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Policy Brief

A NEW CASE FOR WASTEWATER REUSE IN SAUDI ARABIA: BRINGING ENERGY INTO THE WATER EQUATION

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Dubai Initiative – Policy Brief

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June 2011

ACKNOWLEDGMENTS

The research for this report for the Energy Technology Innovation Policy (ETIP) is generously supported by The Dubai Initiative and by The Science, Technology, and Public Policy Program of the Belfer Center for Science and International Affairs.

All responsibility for any errors or misjudgments rests solely with the authors.

CITATION INFORMATION

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This policy memo may be cited as: Kajenthira, Arani, Diaz Anadon, Laura, and Siddiqi, Afreen, “The Case for Cross-Sectoral Water Reuse in Saudi Arabia: Bringing Energy into the Water Equation.” Dubai Initiative Policy Brief. Cambridge, Mass.: Energy Technology Innovation Policy Program, Belfer Center for Science and International Affairs, Harvard Kennedy School, Harvard University, June 2011.

Industrial and urban water reuse should be considered along with desalination as options for water supply in Saudi Arabia. Although the Saudi Ministry for Water and Electricity (MoWE) has estimated that an investment of \$53 billion will be required for water desalination projects over the next 15 years [1], the evolving necessity to conserve fossil resources and mitigate GHG emissions requires Saudi policy makers to weigh in much more heavily the energy and environmental costs of desalination. Increasing water tariffs for groundwater and desalinated water to more adequately represent the costs of water supply could encourage conservation, but also reuse, which may be more appropriate for many inland and high-altitude cities. The Saudi government should expand its support for water conservation and reuse within industry through financial incentives or through the implementation of cleaner production standards that encourage energy and water conservation and reuse. The case studies discussed in this work suggest that the implementation of water conservation, reuse and recovery measures in the natural gas [2] and crude oil [3] sectors alone have the potential to conserve up to 222 million m³ of water annually [2-4], or 29% of the total industrial water demand in 2009 [5]. In the municipal sector, increasing secondary wastewater treatment and reuse resulted in substantial cost and energy savings for six inland cities, while an estimated 26% of urban water needs could be met by treated wastewater. Therefore, industrial and domestic water reuse have the potential to appreciably reduce water withdrawals, conserve non-renewable aquifer water, and reduce reliance on desalination, which is primarily driven by non-renewable natural gas. Anticipated investments in desalination projects could also be deferred by prioritizing investment in sewage and water distribution networks that would ensure more effective water reclamation and reuse while simultaneously conserving non-renewable groundwater and natural gas resources and preventing the lock-in of potentially unnecessary desalination infrastructure that is likely to become more efficient in future.

BACKGROUND

The arid nature of the Arabian Gulf has resulted in water playing a dominant role in human settlements and socio-economic interactions [6]. Although originally reliant upon agriculture, oil and gas have played an increasingly significant role in the economies of this region since their discovery in the early 20th century [7]. Rapid population growth and increased urbanization [8] in the Gulf over the past decade have created major challenges in the provision of infrastructure and public services [9], including clean water. Although the agricultural sector is responsible for the highest percentage of total water withdrawals in both the Arabian Gulf and worldwide [10], the present growth of the service sector economy in the Gulf region is likely to result in increased volumes of wastewater in the municipal and industrial sectors [11] that should be effectively reclaimed and reused to better address water scarcity. Only 65% of the wastewater generated in the Arabian Peninsula is treated at present [5], and increases in both urban populations and wastewater

volumes have resulted in overloaded treatment plants and highly variable, often ineffective treatment [12]. At least 35% of the total wastewater produced is discharged in the untreated form and most likely used in crop irrigation by urban and peri-urban farmers [12].

FOCUS: SAUDI ARABIA

Saudi Arabia occupies over 70% of the Arabian Peninsula [13], an area approximately $\frac{1}{4}$ the size of the United States, and is the largest country in the world with no lakes or rivers [14] to sustain its population of 25.7 million [15]. Despite possessing annual renewable water resources of only 2.4 billion m^3 [13], Saudi Arabia's water withdrawals exceeded 20 billion m^3 in 2010 [13, 16], making it the third-largest per capita water user worldwide [16]. Over 80% of Saudi Arabia's water supply (primarily in the agricultural sector) is withdrawn from non-renewable groundwater aquifers [17]. At present abstraction rates [5, 13], it is estimated that these aquifers contain only a 15-25 year supply. Water demands have been exacerbated by rapid population growth and increased urbanization [8] and are expected to double over the next two decades [18], with the municipal and industrial sectors increasingly reliant on desalination.

Desalination – particularly the large-scale thermal desalination prevalent in Saudi Arabia – is a capital and energy-intensive means of producing fresh water. The operating cost of a multi-stage flash (MSF) cogeneration plant is approximately \$0.60/ m^3 , of which \$0.27 and \$0.19 - or nearly 77% - are attributable to thermal and electrical energy, respectively [19, 20]. Plant operation also results in GHG emissions of 10-20 kg CO_2/m^3 of desalinated water produced [20], and environmental costs of the ocean disposal of the resulting brine remain unknown. Saudi Arabia's substantial thermal desalination capacity has largely been made feasible by its wealth of oil and gas resources: the largest producer and exporter of total petroleum liquids worldwide [21], Saudi Arabia also possesses the fourth-largest natural gas reserves globally [21]. Perhaps unsurprisingly, the country's economy is also highly carbon intensive, with a carbon intensity of 1.15 tonnes of CO_2 per thousand US dollars in 2009 in comparison to the US economy's carbon intensity of only 0.38 [22]. The Saudi Minister of Water and Electricity estimated that 25% of Saudi oil and gas production in 2009 was used domestically to generate electricity and produce water, with present demand rates suggesting that this figure will reach 50% by 2030 [23]. Natural gas demands are consequently also anticipated to double from 2007 to 2030, from 7.1 to 14.5 billion cubic feet (bcf) per day [21].

The majority of natural gas in Saudi Arabia (50-60%) is associated with petroleum deposits and production costs for this associated gas have to date been consistent with the subsidized domestic gas price of \$0.75/MMBtu [21]. However, the increasing domestic demand, combined with OPEC crude oil production constraints, has necessitated the

development of offshore high-sulfur gas fields with estimated production costs of \$3.50-\$5.50 per MMBtu [21]. The disparity between associated and high-sulfur gas production costs will likely impact the domestic gas price and suggests that power generation and thermal desalination will become even more expensive in the near future. In addition, the carbon intensity of the Saudi Arabian economy and increasing evidence of the negative impacts of CO₂ emissions from energy use imply that over time, even fossil-rich countries will need to reduce carbon intensity. As the continued use of natural gas in the desalination industry is less justified with rising natural gas prices and also contributes to the carbon intensity of Saudi Arabia's economy, it is increasingly urgent to identify ways to meet the domestic water demand both sustainably and inexpensively.

Increased wastewater reuse has long been recognized as a potential intervention strategy in addressing water scarcity [24], however the lack of national policies and/or strategies to support wastewater treatment and reuse has significantly restricted reuse in most Arab countries [20]. Some of these constraints include: "incomplete economic analysis of the wastewater treatment and reuse options, usually restricted to financial feasibility analysis", and the "perceived high cost of developing wastewater collection networks and wastewater treatment plants and low returns" which, when combined with a disparity between water pricing and regional water scarcity and inefficient irrigation and water management systems, do not allow for effective water reuse [12].

Our study takes a novel approach in exploring the potential for increased wastewater reuse in Saudi Arabia by evaluating not only the economic and environmental costs but also the potential energy implications of reusing reclaimed wastewater rather than fossil groundwater and/or desalination in the municipal and industrial sectors. As the petrochemical sector is responsible for over 80% of Saudi Arabia's GDP, our industrial assessment focused on the cost and energy implications of reducing total groundwater use in the oil and gas industry through increased water conservation, reclamation, and reuse. Similarly, our municipal analysis explored the energy, environment, and cost implications of transporting desalinated water to six inland cities that together contain approximately 35% of the total population.

Water for energy: the oil and gas sector

Case study data from the national oil company Saudi Aramco indicated that an existing natural gas plant could reduce its annual water withdrawals of 1.98 million m³ by almost 45% through the implementation of water conservation, reuse and recovery mechanisms [2]. Implementation of similar measures across Saudi Arabia's natural gas sector [25] could result in the conservation of over 23 million m³ of water while also saving up to 1.6 x 10⁶ kWh of energy and 1.5 x 10⁶ of CO₂. Similar initiatives at Saudi Aramco's

Riyadh Oil Refinery could reduce daily water consumption by 8,400 m³ [3], and such reductions at oil refineries across the sector could save up to 199 million m³ of water annually. Based on this modeling approach, combined water savings across the oil and natural gas sectors due to the institution of water recycling, reuse and conservation measures were estimated at up to 222 million m³ annually, or ~29% of total industrial water withdrawals in 2009. Assuming that seawater reverse osmosis is used to supply potable water in other refineries, water savings of up to 544 x 10³ m³/day could result in cost savings of over \$91 million annually, as well as reducing energy consumption and GHG emissions by up to 1.79 billion kWh and 1.72 billion kg CO₂, respectively. This analysis suggests that reducing water withdrawals and maximizing water reuse across the petroleum sector could appreciably reduce industrial water withdrawals within Saudi Arabia. Financial support from the Saudi government (*e.g.*, loans, loan guarantees, tax credits) for renovations and process improvements to increase water efficiency could encourage water reclamation and reuse in this sector.

Energy for water: the municipal sector

In the municipal sector, the energy and economic costs (Appendix 1) of desalinated water production and transportation relative to local wastewater treatment (requiring little or no transportation) were modeled for six inland population centers: Mecca, Taif, Medina, Khams, Abha, and Riyadh. Most significantly, for all of these inland cities, the provision of desalinated water is more energy-intensive than the secondary or tertiary treatment of local wastewater. Based on our assessment, the treatment and reuse of the wastewater produced in these six population centers had the potential to reduce desalinated and groundwater withdrawals by almost 192 million m³ or 8% of the total municipal water withdrawals in 2009. Secondary wastewater treatment also resulted in substantial cost savings for all of the cities considered, however, tertiary wastewater treatment was more expensive than desalinated water provision in three out of six cities. Overall, an estimated 26% of urban water needs could be met by treated wastewater, resulting in savings of up to 4.0 × 10⁹ kWh of energy (2% of Saudi Arabia's electricity consumption in 2010 [26]), in these cities alone. The Saudi Arabian government should continue to prioritize the anticipated investment of \$23 billion into Saudi Arabia's sewage collection and treatment infrastructure [27] as it has been estimated that the combination of increased water reuse with widespread conservation measures could allow Saudi Arabia to meet about 50% of its municipal water demand – 2.3 billion m³/year in 2006 – with treated wastewater [28].

POLICY RECOMMENDATIONS

Encourage reuse before desalination, particularly for cities at high elevations

Desalination processes are energy-intensive and have to date been primarily powered by non-renewable fossil fuels [29]. Even though the cost of desalinating water has declined in recent years [30], production costs do not account for environmental [31] or transportation [31, 32] costs. Despite this, desalination continues to be the preferred option for countries in the Arabian Peninsula [33]. Riyadh, located at an altitude of 612m, presently receives desalinated water from a facility in Jubail, over 400 kilometers away [17, 34]. Given a production cost of \$0.60/m³ (2009 dollars, [20]) and an approximate transportation cost of \$0.706/m³ (2009 dollars, [31, 32]), the provision of desalinated water to Riyadh costs well over \$1.00/m³, while secondary or tertiary wastewater treatment costs \$0.13-0.63/m³ [24] or \$1.19-\$2.03 [35] (2009 dollars), respectively, and requires little or no transportation, making it less energy-intensive, more sustainable, and more cost-effective than transporting increasing quantities of desalinated water. Urban water reclamation and reuse could be increased in cities located inland and/or at high altitudes, particularly given that both domestic water demand and its associated wastewater are expected to increase over the next few decades. Plans to increase the urban water tariff from \$0.027/m³ to as much as \$1.40/m³ [36] should be accelerated to reduce overall water consumption, and water tariffs should be delineated based on water source. The use of treated water could be incentivized by reducing tariffs for treated wastewater and increasing tariffs for aquifer groundwater and desalinated water to better reflect energy and environmental costs. Finally, the introduction and enforcement of water regulations similar to the U.S. Clean Water Act could encourage industrial water conservation and reuse by implementing more restrictive standards for discharged wastewater [37].

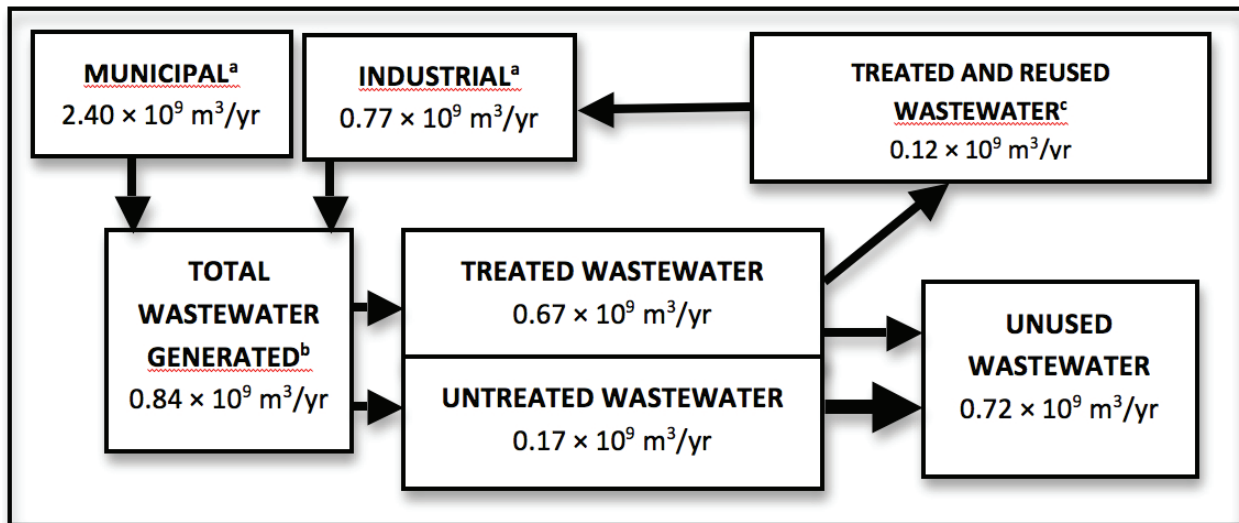
Ensure effective reuse while considering social norms and health implications

Treated effluent in Saudi Arabia is primarily reused in large cities for the irrigation of non-edible crops [13] (36%), land discharge (34%), sea discharge (18%) and industrial purposes, groundwater recharge and landscaping (12%) [11]. Wastewater reuse guidelines are more restrictive in Saudi Arabia than in other countries in the region [38], but although the development of more discriminating standards for water reuse could allow for increased use of treated wastewater without jeopardizing public health [39, 40], the reuse of wastewater within the industrial, rather than the agricultural, sector may present fewer public health implications while simultaneously decreasing demands on non-renewable groundwater and energy. Additionally, although the use of recycled wastewater for drinking and ablution was authorized by the Council of Leading Islamic Scholars

(CLIS) in Saudi Arabia in 1978, there remains strong public resistance towards the use of recycled water for this purpose [41] and the reuse of treated wastewater in industry is likely to encounter less resistance than domestic reuse. Water use requirements in the industrial sector are also relatively consistent year-round in comparison to more seasonal uses such as irrigation [42].

Fulfill commitments to increase sewerage rates to 100% and expand distribution infrastructure; this could have significant impacts on desalination planning

Saudi Arabia has by far the lowest overall sewerage rate of the GCC countries, at 37% [12]. Sewage systems are only available in large urban centers and wastewater disposal is limited only to cesspits in small towns and rural areas [39], resulting in over 467 million m³ of wastewater being discarded annually [5]. In addition, an average of 20% of distributed water is unaccounted for in Saudi Arabia, due to outdated and in some cases deteriorating infrastructure [43]. In Riyadh, as much as 60% of the water supply is lost through leakage in the 10,000 kilometers of pipes that transport water to the urban population of 5 million [1]. Recognizing the potential of wastewater as a future water source, the Saudi government created a National Water Company (NWC) to help increase wastewater network coverage to 100% [44] through public-private partnership (PPP) [1]. The NWC is in the process of awarding PPP management contracts for Saudi Arabia's five largest cities, which are together responsible for 65% of the country's total water consumption, in order to reduce water leakage, to ensure continuous water provision, and to expand wastewater treatment [1]. This is a crucial first step in reducing total water withdrawals: if the volume of treated wastewater presently being discarded (0.55 x 10⁹ m³) was instead reused in industry, it could reduce industrial water withdrawals by more than 70% (Fig. 1).

Figure 1: Wastewater production, treatment and reuse in Saudi Arabia, 2009

^aMunicipal and industrial water demand is met primarily by desalinated and groundwater. Treated wastewater is not reused for urban water supply.

^bWastewater is limited by low sewerage rates partly attributable to inadequate wastewater treatment networks

^cWastewater reuse was calculated based on present reuse of approximately 18% [36, 45]

The Saudi Ministry for Water and Electricity (MoWE) has estimated that an investment of \$53 billion will be required for water desalination projects over the next 15 years, with an equivalent amount required for the sewage sector [1]. Yet by prioritizing investment in sewage and water distribution networks, such an increase in desalination capacity may prove unnecessary and also help conserve natural gas reserves.

* * *

Therefore, increased water conservation and reuse within the industrial and domestic sectors have substantial potential to reduce total groundwater withdrawals in Saudi Arabia and the use of reclaimed water should be considered in addition to desalination as a future water supply option.

APPENDIX A: COSTS, ENERGY REQUIREMENTS, AND CO₂ EMISSIONS FOR WATER PRODUCTION

Table 1: Energy requirements, GHG emissions and costs for various types of potable water

Process	Energy Requirements			GHG emissions (kg CO ₂ /m ³ H ₂ O)	Costs (\$/m ³) (2009 dollars)	Product water recovery ratio (%)
	Thermal energy (MJ/m ³)	Electrical energy ^a (kWh/m ³)	Total electric equivalent (kWh/m ³)			
Treated surface water	-	0.15-0.30 ^c	0.15-0.30 ^c	0.29 ^b	nd	n/a
Groundwater	-	0.4-0.8 ^d	0.4-0.8 ^d	0.77 ^b	\$0.31-1.68 ^e	n/a
Secondary treated wastewater	-	0.13-0.64 ^f	0.13-0.64 ^f	0.12-0.61 ^b	\$0.13-0.63 ^g	n/a
Tertiary treated wastewater	nd	0.8-1.0 ^c	0.8-1.0 ^c	0.77-0.96 ^b	\$1.19-2.03 ^h	n/a
MSF: <i>Seawater (cogeneration)</i>	250-300 ⁱ	3.5-5.0 ⁱ	15-25 ⁱ	10-20 ^m	\$0.60 ^{im}	10-14 ^k
MED: <i>Seawater (cogeneration)</i>	150-220 ⁱ	1.5-2.5 ⁱ	8-20.1 ⁱ	11.2-19.6 ^{bim}	\$0.50 ^m	12-15 ^k
RO ^a : <i>Seawater (cogeneration)</i>	-	5-9 ⁱ	5-9 ⁱ	8.6 ^{bi}	\$0.46 ^m	34 ^k
<i>Brackish groundwater</i>	-	0.98 ^c	0.98 ^c	0.94	\$0.26 ⁱ	
Distribution (per km):						
<i>Horizontal</i>	nd	nd	0.00024 ⁿ	nd	\$0.001 ^l	n/a
<i>Vertical</i>	nd	nd	0.223 ⁿ	nd	\$0.92 ^l	n/a

MSF: Multistage flash distillation

MED: multi-effect distillation

RO: reverse osmosis

nd: no data

n/a: not applicable

^a Electrical energy inputs vary based on whether or not an energy recovery system is used.

^b CO₂ emissions are estimated based on the assumption that 1 kWh of electricity production results in 0.96 kg of CO₂ emissions.

^c[35] ^d[46] ^e[17] ^f[47] ^g[24] ^h[39] ⁱ[48] ^j[49] ^k[50] ^l[31] ^m[20]

ⁿEstimated based on the vertical transportation costs cited [51]

Surface water and groundwater

Energy and production costs for surface water and groundwater are mostly due to drilling and pumping [17].

Wastewater treatment

Primary wastewater treatments merely remove a portion of the suspended solids and organic matter from wastewater, while secondary treatments remove a higher proportion of biodegradable organic matter (both in solution and suspension) as well as suspended solids and typically involve some form of disinfection [42]. Tertiary treatments remove residual suspended solids after secondary treatment, usually through granular medium filtration, surface filtration, and/or membranes, and typically include disinfection and nutrient removal [42]. Finally, advanced treatments remove trace constituents, as required, for specific water reuse applications [42].

Desalination processes

Multistage flash distillation (MSF) and multi-effect distillation (MED) are desalination processes that require two types of energy: low temperature heat (usually supplied through imported steam from a power generation plant [52]) and electricity. The efficiency of an MSF desalination plant is quantified by the gain output ratio (GOR) and the performance ratio (PR): the ratio between the amounts of water produced per unit mass of dry saturated steam supplied to the system, and the amount of product water in kilograms per million joules of low-temperature heat supplied to the system, respectively.

For an MED plant, the specific thermal energy consumption and process performance are measured by the GOR as the amount of product distillate per unit mass of dry saturated heating steam; maximizing GOR for a given heat source temperature means minimizing thermal energy consumption [52].

Reverse osmosis desalination filters saline solutions at high pressure through a porous membrane; pressurization of the saline solution is usually accomplished using pumping devices, which are driven either directly by diesel engines, steam, or gas turbines, or indirectly by electricity using electric motors [52]. Specific energy consumption in RO desalination systems is highly dependent on feed water characteristics, plant design and operating conditions, although the inclusion of energy recovery systems (which convert the hydraulic energy of the rejected solution to useful energy) helps minimize overall energy consumption [52].

REFERENCES

- [1] U.S.-Saudi Arabian Business Council. (2010) Public-Private Agreements Upgrade Saudi Water Infrastructure. *U.S.-Saudi Business Brief*. 9-10.
- [2] T. Y. Al-Ghasham, *et al.*, “Industrial Wastewater Treatment for Reuse, Assessment Study In A Saudi Aramco Facility,” *Saudi Aramco Journal of Technology*, vol. Fall 2005, pp. 52-60, 2005.
- [3] JETRO, “The Study on Wastewater Treatment and Water Reuse in Saudi Aramco, Saudi Arabia,” Japan External Trade Organization (JETRO) Water Re-use Promotion Center, Sumitomo Corporation, Riyadh, January 2009.
- [4] Saudi Aramco. (2009, *Saudi Aramco by the Numbers*. Available: <http://www.saudiaramco.com/irj/go/km/docs/SaudiAramcoPublic/FactsAndFigures/F%26F2009/SABytheNumbers.pdf>
- [5] FAO. AQUASTAT [Online]. Available: <http://www.fao.org/nr/water/aquastat/main/index.stm>
- [6] Arab Water Council, “Arab Countries Regional Report,” Arab Water Council, 2009.
- [7] P. Beaumont, “Water policies for the Middle East in the 21st century: the new economic realities,” *International Journal of Water Resources Development*, vol. 18, pp. 315-334, 2002.
- [8] Central Intelligence Agency. The World Factbook [Online]. Available: <https://www.cia.gov/library/publications/the-world-factbook/index.html>
- [9] The World Bank. (2008, November 19, 2010). *Urban Challenges in the MENA Region*. Available: <http://go.worldbank.org/AGTL4WQE40>
- [10] The Economist. Economist Intelligence Unit [Online]. Available: www.eiu.com
- [11] B. Jimenez and T. Asano, Eds., *Water Reuse: An International Survey of current practice, issues and needs* (Scientific and Technical Reports 20). London: IWA Publishing, 2008, p.^pp. Pages.
- [12] M. Qadir, *et al.*, “Wastewater production, treatment, and irrigation in Middle East and North Africa,” *Irrigation and Drainage Systems*, vol. 24, pp. 37-51, 2010.
- [13] FAO, “Irrigation in the Middle East region in figures: AQUASTAT Survey - 2008,” Food and Agriculture Organization of the United Nations, Rome, 2008.
- [14] R. Llamas and E. Custudio, Eds., *Intensive use of groundwater: challenges and opportunities*. Lisse, The Netherlands: A.A. Balkema Publishers, 2003, p.^pp. Pages.
- [15] CIA. The World Factbook [Online]. Available: <https://www.cia.gov/library/publications/the-world-factbook/index.html>
- [16] SAMC, “Forty Sixth Annual Report: The Latest Economic Developments 1431H (2010G),” Saudi Arabian Monetary Agency: Research and Statistics Department, RiyadhJuly 2010 2010.
- [17] ESCWA, “The Role of Desalinated Water in Augmentation of the Water Supply in Selected ESCWA Member Countries,” United Nations, New York, 2001.

- [18] U.S.-SABC. (2010) Public-Private Agreements Upgrade Saudi Water Infrastructure. *U.S.-Saudi Business Brief*. 9-10.
- [19] GWI, "Water Market Middle East 2010," Global Water Intelligence 2010.
- [20] AFED, "Arab Environment: Water. Sustainable Management of a Scarce Resource," Arab Forum for Environment and Development, Beirut, 2010.
- [21] U.S. EIA, "Saudi Arabia Energy Data, Statistics and Analysis - Oil, Gas, Electricity, Coal," U.S. Energy Information Administration, Washington 2011.
- [22] U.S. EIA. International Energy Statistics [Online]. Available: <http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=44&pid=44&aid=2>
- [23] A. Al-Hussayen, "Inaugural speech to Saudi Water & Power Forum," ed. Jeddah: Saudi Water & Power Forum, 2009.
- [24] M. F. Hamoda, "Water strategies and potential of water reuse in the south Mediterranean countries," *Desalination*, vol. 165, pp. 31-41, 2004.
- [25] Saudi Aramco. (2010, October 25, 2010). *Projects*. Available: <http://www.saudiaramco.com/irj/portal/anonymous?favlnk=%2FSaudiAramcoPublic%2Fdocsnav%2FContact+Us&ln=en>
- [26] The Economist. [Online]. Available: www.eiu.com
- [27] Saudi Gazette, "Mideast steps up drive for water reuse technologies: Kingdom third largest consumer of water," in *Saudi Gazette*, ed. Jeddah: Saudi Gazette, 2010.
- [28] P. O'Callaghan, "Decentralized Wastewater Management and Re-use," in *Saudi Water & Power Forum*, Jeddah, 2009.
- [29] D. Zejli and A. Elmidaoui, "Moroccan Potentialities of Renewable Energy Sources for Water Desalination," in *Solar Desalination for the 21st century: a review of modern technologies and researches on desalination coupled to renewable energies*, Hammamet, Tunisia, 2006, pp. 127-138.
- [30] A. D. Khawaji, *et al.*, "Advances in seawater desalination technologies," *Desalination*, vol. 221, pp. 47-69, 2008.
- [31] Y. Zhou and R. Tol, "Evaluating the costs of desalination and water transport," *Water Resources Research*, vol. 41, p. W03003, 2005.
- [32] E. Kally, *Water and Peace - Water Resources and the Arab-Israeli Peace Process*. Westport: Praeger, 1993.
- [33] Desal Data. DesalData.com [Online]. Available: <http://www.desaldata.com/>
- [34] *The Middle East and North Africa 2004*, 50 ed. London: Europa Publications, 2003.
- [35] G. Pearce, "UF/MF pre-treatment to RO in seawater and wastewater reuse applications: a comparison of energy costs," *Desalination*, vol. 222, pp. 66-73, 2008.
- [36] U.S.-SABC, "The Water Sector in the Kingdom of Saudi Arabia," U.S.-Saudi Arabian Business Council, , Vienna, 2009.
- [37] N. R. C. Committee on Advancing Desalination Technology, *Desalination: A National Perspective*. Washington, D.C.: National Academies Press, 2008.

- [38] R. Choukr-Allah, “Wastewater Treatment and Reuse,” in *Water: Sustainable Management of a Scarce Resource*, M. El-Ashry, *et al.*, Eds., ed: Arab Forum for Environment and Development, 2010.
- [39] O. S. Abu-Rizaiza, “Modification of the standards of wastewater reuse in Saudi Arabia,” *Water Research*, vol. 33, pp. 2601-2608, 1999.
- [40] G. Hussain, *et al.*, “Guidelines for Irrigation Water Quality and Water Management in the Kingdom of Saudi Arabia: An Overview,” *Journal of Applied Sciences*, vol. 10, pp. 79-96, 2010.
- [41] A. Al-Damkhi, *et al.*, “On the need to reconsider water management in Kuwait,” *Clean Technologies and Environmental Policy*, vol. 11, pp. 379-384, 2009.
- [42] T. Asano, *et al.*, *Water Reuse: Issues, Technologies, and Applications*. New York: McGraw-Hill, 2007.
- [43] U.S.-Saudi Arabian Business Council, “The Water Sector in the Kingdom of Saudi Arabia,” U.S.-Saudi Arabian Business Council, , Vienna, 2009.
- [44] Saudi Gazette, “Mideast steps up drive for water reuse technologies: Kingdom third largest consumer of water,” in *Saudi Gazette*, ed. Jeddah: Saudi Gazette, 2010.
- [45] L. Al-Musallam, “Water and Wastewater Privatization in Saudi Arabia,” presented at the SAWEA 2006 Workshop: Privatization and Outsourcing of Water and Wastewater, 2006.
- [46] W. A. Abderrahman, “Energy and water in arid developing countries: Saudi Arabia, a case study,” *International Journal of Water Resources Development*, vol. 17, pp. 247-255, 2001.
- [47] SBW Consulting Inc., “Energy Benchmarking Secondary Wastewater Treatment and Ultraviolet Disinfection Processes at Various Municipal Wastewater Treatment Facilities,” Pacific Gas and Electric Company, 2002.
- [48] V. G. Gude, *et al.*, “Renewable and sustainable approaches for desalination,” *Renewable and Sustainable Energy Reviews*, vol. 14, pp. 2641-2654, 2010.
- [49] M. A. Dawoud, “The role of desalination in augmentation of water supply in GCC countries,” *Desalination*, vol. 186, pp. 187-198, 2005.
- [50] ESCWA, “Energy options for water desalination in selected ESCWA member countries,” United Nations, New York, 2001.
- [51] M. N. Christensen, *et al.*, “Energy,” in *Competition for California Water: Alternative Resolutions*, E. A. Engelbert and A. F. Scheuring, Eds., ed Berkeley: University of California Press, 1982.
- [52] Economic and Social Commission for Western Asia, “Energy options for water desalination in selected ESCWA member countries,” United Nations, New York, 2001.

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The Dubai School of Government (DSG) is a research and teaching institution focusing on public policy in the Arab world. Established in 2005 under the patronage of HH Sheikh Mohammed Bin Rashid Al Maktoum, Vice President and Prime Minister of the United Arab Emirates and Ruler of Dubai, in cooperation with the Harvard Kennedy School, DSG aims to promote good governance through enhancing the region's capacity for effective public policy.

Toward this goal, the Dubai School of Government also collaborates with regional and global institutions in its research and training programs. In addition, the School organizes policy forums and international conferences to facilitate the exchange of ideas and promote critical debate on public policy in the Arab world.

The School is committed to the creation of knowledge, the dissemination of best practice and the training of policy makers in the Arab world. To achieve this mission, the School is developing strong capabilities to support research and teaching programs including

- applied research in public policy and management;
- master's degrees in public policy and public administration;
- executive education for senior officials and executives; and,
- knowledge forums for scholars and policy makers.