Water-Energy Nexus in Saudi Arabia

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Water-Energy Nexus in Saudi Arabia

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Abstract

Water and energy systems have often been treated as separate "silo" systems over the entire pathway from production to consumption. However, their close interdependence requires some perspective of the water-energy nexus (WEN), especially in regions with very high water stresses combined with a myriad of rapid changes in resource production and consumption. This work provides a comprehensive analysis of the interdependence of water and energy in Saudi Arabia, including collecting data to map out energy and water consumption across the Kingdom. By combining and cross-referencing numerous data sources, this work creates the first country-wide Sankey diagram describing the interdependence of water and energy use in the Kingdom, and provides the most comprehensive mapping of power plant type and size. Additionally, this work reviews the energy and water industries, including outlining trends in population, urbanization, natural gas, oil, electricity, desalination, water use in energy production, and energy use in water production. Overall, a clear pattern has emerged: converging trends of rapid population increases, dwindling water resources, and rapidly growing desalination means that water use must be one of the primary driver of resource planning in Saudi, and plans to shift energy production to reduce GHG emissions must include water needs.

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keywords: water-energy nexus; oil and gas; electricty production; water use; desalination; Saudi Arabia

1. Introduction

The balance between the increasing supply and demand of water and energy is progressively becoming a serious challenge worldwide. With increasing depletion levels of freshwater sources, sea water treatment (desalination) is increasingly becoming the only available alternative to fresh water supply, especially in arid regions. Desalination, however, is an energy intensive enterprise that can only be secured under the condition of abundant energy supply. Similarly, water is an essential ingredient for most conventional and non-conventional (renewable) forms of energy production and power generation (except for most winds and PV applications). The water–energy nexus (WEN) is an analytical framework that treats water and

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energy use as an integrated system. It factors the amount of water used in power generation and energy production as well as the amount of energy consumed in water treatment[1,2]. Saudi Arabia, an arid land with very limited fresh-ground-water resources and an ample reserve of oil and gas. It is estimated that up to 9% of the total annual electrical energy consumption may be attributed to ground water pumping and desalination in Saudi Arabia [1,3]. This article adopts the water-energy nexus perspective to reveal some of the challenges and opportunities in water treatment and power generation in Saudi Arabia.

2. Background

2.1. Population and Urbanization

Saudi Arabia is the second largest Arab state behind Algeria (land size) and comprises majority of the Arabian Peninsula [4][5]. Saudi Arabian population reached 32,203,206 on July 31st 2016 [6]. By 2050 Saudi Arabia's national population is predicted to grow by 77% to more than 56 million from 32 million. Today the median age of the population is 26 years; with Saudis expecting to live to 75 years, high population growth, and prolonged life expectancy rates will put severe pressure on future water and energy resources [7]. Figure 1(a) presents population growth of the six gulf cooperation council (GCC) countries and Yemen throughout the years from 1960 to 2016 [8]. Urbanization on the other hand will result in increasing population density in urban areas and this increase in population density puts stress on the local environment [9]. According to world meters [6], 78.8 % of the Saudi population is urban (25,344,685 people in 2016) with the rate of urbanization increasing at 2%. If urban growth outpaces the rate at which growth may be sustainably supported, Saudi Arabia will experience a heightened threat to its natural resource [7]. Figure 1(b) presents the urbanization rise rates among Yemen and GCC countries. It shows Saudi Arabia among the increasingly urbanized countries.

(a) Population rise of GCC countries and Yemen (1960-2016)

(b) Urbanization rise of GCC countries and Yemen (1950 – 2050)

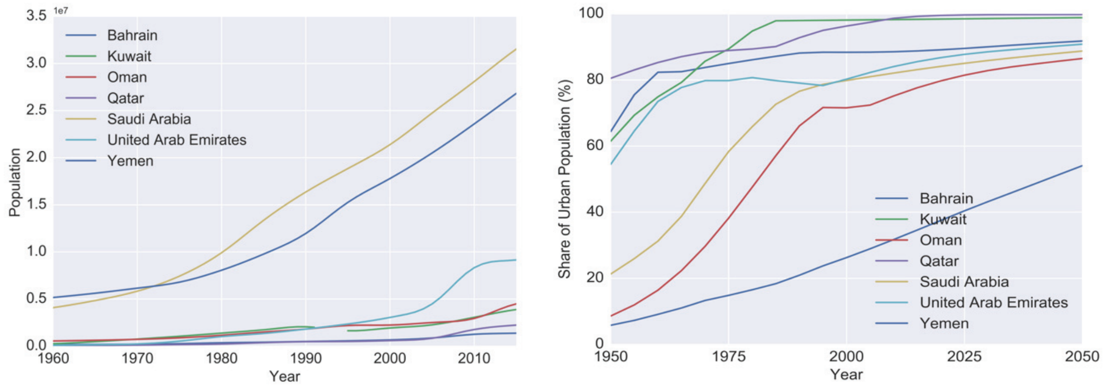

Figure 1: (a) Percentage of population increase in GCC countries and Yemen (1960 - 2016); (b) Percentage of urbanization increase in GCC countries and Yemen (1950 - 2050). Graphs created using data from the World Bank [8]

3. Water

Saudi Arabia's average annual rainfall is less than 100mm. Moreover, the high evaporation rates limit the availability of surface water sources. The over-extraction of groundwater resources and a lack of perennial rivers have led to the development of extensive desalination facilities [7]. Since 2005, desalinated water has accounted for approximately 70% of the nation's water use. Saudi Arabia is already the world's largest producer of desalinated water. Desalination plants in the country accounts for about 18% of the total world output. and the kingdom plans to double desalination capacity over the next decade. However, the consumption of water in Saudi Arabia has reached alarming levels. Desalinated water consumption is growing at around 14% per year; that is twice the total domestic consumption of water and six times the growth rate of the population. It stands at a rate that is twice the world average, using much more water than countries endowed with greater water resources [5]. The average per capita water consumption rate is estimated at 100 – 350 liters per day for urban areas and 15-20 liters for rural areas [7]. Figure 2 (a): presents water footprint for GCC countries and Yemen. It shows that Saudi Arabia scores as the highest water consumer among the seven countries in total. The figures show that almost 75% of water consumption in Saudi is dedicated to agriculture, followed by about 25% of water consumed domestically. The remaining amount is divided between industrial and grazing. The figure also shows that Yemen is the second highest water consumer among the seven countries. Figure 2 (b) presents water consumption per capita in the same regions. It interestingly shows that the United Arab Emirates is the highest water consumer per capita among the seven countries in total.

(a) Water footprint of GCC countries and Yemen

(b) Water footprint of GCC countries and Yemen per capita

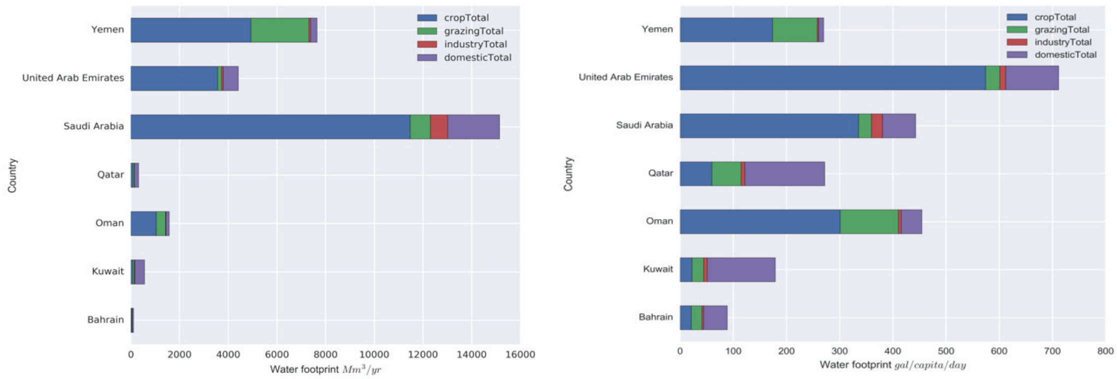

Figure 2 : (a) Water footprint assessment of GCC countries and Yemen; (b) Water footprint assessment per capita use of GCC countries and Yemen. Graphs were generated using data from water footprint network [10]

4. Energy

4.1. Oil and Gas

The Kingdom has the lion's share of global oil production capacity. It holds the world's largest (conventional) crude oil reserves. As of 2013, it was the largest exporter of total petroleum liquids, and the second largest petroleum liquids producer behind the United States. The Kingdom is also the largest consumer of petroleum in the Middle East with more than 3 million barrels per day of domestic oil consumption. It is ranked as the 6th largest oil consumer in the world behind the US, China, Japan, India and Russia with a domestic consumption almost doubling since 2000. With 6.7 tons oil equivalent (toe) per capita in 2013, its energy consumption is among the highest in the world (13th position; 7 toe in the US, 3.2 toe in the EU and 1.9 as a world average). Thus, unlike the general trend observed in most countries, Saudi energy consumption has been growing at a faster pace than its GDP, resulting in an increased energy intensity (137 toe of energy use per 1000$ of GDP in 2011; 95 toe in the EU) [5]. Although the Kingdom does not export nor import natural gas, Saudi Arabia holds the 5th largest natural gas reserves- solely used for its domestic demand- with proven reserves of 8.2 trillion cubic meters (tcm), 4.4% of world natural gas proved reserves, and produces 103 billion cubic meters (bcm) annually [5]. Only Russia, Iran, Qatar and United States have more. The kingdom relies heavily on hydrocarbons as feedstock for the electricity sector:

Saudi Arabia is by far the largest user of crude oil for power generation in the world. Oil accounts for two thirds of the input into electricity generation, with natural gas providing most of the remaining portion [3,9].

4.2. Electricity

The electricity sector is the third main consuming sector of oil behind transportation and desalination. It uses around 700,000 bbl/d of oil consumed during the summer peak demand[5]. Saudi electricity generation is heavily dependent on hydrocarbons, with crude oil accounting for 29% of electricity production in 2013, diesel (15%), heavy fuel oil (10%) and natural gas providing the remaining 46% [5]. The electricity use in Saudi Arabia has risen by about 7-8% annually since 1990, with summer peak demand increasing by 93% between 2004 and 2013 (from 28 to 54 GW). Between 2013 and 2020, the Saudi electricity demand is expected to increase by over 6% annually. This future electricity demand growth will require power generation capacity to increase to 120 GW by 2032 [5]. However, Saudi reformed energy policy has a particular focus on electricity production. It is based on a diversification program of the energy mix towards renewable in order to meet the increasing demand of electricity [5]. With regard to the potential of renewable energy in Saudi Arabia; studies show that Saudi's geographic location is ideal for harnessing solar energy. The solar radiation atlas states that the country receives annually about 3,245 sunshine hours accounting for an annual solar radiation figure for over 2,200 kWh/m^2 [11].

5. Water – Energy Nexus

As stated earlier, the water-energy nexus refers to the interdependency between water and energy. Water is used in power generation and energy production. The primary use of water in Saudi is energy production is to cool thermal power plants and in the extraction, transport and processing of fuels. Energy on the other hand is vital for providing fresh water. It is used to power systems that collect, transport, distribute water and treat it [12][2].

5.1. Water use in energy production

Water is a crucial input to the oil and gas production. Water is used to enhance production of declining conventional and offshore wells. In Saudi Arabia; energy production accounts for the second largest use of water behind agriculture and is expected to continue rising over the next 15-20 years[13]. Water is also used at power plants for electricity generation, predominantly for cooling. It has a significant effect on the overall water supply and the ecological health of surface water bodies. In discussing water use, it is important to distinguish between withdrawal and consumption. "Withdrawal" refers to water taken from a watershed or aquifer, irrespective of whether it is ultimately discharged back to the watershed. "Consumption" refers to water withdrawn that is specifically not discharged back to the watershed. The type of cooling system determines whether water will be withdrawn or consumed during the process of power generation. The two most common cooling systems are cooling towers and once-through cooling. By identifying the type of cooling system, it is possible to estimate the amount of water used in power generation[14][15].

5.2. Energy use in water production

While desalinated water has ensured Saudi Arabia has enough water to meet demand, it does create its own challenges. The process requires high energy input; more than half of domestic oil consumption is required to run the plants. The high costs and energy consumption associated with the desalination process have created a consequence where Saudi Arabia's desalination aptitude, and therefore water security is closely linked to the stability of its oil supply[7]. Thus, the key issue identified here is that desalination is very costly and is not sustainable in its current form in the long run. It accounts for 10% to 20% of the energy consumption in Saudi Arabia. The low water costs paid by the end users in the Kingdom are equivalent to 5-10% of the actual production cost in the public sector. Unless alternative energy and energy conservation measures are implemented, the overall demand for fossil fuel for power, industry, transportation and desalination is estimated to grow from 3.4 million barrels of oil equivalent per day in 2010 to 8.3 million barrels of oil equivalent per day in 2028 [5].

Figure 3 shows a Sankey diagram of water-energy nexus illustrating the interconnectivity between both systems. It shows resources and consumption of water and energy in Saudi Arabia. As mentioned above, agriculture is the largest consumer of water in Saudi Arabia. It also shows that Desalination and residential are the main consumers of energy in Saudi Arabia. The data used for generating the Sankey diagram was collected by cross-referencing several sources; enipedia from TU delft and Y databases, desal-data.com, Z, AQUASTAT data base, and several others. In addition, calculations were performed whenever needed; efficiency for each power system was calculated using the CO2 emissions per kWh provided from the same references. Moreover, average efficiency numbers for each type of desalination plant was used to calculate its power inputs.

A Sankey diagram of water and energy resources and consumption in Saudi Arabia

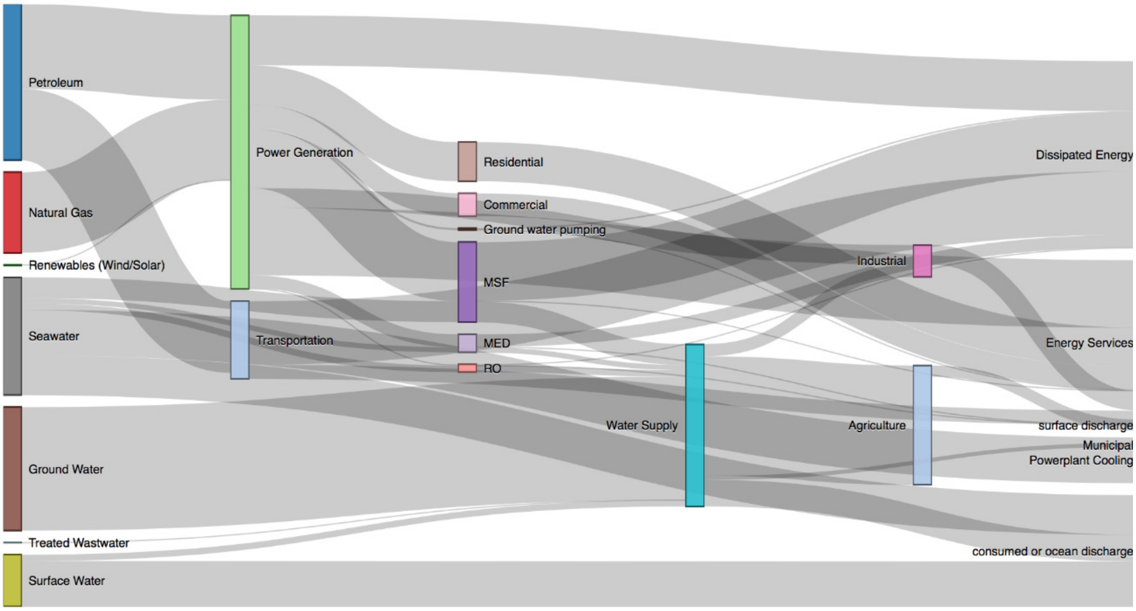

Figure 3: A Sankey diagram of water and energy resources, production, and consumption in Saudi Arabia. Created by combining multiple data sources for water and energy use and production, and making calculations with available data on system efficiencies[16][17] [18][19][20].

6. Conclusion and Future Work

The article reveals the embedded interlinks between water and energy systems in Saudi Arabia. Both water and energy sustainability in Saudi Arabia is thoroughly dependent on one another. However, the systemic structure of the water-energy nexus in Saudi Arabia is far from sustainable. Electricity and water consumptions are both rising at rates that exceed the international standards. Desalination is major energy consumer in Saudi Arabia, with production expect to increase substantially in coming years, and substantial improvement in energy efficiency will be a significant factor in facilitating energy efficiency in Saudi Arabia. Moreover, the growth of cities and increased population, coupled with the rise in the living standards, has resulted in an unappreciated demand for water and caused domestic and industrial water consumption to increase significantly. A greater investment in demand-side management strategies to increase conservation practices and decrease consumption rates is urgently required.

In light of these facts, the present path of water, energy, and electricity consumption in Saudi Arabia is not sustainable in the long run. The rising domestic energy consumption could result in the loss of 3 million barrels per day of crude oil exports by the end of the decade if no changes were made to current trends, Saudi Arabia may become a net oil importer by 2038 if the domestic consumption is not curbed significantly. Such results suggest that policy makers should explicitly consider energy implications in future restructuring of water demand and vice versa. This will help in making more integrated decisions on water and energy infrastructure systems. Saudi Arabia is the largest country in the world to be so entirely dependent on desalination for its freshwater supply.

Future work will focus on both analyzing WEN systems in other countries with similar climate conditions to Saudi Arabia and quantifying the amount of water used in electricity production in Saudi Arabia. The purpose of this analysis is to learn more about the most efficient systems and understand their implementation policies with the aim of improving WEN sustainability in Saudi Arabia. In addition, the quantification of water amount used in electricity production in Saudi Arabia will assist in proposing the appropriate energy mix to meet the future demand in the country with less water use including both conventional and renewables.

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