oil from Saudi Arabia, which is more than the volume of Bahraini domestic production (Bahrain NOGA 2015).

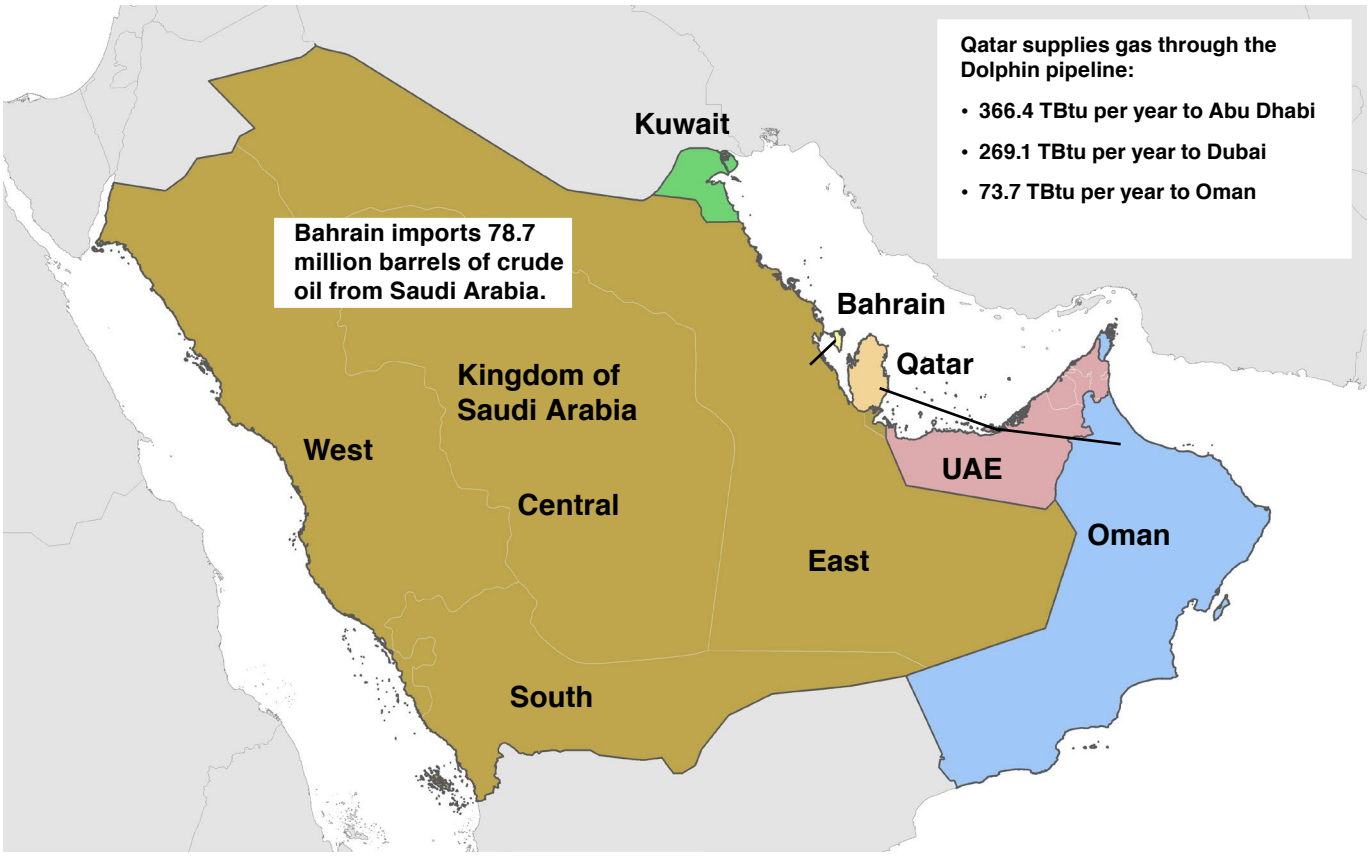

Figure 9. Map of GCC with trade linkages and quantities shown in black.

Source: OPEC, KAPSARC.

In Saudi Arabia, the south and central regions have the highest incidence of solar irradiance. The level of solar irradiance varies across seasons, from a low of 660 watts per m^2 (W/m^2) in winter to 760 W/m^2 in summer. Across seasons, solar irradiance is consistently highest between 12:00 (noon) and 14:00 (Figure 3.3). Solar incidence for Abu Dhabi follows similar patterns, but is slightly higher: about 700 W/m^2 in winter and 800 W/m^2 in summer, with the highest irradiance still occurring between 12:00 and 14:00. Average solar insolation for the four regions in Saudi Arabia and Abu Dhabi is shown in Figure 10.

Wind

Wind is available during all hourly segments across the GCC. In non-coastal regions (e.g., KSA-central), wind speeds peak in the evening hours and decrease during daylight hours. Wind speed in coastal areas (e.g., KSA-east, Abu Dhabi) exhibits the opposite behavior, peaking during daylight hours.

Wind speed in Saudi Arabia varies significantly over regions and seasons. Across all regions and seasons, average wind speeds are higher between

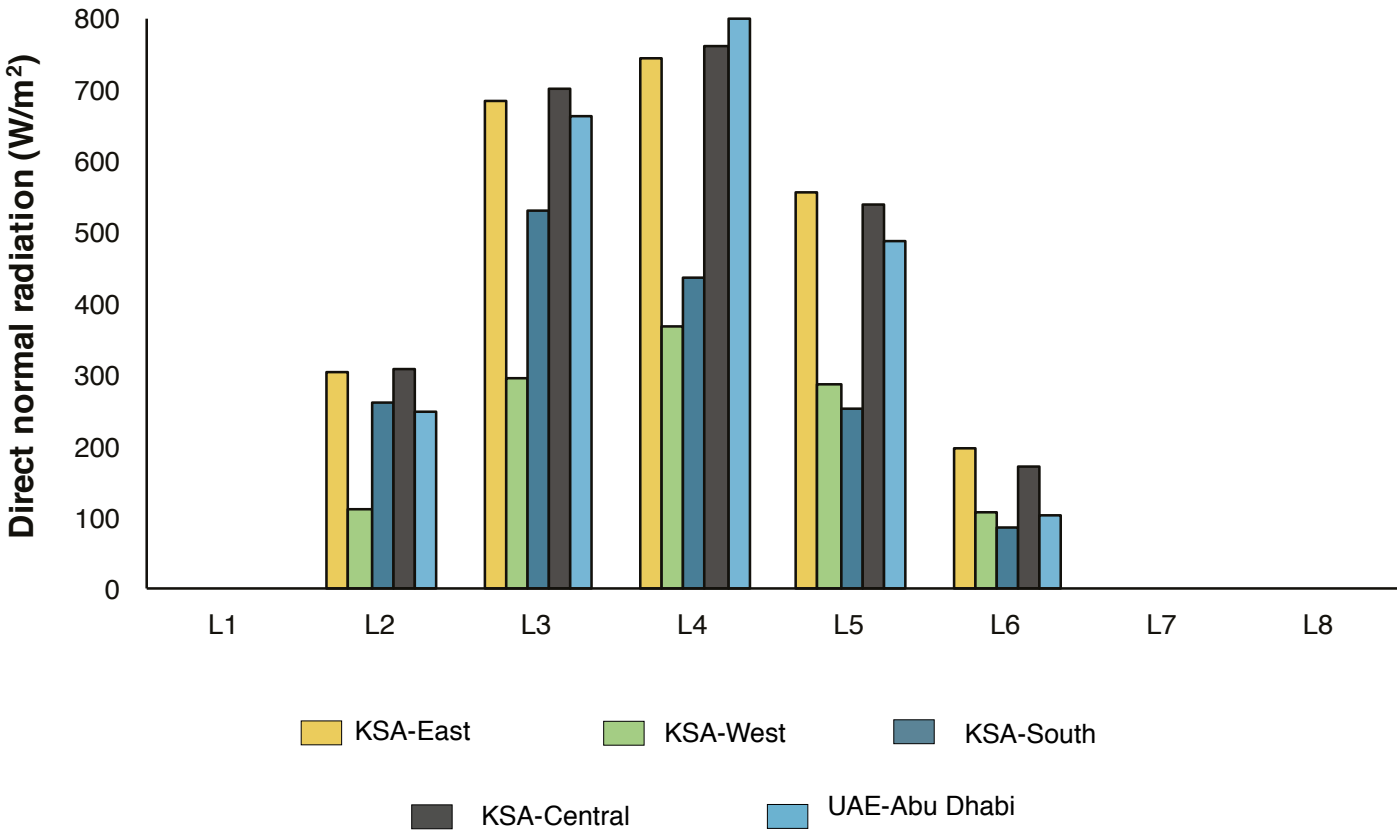

Figure 10. Average direct solar irradiance for Saudi Arabia and Abu Dhabi during summer.

Source: NREL, KAPSARC.

14:00 to 17:00. The highest wind speed of nearly 8 meters per second (m/s) is found during this three-hour period in the eastern region in spring and fall (Figure 11). In summer, the highest wind speed in the eastern region is about 6.7 m/s; in winter, the highest wind speed is about 7.4 m/s. In Abu Dhabi, the highest wind speed also occurs between 14:00 and 17:00, across all seasons. Wind speeds in Abu Dhabi are on average lower than in Saudi Arabia: the highest wind speed is 5.8 m/s in summer, followed by 5.7 m/s in spring/fall and 4.9 m/s in winter.

While not analyzed in-depth in this chapter, Kuwait shows wind speeds suitable (i.e., greater than 5 m/s) for wind power development in some areas. Measurements for different locations in Kuwait show that the summer months have the strongest wind speeds (Al Otaibi 2011).

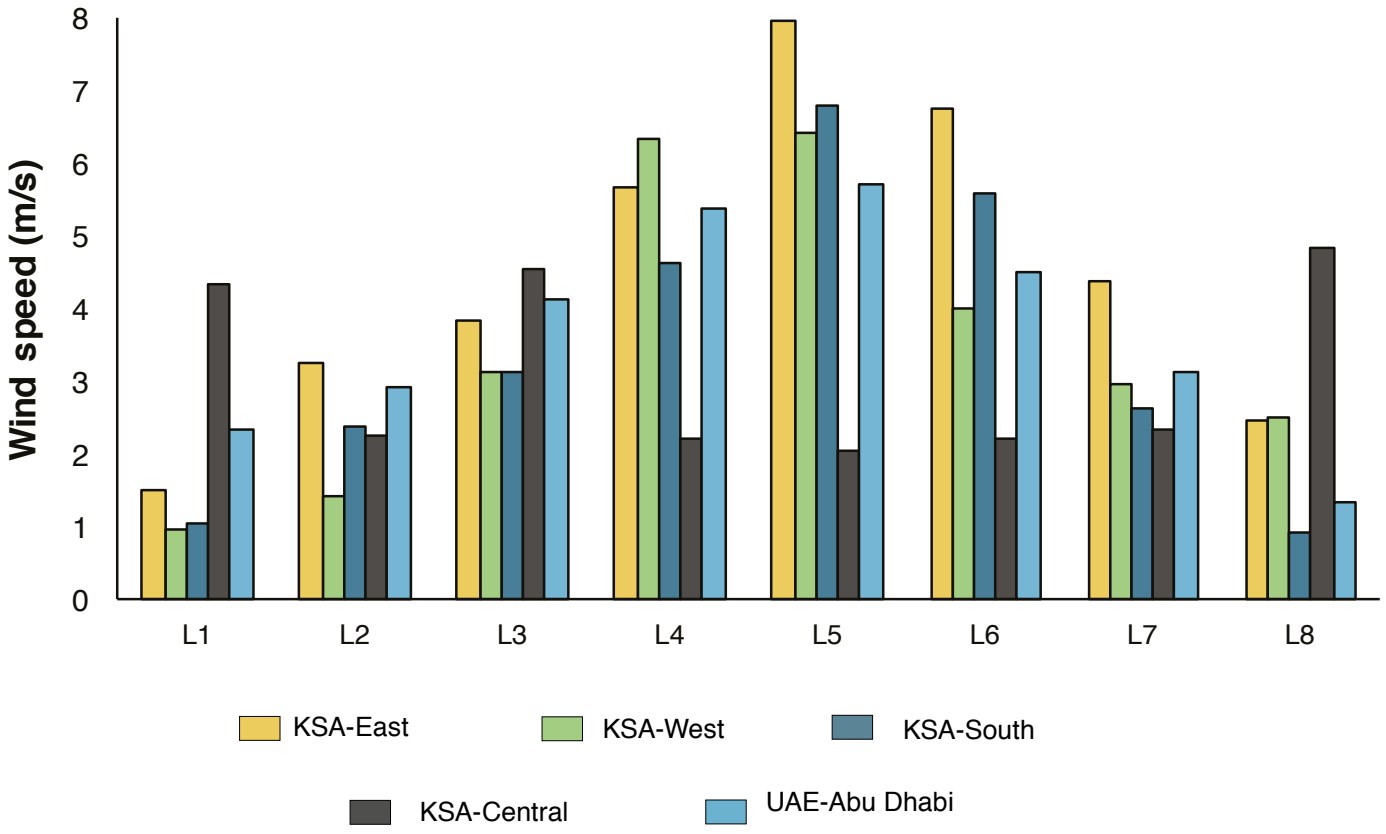

Figure 11. Average wind speed for Saudi Arabia and Abu Dhabi during spring/fall.

Source: Al Otaibi, KAPSARC.

Fuel Pricing and Tariffs

Across the GCC, fuel prices to industry and tariffs to end-users are administered by governments: low-price energy products and services are considered as a way of supporting domestic industries and maintaining citizens' quality of life. This chapter uses the term subsidies as defined by Lahn, meaning "the gap between the regulated sales price of fuel and the cost of its supply" (Lahn 2016).

This section presents fuel prices for the power and water sectors to illustrate the challenge of integrating individual energy systems. It does not explicitly examine energy products (electricity, petrol and diesel) or water tariffs.

At present, the regulated price of energy is a major barrier to renewable energy investments and to increased cooperation among GCC member states. Low prices incentivize investment in less efficient technologies and discourage conservation while also straining countries' finances (Fattouh and El-Katiri 2013; Fattouh and Sen 2016).

Industrial fuel prices

Fuel prices currently paid by industry are an important element of the economic barriers to increasing coordination among GCC energy systems. Because prices are not always transparent or published, it is difficult to assess the actual production costs for each member state. Knowing that subsidies do exist, it is logical for member states to be wary of exporting them. Depending on data availability, prices for the four input fuels for the power and water sectors are indicated in Table 3.

Bahrain: Reform is underway to gradually raise prices for natural gas and diesel. According to the 2015 annual report by the National Oil & Gas Authority, natural gas prices will rise from $2.50 per million British thermal units (MMBtu) in 2015 to $4/MMBtu in $0.25 increments each year. The price of natural gas as of April 1, 2016, is $2.75/MMBtu. Diesel prices as of January 1, 2016, is $0.40 per liter for domestic consumption. The value in Table 4.1 assumes that this price applies to industrial customers (Bahrain NOGA 2015).

Kuwait: Crude oil and natural gas are around two times more expensive in Kuwait than in Saudi Arabia, while HFO and diesel are three to four times more costly (Kuwait MEW 2015).

Oman: The power sector in Oman consumes natural gas, which in 2015 doubled in price to $3/MMBtu (OPWP 2015).

Table 3. Regulated prices of selected fuels for the power and water sectors as of November 2016.

Country	Crude oil (USD/bbl)	Natural gas (USD/MMBtu)	Diesel (USD/ton)	HFO (USD/ton)
Bahrain	-	2.75	268.48	-
Kuwait	13.77	3.53	496.60	98.90
Oman	-	3	-	-
Qatar	-	1.00 to 2.00	-	-
Saudi Arabia	6.35	1.25	105.26	28.52
UAE	-	1.00 to 2.00	TBD	-

Source: Bahrain National Oil & Gas Authority, Kuwait Ministry of Electricity and Water, Oman Power & Water Procurement Company, Qatar Electricity & Water Corporation, Saudi Gazette, Boersma and Griffiths, Lahn.

Qatar: Qatar's power producers consume natural gas. Independent power and water producers (IPWPs) pay between $1/MMBtu and $2/MMBtu depending on when they signed their contracts with Qatar Petroleum.

Saudi Arabia: Saudi Arabia raised the price of industrial fuels in January 2016. The price of natural gas increased by 67 percent, from $0.75/MMBtu to $1.25/MMBtu. The price of ethane, an important feedstock for the petrochemicals sector, rose from $1.25/MMBtu to $1.57/MMBtu, a 25 percent increase. Diesel for industrial use experienced a fourfold increase to $105.26/ton while the price of HFO doubled to $28.50/ton. Arabian Light crude oil rose by 50 percent (Saudi Gazette 2015). Due to demand being greater than supply, natural gas volumes are allocated by the government; however, the level of allocation to individual industries is not reported. In the absence of a reported value, the utility sector's natural gas allocation is assumed to equal the consumption data provided by the SEC (see The GCC Energy System).

UAE: It is difficult to ascertain prices paid by the utility sector in the UAE as prices are not publicly available as highlighted in Section 2. Abu Dhabi produces natural gas and receives deliveries from the Dolphin pipeline – reportedly at $1.30/MMBtu (Neuhof 2013). Dubai gets gas from the Dolphin pipeline and receives LNG deliveries at the Jebel Ali terminal at spot prices. The price paid by utilities may be an average cost from all sources, or it may be that the 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 (ADNOC) calculates the production cost of associated gas at $1/MMBtu (Boersma and Griffiths 2016). Additionally, a recent study by Lahn estimated natural gas prices at between $1/MMBtu and $2/MMBtu (Lahn 2016).

Electricity and water tariffs

Electricity and water tariffs are also undergoing reforms to provide consumers with incentives to reduce consumption and decrease government subsidies. In September 2015, Qatar initiated a price hike for electricity and water. The UAE have also undertaken substantial tariff reforms. Several studies examine in detail recent subsidy reforms for electricity and water, as well as their impacts on demand (Wogan and Cote 2016; Krane and Hung 2016; Boersma and Griffiths 2016; Fattouh and Sen 2016; Lahn 2016).

Policies, Targets and Reforms

Given growing energy demand, GCC states have announced plans to both diversify electricity production (by deploying renewable and nuclear capacity) and to reduce demand (through efficiency measures). This section outlines announced targets and reforms of the power and water sectors. Announced renewable energy and energy efficiency targets in the GCC are summarized in Table 4 (IRENA 2016; Oman PAEW 2015b; Dubai Supreme Council of Energy 2014).

Renewable energy mix

The GCC region is endowed with substantial renewable energy resources (as highlighted in Resources). Renewables-based power generation has the potential to meet the GCC states' commitments to sustainable development while contributing to wider economic diversification goals. Collectively, GCC countries have set a target to install 80 GW of renewable energy capacity by 2030, which is more than half of all existing conventional capacity. Saudi Arabia has a medium-term target of 9.5 GW of renewables by 2023. Qatar targets 20 percent (1.8 GW) of capacity from renewables by 2030, by which time Kuwait should have 5.3 GW. The UAE has regional targets: in Dubai, 25 percent of electricity will come from solar plants by 2030, while Abu Dhabi has a target for solar reaching 7 percent of installed capacity by 2020. Bahrain aims to increase renewable energy to 5 percent of total installed generation capacity by 2020.

Table 4. Announced renewable energy and energy efficiency targets.

Country	Renewable targets		Efficiency targets	
Bahrain	5% of installed capacity	2020		
Kuwait	CSP = 5.7 GW	2030	Improve generation efficiency by 5%	2020
	Solar PV = 4.6 GW	2030		
	Wind = 0.7 GW	2030	Improve generation efficiency by 15%	2030
	15% of generation	2030		
Oman	Currently preparing a long-term energy strategy			
Qatar	1.8 GW solar	2030	20% reduction in per-capita electricity consumption	2017
	20% of generation	2030	30% reduction in per-capita water consumption	2017
Saudi Arabia	9.5 GW = mix of wind, solar PV, CSP solar and waste-to-energy	2023	Reduce peak demand by 14%	2021
			Reduce electricity consumption by 8%	2021
UAE (no national target)	7% of installed capacity in Abu Dhabi	2020	Reduction in power consumption by 30%	2030
	25% of electricity supply in Dubai	2030		
	75% of electricity supply in Dubai	2050		

Source: IRENA, Oman Public Authority for Power and Water, Dubai Supreme Council of Energy.

Energy efficiency

Throughout the GCC region, administered prices for industries and consumers contribute to growing energy demand, in part because they disincentivize conscientious consumption. To temper demand growth, GCC member states (with the exception of Bahrain) have announced short- to long-term energy efficiency targets. By 2021, Saudi Arabia aims to cut peak electricity demand by 14 percent while also reducing overall electricity consumption by 8 percent. The UAE has a long-term target of reducing energy consumption by 30 percent by 2030 (DEWA 2014). Qatar has an aggressive short-term target of 20 percent reduction in per-capita electricity consumption by 2017. Kuwait has set targets to improve power generation efficiency by 5 percent by 2020 and 15 percent by 2030.

Nuclear power

Following a feasibility study commissioned in 2006, two GCC countries have begun to seriously pursue nuclear power: the UAE and Saudi Arabia have gone as far as setting up strategic nuclear power plans (WNA 2016). The UAE began building its first nuclear power plant in Abu Dhabi in 2012, with the first reactor due to come online in 2018 (see this link: https://www.thenational.ae/uae/government/construction-of-uae-s-first-nuclear-reactor-complete-but-operation-delayed-to-2018-1.42360); three additional reactors are anticipated to start by 2020 for a total installed capacity of 5.6 GW (Emirates Nuclear Energy Corporation 2016). Saudi Arabia is considering constructing 16 nuclear power reactors amounting to 17 GW by 2040 to meet 15 percent of the Kingdom's power demand (El-Katiri 2012). For scale, the planned investments in renewables is almost four times that of planned nuclear capacity.

Power sector reforms

While GCC governments continue to play a significant role in the generation, transmission and distribution of electricity, all of them are in the process – albeit at different stages – of reforming their power sectors. This reform can reduce overall demand (and therefore the cost to governments of electricity supply) by incentivizing investment in more efficient technology and reducing end-consumer demand. All GCC countries have IPWPs and all are pursuing a structure in which a single buyer purchases electricity from generators. Some member states are much further in the liberalization process. Oman, for example, has put in place laws to reform the power structure and established a plan for a spot power trading market. Saudi Arabia has approved plans for unbundling the state-owned electricity company, which is anticipated to lower the cost of generation and reduce financial burden on the Saudi government.

Bahrain: The power sector in Bahrain was vertically integrated until 2016, when the government privatized its generation stations. The Ministry of Electricity and Water Affairs (through the Electricity and Water Authority) oversees electricity generation, transmission and distribution. In March 2016, the ministry reduced subsidies to electricity and water consumption through an adjustment resolution on tariffs (Bahrain EWA 2016).

Kuwait: The Ministry of Electricity and Water is mostly responsible for electricity production, transmission and distribution in Kuwait. In 2013, the Az-Zour North gas-fired power plant became Kuwait's first independent power plant in which the Kuwaiti government holds a major share (60 percent) (APICORP 2016).

Oman: Market reform in Oman was introduced through the Law for the Regulation and Privatization of Electricity and Related Water Sector in 2004 (known as the Sectoral Law) with the aim to unbundle the state-run power industry (OBG 2016). At present, IPWPs sell to the Oman Power and Water Procurement Company (OPWP). The Oman Electricity Transmission Company has sole responsibility for transmission while distribution is conducted via three companies: the Muscat Electricity Distribution Company (MEDC), and the Majan and Mazoon electricity companies. While OPWP buys electricity from IPWPs by entering into power purchase agreements (PPAs), the transmission company is regulated by price controls and no subsidies are involved. Direct subsidies are channeled through the distribution companies.

Qatar: The power sector in Qatar was reformed in 2000 by separating power generation and water production from their transmission and distribution. Currently, power generation and water production are carried out by KAHRAMAA and by some IPWPs. The QEWC holds shares in these IPWPs, in most cases at more than 50 percent (QEWC 2014). It is responsible for nearly all electricity generation and water supply, and its shares are publicly traded. Transmission and distribution of electricity and water are the sole responsibility of the QEWC. To meet projected electricity and water demand, the QEWC is also actively involved in initiating and negotiating with IPWPs for the construction of additional production capacity (KAHRAMAA 2014; QEWC 2014).

Saudi Arabia: The Ministry of Energy oversees overall policies, plans and strategies for the electricity and water sectors in the Kingdom. An independent regulatory authority, the Electricity and Cogeneration Regulatory Authority (ECRA), oversees regulation of the electricity and water desalination industries. ECRA has approved plans for the unbundling of the power market structure, which is currently vertically integrated (ECRA 2014). As of 2017, the SEC is the utility company responsible for generation, transmission and distribution of electricity; its stocks are publicly traded, although more than 81 percent of SEC shares are owned by the Saudi government and Saudi Aramco. A new principal buyer, the Saudi Company for Purchasing Power, was established in 2017 (Roscoe 2017). Some large industrial consumers generate their own electricity and can sell surplus electricity to SEC by connecting to the transmission grid. At the end of December 2015, the government announced a tariff reform that increased electricity rates for the highest consumption tiers (Wogan and Cote 2016). Also, Saudi Aramco has announced an initial public offering of some of its equity, to be released in 2018.

UAE: The power sector in the UAE 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) generate nearly 96 percent of the Abu Dhabi's power, which the Abu Dhabi Water and Electricity Company purchases through bidding processes under PPAs. Transmission of electricity and water is carried out by the Abu Dhabi Transmission and Dispatch Company.

Data Maintenance and Validation

Public sources were used entirely to develop this overview and populate the data sets on OpenKAPSARC. As noted in the text, some data were not available at time of publishing.

Contributions from the GCC energy and policy community are encouraged to make the data repository as current and representative as possible, which will be reflected in forthcoming annual overviews.

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Appendix A: Fuel Consumption

Table A1. Estimated fuel consumption by power and water sectors (TBtu).

Country	Crude oil	Natural gas	Diesel	HFO	Total
Bahrain	-	235.3	-	-	235.3
Kuwait	26.3	354.6	46.9	274.3	702.1
Oman	-	264.2	-	-	264.2
Qatar	-	433.6	-	-	433.6
Saudi Arabia	865.1	670.3	469.8	275.0	2,280.1
UAE – Abu Dhabi	1.0	689.4	1.1	-	691.5
UAE – Dubai	> 0	467.0	0.7	-	467.8
UAE – Sharjah	-	59.2	-	16.9	76.1
UAE – FEWA	-	3.4	-	1.2	4.6
Total	891.4	3,177.0	518.5	567.4	5,154.3

Source: Kingdom of Bahrain National Oil & Gas Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Electricity & Cogeneration Regulatory Authority, UAE Ministry of Energy, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

Table A2. Fuel consumption in physical and energy units.

Country	Crude oil (MMbbl)	Natural gas (TBtu)	Diesel (MM tons)	HFO (MM tons)
Bahrain	-	235.33	-	-
Kuwait	4.85	354.6	1.14	6.96
Oman	-	264.18	-	-
Qatar	-	433.6	-	-
Saudi Arabia	151	670.29	10.80	6.52
UAE – Abu Dhabi	0.17	689.37	-	-
UAE – Dubai	-	467.02	-	-
UAE – Sharjah	-	59.22	-	0.40
UAE – FEWA	-	3.44	-	0.03

Source: Kingdom of Bahrain National Oil & Gas Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Electricity & Cogeneration Regulatory Authority, UAE Ministry of Energy, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

Appendix B: Disaggregated Power and Cogeneration Capacities

Table B1. Power capacity in GW.

Country	Steam turbine (ST)	Gas turbine (GT)	Combined cycle gas turbine (CC)	Photovoltaic (PV)
Bahrain	-	0.71	0.95	-
Kuwait	8.97	7.03	2.27	-
Oman	-	-	5.79	-
Qatar	-	0.38	2.007	-
KSA – east	10.17	9.61	5.24	0.01
KSA – west	13.92	9.07	1.29	0.002
KSA – south	1.02	4.11	-	0.0005
KSA – central	0.23	13.07	5.42	0.0035
UAE – Abu Dhabi	-	-	-	0.05
UAE – Dubai	-	1.85	-	0.01
UAE – Sharjah	-	1.86	-	-
UAE – FEWA	-	0.19	-	-

Source: Kingdom of Bahrain Electricity & Water Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Saudi Electricity Company, Electricity & Cogeneration Regulatory Authority, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

Table B2. Cogeneration capacity in GW.

Country	ST w/ MSF	GT w/ HRSG	CC w/ MSF	ST w/ variable MSF	CC w/ MED
Bahrain	0.1	-	1.03	-	-
Kuwait	-	-	-	-	-
Oman	-	-	2.39	-	-
Qatar	-	1.67	4.51	-	-
KSA – east	1.72	-	2.24	1.07	0.73
KSA – west	2.12	0.20	-	1.20	0
KSA – south	0.11	-	-	-	-
KSA – central	-	-	-	-	-
UAE – Abu Dhabi	-	1.65	13.85	-	-
UAE – Dubai	-	-	7.80	-	-
UAE – Sharjah	0.89	-	-	-	-
UAE – FEWA	-	0.19	-	-	

Source: Kingdom of Bahrain Electricity & Water Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Saudi Electricity Company, Electricity & Cogeneration Regulatory Authority, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

Table B3. Cogeneration capacity in million m^3/day.

Country/ region	MED	MSF	RO	ST w/ MSF	GT w/ HRSG
Bahrain	-	0.06	0.06	0.02	-
Kuwait	-	1.77	0.23	-	-
Oman	-	-	0.44	-	-
Qatar	-	0.01	-	-	0.75
KSA – east	-	-	0.22	0.87	-
KSA – west	0.04	-	0.98	1.01	0.10
KSA – south	0.18	-	0.22	-	-
KSA – central	-	-	-	-	-
UAE – Abu Dhabi	-	-	-	-	-
UAE – Dubai	-	-	0.09	-	-
UAE – Sharjah	-	-	0.07	0.90	-
UAE – FEWA	-	-	0.11	-	-

For Sharjah, we assume that non-cogeneration technology is RO.

Country/ region	CC w/ MSF	ST w/ variable MSF	CC w/ variable MED
Bahrain	0.36		
Kuwait	-	-	-
Oman	0.61	-	-
Qatar	0.62	-	-
KSA – east	1.14	0.54	0.37
KSA – west	-	0.57	-
KSA – south	-	-	-
KSA – central	-	-	-
UAE – Abu Dhabi	3.47	-	-
UAE – Dubai	-	-	-
UAE – Sharjah	-	-	-
UAE – FEWA	-	-	0.09

Source: Kingdom of Bahrain Electricity & Water Authority, Kuwait Ministry of Electricity & Water, Oman Power and Water Procurement Company, Qatar Electricity & Water Corporation, Saudi Electricity Company, Electricity & Cogeneration Regulatory Authority, Abu Dhabi Water and Electricity Company, Dubai Electricity and Water Authority, Sharjah Electricity and Water Authority, Federal Energy and Water Authority, KAPSARC.

Appendix C: Load Segments

We represent solar and wind by discretizing observations for 8,760 hours into three seasons (summer, winter, and a combined spring and fall) each with two representative days (weekday and weekends). Representative days are further discretized into eight segments to improve computation time. Segment lengths were chosen to capture the shape of the curve in both low and peak periods throughout the day, i.e., peak segments have shorter durations (two hours) while flatter segments have longer durations (four hours). The segments are presented in Table C1.

Table C1. Hours per load segment.

Load segment	Period	Hours
L1	00:00 - 04:00	4
L2	04:00 - 08:00	4
L3	08:00 - 12:00	4
L4	12:00 - 14:00	2
L5	14:00 - 17:00	3
L6	17:00 - 19:00	2
L7	19:00 - 21:00	2
L8	21:00 - 24:00	3

Source: KAPSARC.

Notes

Notes

About the Authors

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About the Project

The objective of this project is to assess potential economic and technical gains that could be realized by utilizing the GCC Interconnector to deliver electricity at least-cost across the GCC.

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