WATER GLOBAL PRACTICE

Advancing Knowledge of the Water-Energy Nexus in the GCC Countries

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Abbreviations

GCC	Gulf Cooperation Council
GDP	gross domestic product
GHG	greenhouse gas
HELCOM	Helsinki Commission
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt-hour
m^3	cubic meter
MAP	Mediterranean Action Plan
MED	multi-effect distillation
MEWA	Ministry of Water, Environment and Agriculture
MSF	multi-stage flash
NSS	National Subsidy System
ppt	parts per thousand
RO	reverse osmosis
SEEP	Saudi Energy Efficiency Program
TD	thermal desalination
WEF	water-energy-food

Foreword

Water has always been a source of risks and opportunities in the Middle East and North Africa, and perhaps particularly so for the Gulf Cooperation Council (GCC) countries. For millennia, investments and innovations in water management have contributed to social and economic development and to extraordinary accomplishments across a range of sectors, including trade and agriculture. In a different way, energy resources have provided tremendous opportunities as well as risks in the Gulf region.

In this report we are addressing the water-energy nexus in the Gulf region. We hope that the findings presented here stimulate discussion and debate among technical experts and researchers, as well as representatives from governments, civil society, and the private sector.

Climate change and a growing population make it increasingly urgent to find ways to better manage the water-energy nexus. The desalination, pumping, distribution, and treatment of water require significant energy resources. The extraction of energy resources and production of energy, meanwhile, consume substantial amounts of water. In addition, negative environmental effects often follow poor management of the water and energy sectors. Up till now, reform policies have not adequately addressed the challenges. Water and energy subsidies deepen the dependence of both the water and energy sectors on oil revenues. A strong reliance on cheap energy for the provision of water security will, in the long run, be unsustainable. Reform efforts should aim for a proactive and coordinated approach that can lead to a green, inclusive, and more resilient low-carbon economy.

The report highlights the challenges the Gulf region is facing in relation to the water-energy nexus, and at the same time highlights the opportunities going forward, drawing, in part, on key innovations in the region. Moving forward on this critical agenda will require action on several levels. The region can transition to greater reliance on renewable sources of energy for desalinizing seawater, scale the use of renewables to decrease emissions, introduce measures to replenish marine habitats, invest in research to drive innovation, move toward policies and tariffs that encourage more efficient use, and leverage wastewater as a valuable asset for improving water security.

The stakes are high. The countries of the Gulf region would do well to increase their efforts to reform both the water and energy sectors and in particular the management of the water-energy nexus for improved water and energy security. These potential reforms include addressing subsidy and pricing structure that discourage conservation, promoting the reuse of treated wastewater, and increasing investments in renewable energy. These efforts, if undertaken, would also have positive effects on the climate, jobs, and fiscal sustainability. The World Bank stands ready to work in partnership with governments, civil society, and the private sector as well as regional and international organizations to improve the management of the critical water and energy nexus.

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Acknowledgments

This report is the outcome of a number of studies as well as consultations carried out and commissioned by the World Bank. The work was led by Anders Jägerskog, with Shawki Barghouti. The following background papers were commissioned in preparation for this report:

- “Water and Energy Nexus in GGC Region: The Role of Innovation in Improving the Nexus” (2021) by Mohamed Dawoud (Environment Agency, Abu Dhabi)
- “A Review Paper on Water-Energy Nexus in the GCC Countries: An Economic and Policy Perspective” (2021) by Slim Zekri (Sultan Qabus University, Oman)
- “The Water-Energy Nexus in the GCC Countries” (2021) by Waleed K. Zubari (Arabian Gulf University, Bahrain)

Support and guidance were provided by Issam A. Abousleiman (Regional Director, GCC countries), Ayat Soliman (Regional Director, Middle East and North Africa), Carmen Nonay and Michael Haney (Middle East and North Africa Water Practice Managers), and Erik Magnus Fernstrom and Husam Mohamed Beides (Middle East and North Africa Energy Practice Managers). World Bank colleagues who contributed to the report include Adeel Abbas Syed, Waleed Saleh I. Alsuraih, Suhail J. S. Jme’An, Alexandra Pugachevsky, Yisgedullish Amde, Nagaraja Rao Harshadeep, and Luis Alvarez Garcia-Moran.

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Executive Summary

The Gulf region faces a volatile future in which water and energy interact in dynamic ways. To prepare for this future, the Gulf Cooperation Council (GCC)[1] has options to create more equitable and sustainable outcomes. Deepening resilience to anticipated future conditions can extend benefits in and beyond the region, demonstrating a model for mitigating and adapting to rising climate stress.

Linked resource provision can align risks, rewards, and responsibilities. A more comprehensive analysis and "nexus" approach recognizes the interconnected nature of the water and energy sectors.[2] The lifting, heating, treating, and distribution of water requires large amounts of energy. Energy extraction and production, in turn, needs substantial quantities of water.

Climate change exacerbates the challenges of this water-energy nexus. As temperatures rise, governments face pressure to reform policies or risk long-term instability. GCC countries need to take immediate measures to incorporate climate change challenges in policy planning and investment programs in most sectors of the national economy. To date, adaptive measures have too often been reactive, short term, expensive, and fragmented. A proactive and coordinated approach can speed the transition to a more resilient low-carbon economy.

To enhance nexus management, this working paper highlights challenges and opportunities. The synthesis[3] draws on background papers commissioned for this work and integrates World Bank analyses, and studies of the nexus challenge in the Gulf region. The paper provides a suite of policy options for GCC policy makers to consider as populations grow, water grows scarce, extreme weather worsens, carbon emissions rise, and oil and gas export revenues diminish.

1. Challenges

Water and energy subsidies deepen each sector's dependence on oil revenues. In a hot, dry region, securing water and energy for nearly 60 million people grows expensive. Yet the legacy of significant subsidies hides both actual and opportunity costs of the provision of these subsidies. Low tariffs encourage overconsumption and have led to the world's highest per capita water consumption in the GCC countries (Mishref and Al Balushi 2018).

All six Gulf countries are energy rich and water poor. Each country has invested assets generated from abundant oil and gas resources to overcome the scarcity of arable land and water resources. In recent decades, the efforts of governments have dramatically improved the quality of life. Now, rising demands for finite water, in this environment of inefficient subsidization, may limit or erode this progress.

Cheap, abundant fossil fuels provide an unstable foundation for water security. Almost all freshwater in the GCC comes from plants that desalt seawater or wells that pump deep aquifers. This supply-driven approach is carbon and energy intensive. Rising demand for each resource compounds pressure on the other and encourages excessive and inefficient use of both.

Increased reliance on desalination will drive up energy demand. As the GCC countries deplete their groundwater reserves, increased dependence on desalination is inevitable. From 2014 to 2018, the GCC's annual production of desalinated water grew by 18.7 percent and it is projected to continue to grow, thereby also significantly increasing the need for energy.

Domestic electricity and water consumption reduce fossil fuels available to export. Barring further efficiency improvements (World Bank 2019), demand for freshwater will double the energy needed to desalt seawater. Since 1980, Saudi Arabia's water consumption has increased by a factor of fifteen. It already burns a third of its oil production just to meet domestic water and energy needs (Rambo et al. 2017).

Freshwater production risks GCC hydrocarbon exports and their important contribution to budget revenues (Zubari 2021). For example, in three decades Saudi Arabia may require 18 billion cubic meters per year, a projected sixfold increase from 2018, which will significantly increase the need for energy (Al-Badi and Al-Mubarak 2019). By 2050 certain GCC members may lack enough natural gas to desalinate water needed for municipal usage alone (Al-Badi and Al-Mubarak 2019).

Desalination relies on, and aggravates, increasingly saline sources. The Gulf and Red Sea are naturally saltier than the world's oceans on average, due to elevated evaporation rates and reduced freshwater inflows. New desalination plant effluent triggers a vicious cycle: the higher the salt concentration in waste emptied near source intakes, the more energy required to remove the salt when new seawater is taken in for desalination.[4]

Poor or nonexistent brine abatement is degrading coastal marine life. Hundreds of desalination plants deposit hypersaline waste in shallow coastal zones. Left unchecked, by 2050 this effluent will erode species' integrity and diversity, hurting fisheries, tourism, and coastal communities.

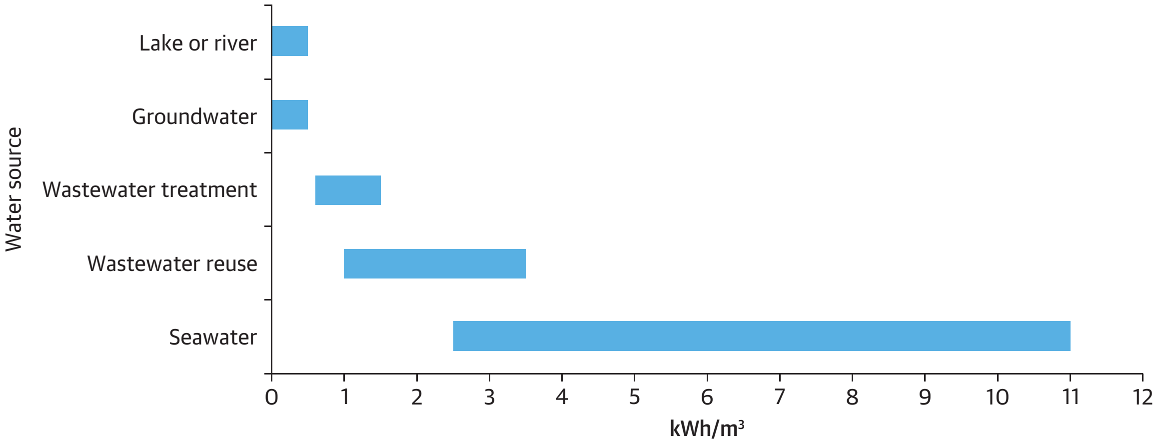
2. Opportunities Going Forward

Water and energy challenges also offer opportunities. The GCC countries can decouple freshwater production from fossil fuel consumption; scale renewables to mitigate emissions; replenish marine habitats; lower risks from the water-energy nexus; diversify sources; and speed the transition toward greener, more resilient, and inclusive development.

Measure progress in kilowatt-hours per unit of water. Graywater reuse and wastewater treatment both require a fraction of the energy per cubic meter of water of desalination (see figure ES.1). Even within desalination, innovative options such as to expand the adoption of reverse osmosis can lower energy intensity, bring down costs, and reduce the carbon impact of water production.

Reserve aquifers for national security, and leverage trade for food security. It takes 1,000 cubic meters of groundwater to grow one ton of grain. By importing this grain, officials can reallocate water to more productive uses. Policies that reduce access to or remove subsidies also encourage grain farmers to move to growing high-value crops.

FIGURE ES.1. **Energy Required to Provide One Cubic Meter of Water Safe for Human Consumption from Various Water Sources**



Source: Zubari et al 2017.

Move toward policies and water tariffs that encourage more efficient domestic use. GCC countries may wish to consider adopting structural and economic instruments that improve efficient water consumption. Incentivizing more efficient demand for desalinated water will decrease energy use, maintain future value of oil reserves, and lower brine effluent discharged into the sea.

Design tariff schemes to balance equity with incentives. "Lifeline" quotas or free basic supplies of water or electricity seek to ensure universal public health and well-being. Yet the benefit of these highly subsidized resources is disproportionately enjoyed by higher-income households and by businesses that do not require subsidization (Andres et al. 2019). GCC countries can ensure more equitable provision and efficient consumption if, as in Oman, tiered tariff bands are matched to targeted subsidies that help low-income households.

Deploy a diverse menu of modern tools to manage demand. Household investments in efficiency can, if scaled, earn national-level returns. Smart meters, sensor faucets, low-flow appliances, and graywater recycling engage end users to reduce waste. Network pressure management, coupled with detection and fixing of leaks, can help control network losses.

Phase in the ecological costs of water and energy infrastructure. The desalination industry currently discharges waste effluent, risking marine resources at no cost to itself. Yet the GCC could make brine abatement a shared policy and a prerequisite for tendering for new plants. By internalizing negative impacts, the GCC could foster technological innovations and enhance production.

Link governance institutions with innovative technologies. Led by countries with limited natural gas supplies, integrated GCC policies can encourage the transition to low-energy desalination, wastewater treatment and reuse, efficient water usage, and alternative energy resources.

Augment the region's energy supply mix with renewables. Renewables not only diversify each country's sources of electricity, they are also increasingly cost competitive, now costing on average US$0.0179 per kilowatt-hour, with a continuing downward trend.

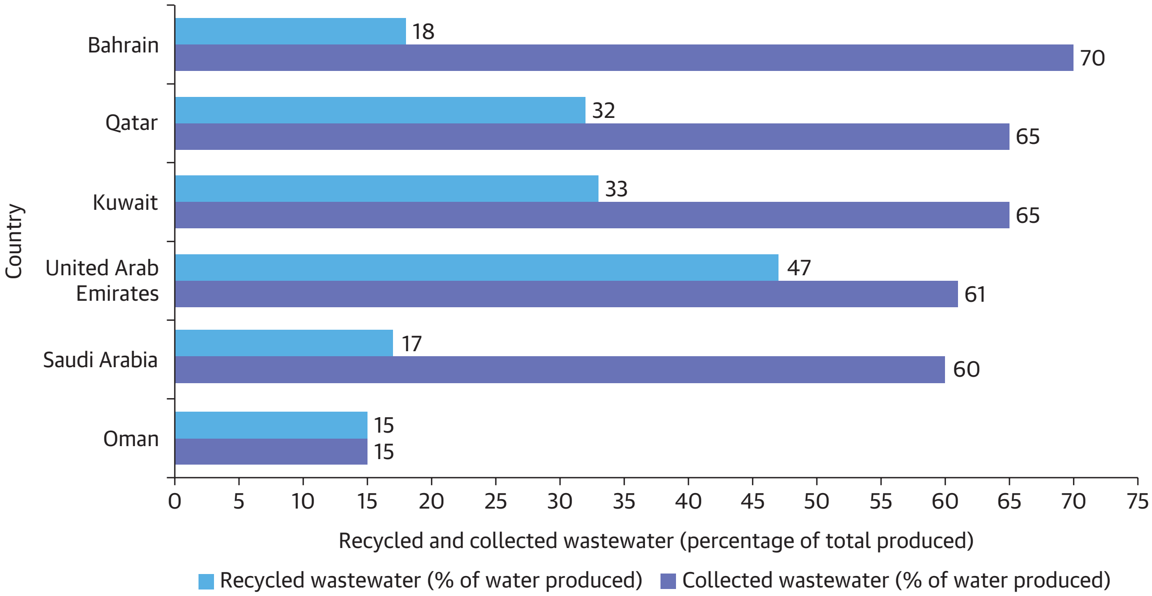
Scale up efforts to reduce dependence on traditional desalination. GCC nations are pioneering a range of clean, lower-cost options to achieve resource security. As an example, Saudi Arabia has invested in what will be the world's largest solar desalination plant (IRENA 2016).

Leverage wastewater as a valuable asset. Traditionally, wastewater has been seen as a liability, a problem with costs. Looking ahead, the region may choose to increase treatment, recycling, and reuse of what may be the region's most overlooked and indispensable resource. Countries can recapture and reuse over 90 percent of wastewater for irrigation, industry, or domestic use (e.g., as practiced in Israel but also in Tunisia and Morocco) (figure ES.2).

Govern the water-energy nexus at the institutional level. Coordination of "soft" infrastructure by responsible agencies can improve investments in more efficient "hard" infrastructure. By uniting these resources under one ministry mandate, as in Saudi Arabia, officials can also leverage modeling tools for more interdisciplinary planning, best practices, and effective implementation.

Exchange regional information on water and energy. GCC members share transboundary aquifers and saltwater bodies. All six will benefit from sharing resource knowledge, data, experience, decisions,

FIGURE ES.2. Collected and Recycled Wastewater as a Percentage of Wastewater Produced



Source: World Bank 2017.

Note: Failure to collect wastewater results in contamination of aquatic environments and freshwater supplies. Failure to recycle wastewater is a missed opportunity to augment water supplies.

and research. GCC Charter priorities include advancing scientific and technological progress in water, and regional studies that will help countries improve management of the water-energy nexus.

Consider pooling funds for a facility that will protect shared natural resources. In line with the GCC Charter, a regional facility could align management of the water-energy nexus while reducing impacts on the Gulf. Regional cooperation could engage resource users, and bridge gaps in knowledge and capacity, while setting a management framework (see below).

Use international precedents to inform a potential regional framework. To address multiple diverse threats to their shared resources, GCC members could collectively agree on standards and measures to curb the increasing salinity of the Gulf. This process to enhance regional collaboration can draw on parallel initiatives focused on other bodies of saltwater—such as the Mediterranean Action Plan or HELCOM in the Baltic—and situate it within the existing GCC structure.

Extend the benefits of cooperation beyond regional boundaries. From the United Arab Emirates' strategic aquifer recharge to Oman's matching reformed tariffs with targeted subsidies and the high level of desalination expertise in the region, GCC countries have unique expertise to advance, scale, and share innovations. As such, the GCC is uniquely positioned to address the most intense aspects of the water-energy nexus. New insights and progress in the region's experience will be of value to enhancing water and energy use worldwide.

Notes

1. Saudi Arabia, Kuwait, the United Arab Emirates, Qatar, Bahrain, and Oman.
2. Recognizing the links between the water-energy nexus and food/agriculture in the region, it is proposed that further follow-up analytical work be undertaken to shed adequate light on this topic. This report does not cover food and agriculture in an exhaustive manner, which future follow-up work could do.
3. The following background papers were commissioned in preparation of this report: Dawoud (2021a), Zekri (2021), and Zubari (2021).
4. Desalination technology and their environmental impacts—reverse osmosis (RO) has a larger recovery rate, which means its effluent is much saltier. At a lower recovery rate, the effluent of multistage effect (MSE) and multistage flash (MSF) technologies is less salty than that of RO plants and their environmental impacts are therefore lower.

Introduction

Energy and water underpin the economic structure and activities of the Gulf Cooperation Council (GCC) countries. The Gulf region is earth's largest source of hydrocarbons, endowed with 30 percent of the world's proven crude oil reserves and 22 percent of its gas reserves (IRENA 2016). Despite this energy wealth, it remains water poor.

The region's inhabitants have for centuries adapted to hot and dry conditions. Yet in recent decades, rapid economic and demographic growth combined with climate change have resulted in increased water needs amid shrinking sources. This demand-supply gap is projected to widen as temperatures rise over the twenty-first century, nudging cities, industries, and farms to innovate new ways to do more with less water.

This report focuses on energy and water, but climate change most acutely impacts domestic food production. Outdoor rain-fed or groundwater-irrigated farms will suffer from rising heat and longer droughts (Al-Saidi and Saliba 2019). Already, annual rainfall rarely exceeds 100 mm, with little to no surface runoff; arable land ranges from a high 4.35 percent in Bahrain to a low 1 percent in Kuwait, Qatar, and Oman (Zurayk, Chaaban, and Sabra 2011).

Climate change may further exacerbate water scarcity. An arid region can expect extreme weather, higher aridity, and a Gulf that increasingly warms, evaporates, expands, and rises above historic sea levels.

The region's unique combination of scarce water and abundant energy has accelerated the adoption of modern desalination technologies. To meet rising domestic needs, GCC nations invested in large-scale innovations that dramatically reduced the costs of seawater conversion. Benefits of progress extend well beyond the region. Today 300 million people in 150 countries rely on 18,426 desalination plants that provide 87 million cubic meters of clean water per day.

Nearly 44 percent of the world's desalination capacity comes from the GCC market (World Bank 2019), giving the region a competitive edge in both experience and expertise. All six countries, working together, can play the leading role in advancing progress, innovation, capacity, and direction of the global desalination industry.

Paradoxically, water stress is due in part to economic progress. Ambitious national development plans have improved living standards for all GCC populations. Yet a consequence of growth has been rising freshwater demand.[1] To meet urban needs with secure supplies, GCC countries have reinvested more of their energy endowment into extracting groundwater, recycling wastewater, and expanding the number, size, and type of seawater desalination plants.

Neither abundant energy nor innovative technology address one threat to desalination arising at its source: the Gulf and the Red Sea are two of the warmest and saltiest water bodies on earth (see table I.1). It takes higher pressure and better membrane performance to remove salt from hypersaline

TABLE I.1. Salinity (TDS) and Temperature of Various Seawater Sources (2019)

Seawater Sources	TDS (ppt)	Temperature (°C)
Red Sea	42–46 (avg. 44)	24–33 (avg. 28)
The Gulf	40–44 (avg. 42)	22–35 (avg. 26)
Mediterranean	38–41 (avg. 40	16–28 (avg. 24)
Caribbean Sea	34–38 (avg. 36)	16–35 (avg. 26)
Indian Ocean	33-37 (avg. 35)	25–30 (avg. 28)
Pacific and Atlantic oceans	33–36 (avg. 34)	9–26 (avg. 18)

Source: World Bank 2019.
Note: ppt = parts per thousand; TDS = total dissolved solids.

coastal waters. The demand for more energy drives up operational costs of reverse osmosis (RO) systems, making desalination increasingly expensive (World Bank 2019).

A vicious cycle of rising demands met by heavy reliance on energy-intensive, unconventional supplies can prove costly in more ways than one (Zubari et al. 2017). The manufacture and extraction of clean water is not just financially expensive, disruptive, and environmentally harmful; it could also roll back much of the economic and social progress that the region has recently achieved.

To avoid erosion of hard-earned gains, GCC governments could coordinate their approach through a common framework—akin to earlier European precedents organized around the Baltic and Mediterranean seas—that elevates the water-energy linkage and the efficient use of resources as a strategic foundation for regional security.

This report summarizes research on the most salient issues affecting the region's sustainable management of complex resource interactions. It narrows the scope from water-energy-food linkages to focus intensely on the risks from, and roles of, the water-energy nexus. The report focuses on the GCC's economic and financial issues, followed by a review of the region's dynamic population growth, and how these dynamics affect the performance of the energy and water sectors as well their associated impacts in the Gulf ecosystem. It moves on to review current activities in the water and energy sectors, then addresses the impact of resource values of seawater desalination, groundwater extraction, and wastewater treatment that pose a threat to the environment at the national levels. It highlights how technological advances and innovations can bring efficiency to the water and energy sectors in ways that contribute to more sustainable growth and economic development. Finally it provides potential policy pathways—policy planning, institutional coordination, legislative frameworks, and associated regulations—that will sustain the efficient and integrated management of water and energy sectors.

Where appropriate, the study illustrates where policies may encourage waste and distort demand—as well as cases that improve fair and efficient outcomes. To strike a balance, it calls for development agencies and academic institutions to support collaborative research that will generate reliable data and useful information. Knowledge and decisions can be anchored under a regional institutional framework that pools resources to improve policies, enhance plans, spur public and private investment in innovations, ensure more efficient water and energy usage, and make an economic case for clean and renewable energy.

Note

1. Ten regional water experts who prepared the GCC Unified Water Strategy 2016-35 found that fast-paced socioeconomic development and its associated rapid population growth dramatically increased water demand.

Chapter 1

How the GCC's Water and Energy Sectors Align with the Region's Expanding Economies and Dynamic Population Growth

1.1 The Context: GCC Members Have Led the World in Converting Energy Resource Wealth into Impressive Development Plans

The GCC countries have invested substantial assets generated from their energy endowment to overcome the physical scarcity of arable land and freshwater resources. National development plans will seek to improve the health and prosperity of urban citizens, serviced by an unconventional water infrastructure, while diversifying away from an overdependence on oil (Mishref and Al Balushi 2018).

Climate change intensifies the scale and speed of countries' transition to resilience. As temperatures rise and finite water resources diminish, the GCC is prompted to pilot, develop, and scale more innovative tools, approaches, systems, and policies that adapt to and mitigate the effects of a changing climate.

To secure resilience, GCC members diversify their economic activities and government revenues. National policies expand the service sector and tourism, information technologies, and the manufacturing and processing of goods and services for both domestic consumption and export (Kabbani and Minnoune 2021). Five- or ten-year plans emphasize economic liberalization, establish a knowledge-based economy, and reduce dependency on oil and gas (Gross and Gaffar 2019). Fiscal reforms cut subsidies, raise water and electricity tariffs, and increase excise taxes on certain products. All six member countries have committed to a 5 percent value-added tax, and Bahrain, Saudi Arabia, and the United Arab Emirates have implemented it on schedule (Gross and Gaffar 2019).

Beneath these reforms, however, lies a quiet challenge that is often overlooked. GCC members can no longer see or manage the consumption of scarce water or abundant energy as self-contained issues. These are not simple, isolated "sectors." Rather, the two vital resources are inextricably linked; neither can be developed without the other. Both are interdependent and require the dynamic evolution of economic activities, food security, demographic changes, and environmental resilience within the Gulf ecosystem amid a changing climate.

Domestic water, energy, and food consumption increases economic risks and ecological threats. Both arise from the same source: GCC countries are on track to consume more energy to produce more desalinated water to meet the rising water demands of an increasing urban population. One consequence is the salinity of the Gulf and Red Sea, which degrades marine biodiversity, species' persistence, fisheries' productivity, and coastal communities (Siderius et al. 2020).

From coral reefs to humpback dolphins, both water bodies have been rich in the diversity, distribution, and density of their living natural resources. But scholars warn of a dire future (Zekri 2021). Kuwait, the United Arab Emirates, Qatar, and Bahrain are most dependent on and at risk from rising salinity.

While Saudi Arabia can and does desalinate the Red Sea, little research suggests that doing so poses any less severe a risk (Elsaid et al. 2020).

Moreover, the relatively high and escalating level of domestic energy consumption by nearly 60 million GCC inhabitants threatens to reduce exports, inhibit economic diversification, and elevate the emissions of greenhouse gases (GHGs) that, in a vicious cycle, worsen climate change.

By expanding knowledge about the region's water-energy nexus, GCC members can better address the excessive and harmful costs—financial, economic, social, and ecological—of extracting either resource without regard to its larger consequences. To that end, new alliances are forming. In December 2020, the EU-GCC Clean Energy Technology Network explored the topic in a report titled "The Water-Energy-Food (WEF) Nexus in the GCC and EU regions: Challenges and Opportunities" (EU-GCC Clean Energy Network 2020). Authorities forged new consensus around analyses and policy briefs focused on the Arab region (e.g., Zubari 2019).

The World Bank considers regional contexts in a global perspective. One recent publication draws on scenarios from North Africa and the larger Middle East to analyze the specific challenges facing the GCC countries (Borgomeo et al. 2018). Another highlights the potential risks and strong opportunities of GCC members in leveraging water for prosperity and development (World Bank 2017). Two of the most important studies on the WEF nexus emerged locally. The first brings a more integrated risk perspective to water, energy, and food supply security in the GCC countries (Al-Saidi and Saliba 2019), while the second applies a multiscale analysis to the Gulf region's WEF nexus (Siderius et al. 2020).

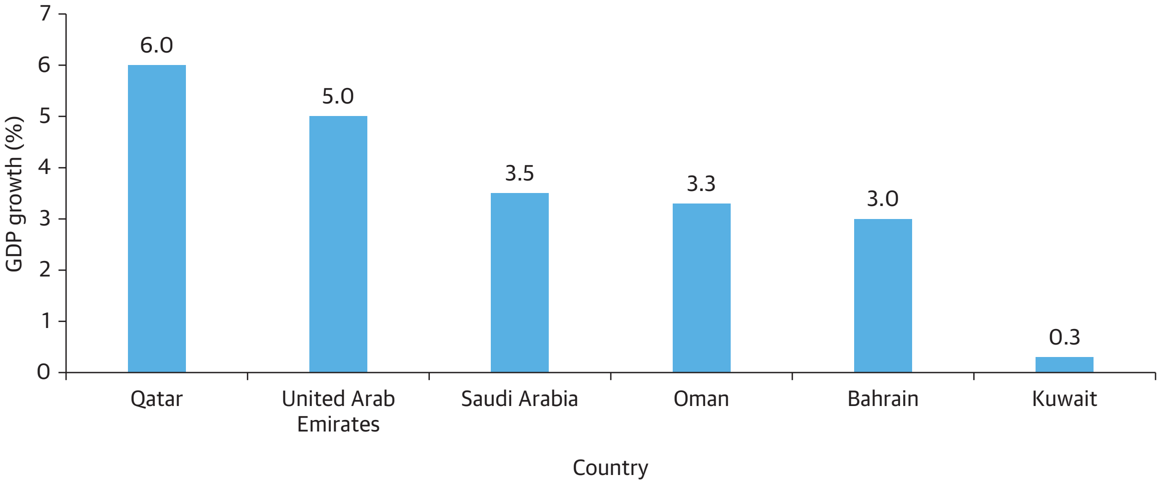
1.2 How Economic Growth Increases Demand for Water and Energy

Despite fluctuations in recent years, the GCC's average gross domestic product (GDP) per capita trend is positive, with economies expanding in all six countries (figure 1.1). Decades of growth and diversification have brought widespread prosperity and rapid concentration into densely populated megacities. What's more, each country has evolved the organizational structure of its water and energy agencies to meet the changing needs of a distinct population and a specialized economy.

As specialized agencies make expansion plans, few emphasize synergy (Zubari et al. 2017). Tighter coordination within and between institutions should be a higher priority (Lahn, Stevens, and Preston 2013), yet the most powerful entities and individuals—who most influence the use of water and energy systems—are often too siloed and fragmented to effectively communicate.

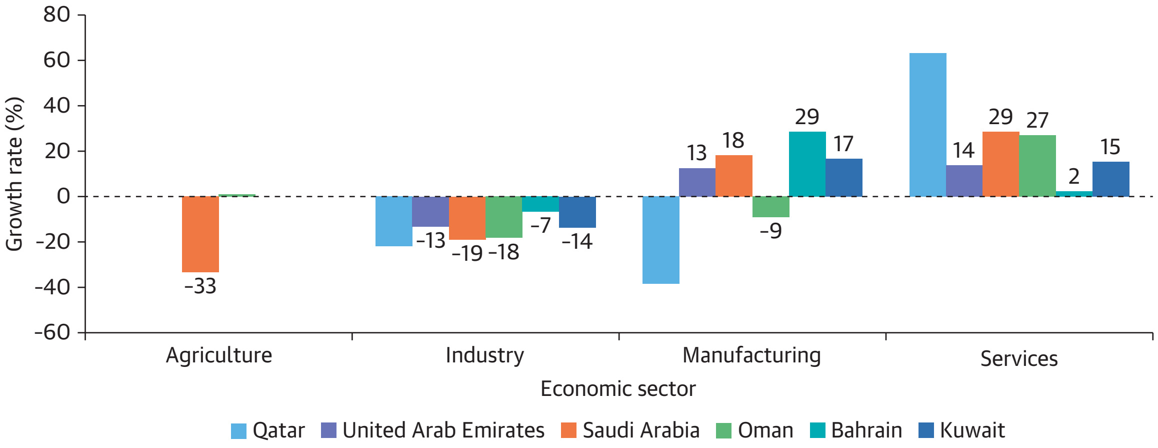
In principle, GCC members recognize the need to collaborate, and all six countries have authorities responsible for both electricity and water. In recent years, a few emirates and states have even introduced an independent regulator to coordinate energy demand policies. However, the sheer number of agencies involved indicates the difficulty and scope of the challenge. Failure to coordinate water and energy into economic development plans could put recent progress at risk of backsliding, as exemplified by the agricultural and industrial sectors (figure 1.2).

FIGURE 1.1. **Growth of GDP in the Six GCC Countries, 2016–20**



Source: Statista.

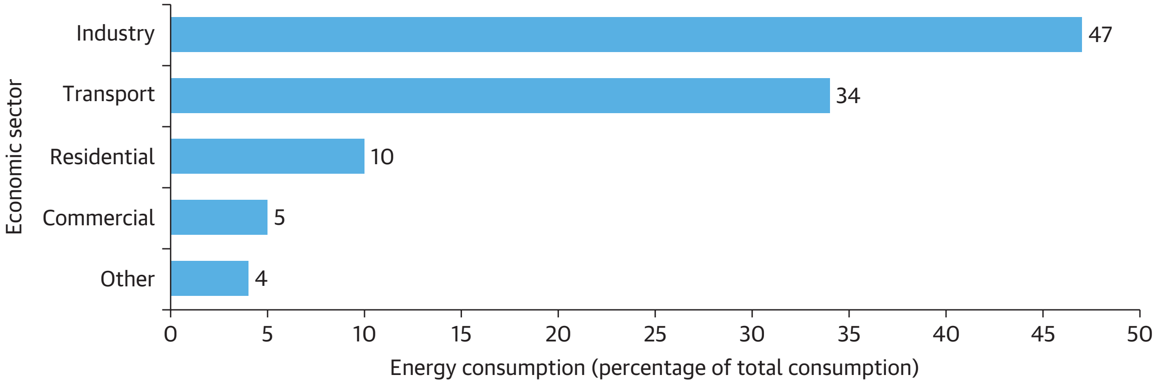
FIGURE 1.2. **GDP Growth Rate by Sector, 2010–19**



Source: World Bank's World Development Indicators.

Despite consuming most of the region's groundwater, the contribution of food production to the GDP of GCC countries (except for Oman) is negligible at best (figure 1.3). The industrial sector's performance is worse, with a negative growth rate from 2010 to 2019 in all six GCC countries. Recent research assessments suggest a nearly inverse relationship across sectors between energy consumption and economic performance (Al-Badi and Al-Mubarak 2019). Industry burns 47 percent of electricity, transport 34 percent, and the rest is distributed between residential, commercial, and other drivers of an economy increasingly dominated by the manufacturing and service sectors (IRENA 2016).

FIGURE 1.3. Share of Energy Consumption by Sector, 2016



Source: Al-Badi and Al-Mubarak (2019).

The value of resource use by families cannot be easily measured in economic criteria. But GCC countries are seeing a dramatic increase in domestic demand for both energy and water. Gulf households consume among the world's highest levels of both resources, per capita. Residential demand is so high (see figure 3.2 for per capita water consumption) (Albannay et al. 2021) that it has begun to erode the share of revenue from energy exports. In short, the collective impact from household consumption slows economic diversification, reduces foreign exchange, drives up waste, and generates excessive emissions (figure 1.3).

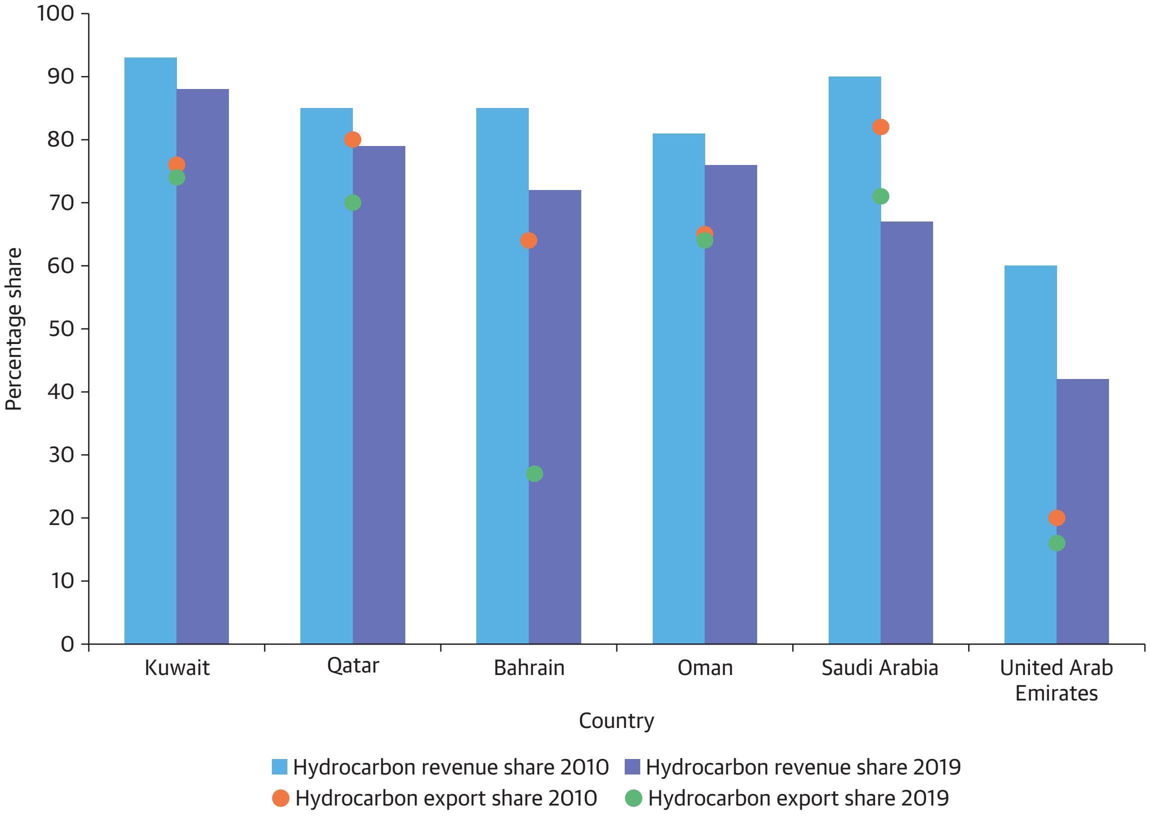
The Gulf region has long enjoyed a dominant role as an energy exporter. Yet in recent years, domestic consumption has grown so fast that each GCC country now has a smaller share of energy left to export (Al-Badi and Al-Mubarak 2019). As the world's largest oil producer, Saudi Arabia still leads the Organization of the Petroleum Exporting Countries (OPEC). Its water and energy demand has risen over the past two decades, and the country now consumes 3.3 million barrels per day, a third of its oil production (Rambo et al. 2017).

Rising populations, industrialization, and economic growth all drive water and energy consumption in the GCC countries. Less appreciated is how demand for one resource impacts the other; for example, energy for water leaves less available for other needs. Diversified growth does not solve this problem by itself. In recent decades, even service sectors such as tourism have only increased their water demand. Consequently, as shown in figure 1.4, with the exception of Oman and Kuwait, the share of hydrocarbon export and revenue in the GCC countries continued to decrease between 2010 and 2019.

1.3 Where Does Population Growth Drive Water and Energy Consumption?

In all six GCC nations, booming populations—both of citizens and of the expatriate workforce—brought about rapid urbanization. Increased demand for potable water supply and sanitation has driven up need for the associated energy resources embedded in water production.

FIGURE 1.4. **Share of Hydrocarbon Revenues and Exports in GCC Countries**



Source: Oxford Economics.

In 2021, GCC countries were home to 60 million people, or 0.74 percent of the world's total population. The GCC's average population growth rate is 1.68 percent (see table 1.1), which means that each year the region adds close to 1 million people who need water and energy to drink, bathe, eat, work, and use air conditioning. Most (51 percent) of this population are the 300,000 expatriates arriving each year (Zekri 2021), most of them residing in the United Arab Emirates (89 percent), Qatar (86 percent), and Kuwait (70 percent).

Some 59 percent of GCC residents live in Saudi Arabia (table 1.1), while 84 percent of the region's population lives and works in cities. Population density is highest in Qatar (248 p/km2), followed by Kuwait (240 p/km2), where it is 16 times higher than in Saudi Arabia or Oman (figure 1.5).

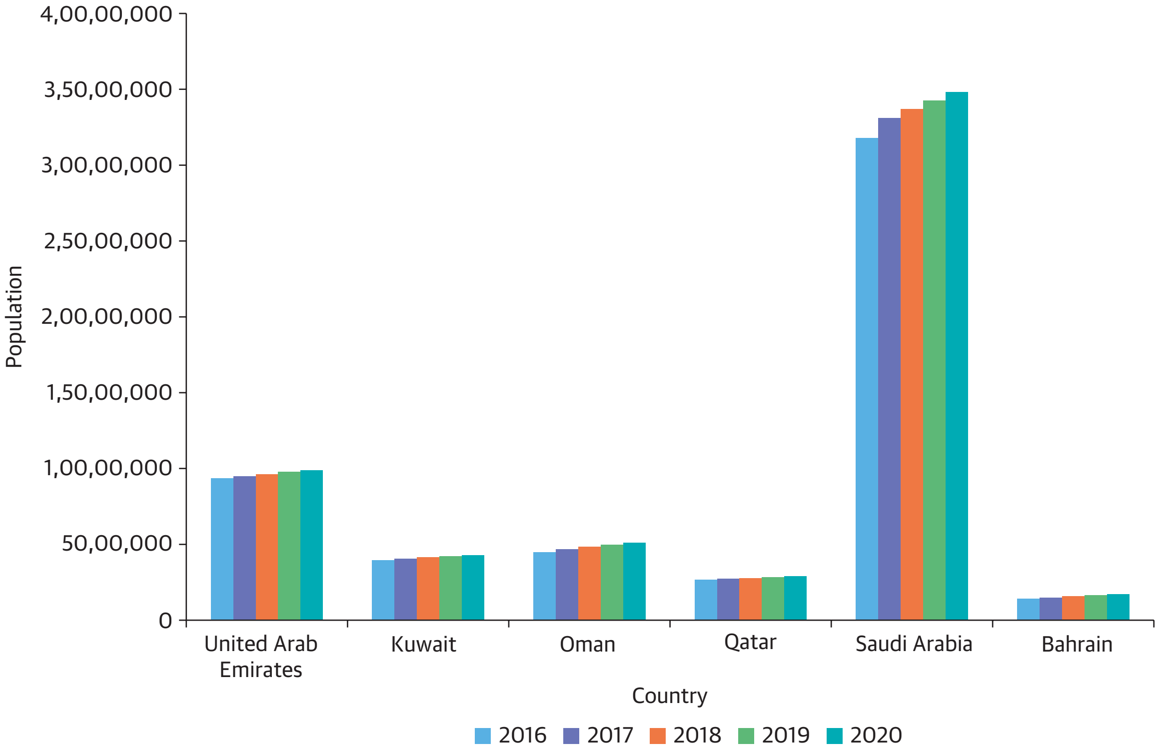
Per capita energy consumption in the GCC countries is substantial to start with, but it surges with urbanization. As a rule of thumb, the higher the population density, the lower the fixed and operating costs of water and electricity, but the higher the per capita demand. Demand for water and energy in Kuwait, Bahrain, the United Arab Emirates, and Oman surpass many leading industrial countries, but Qatar eclipses all nations with the world's greatest consumption of these vital resources (Al-Badi and Al-Mubarak 2019).

TABLE 1.1. GCC Countries' Population and Growth Rate, 2021

Country	Population (2020)	Yearly change (%)	Net Change (persons)	Density (p/km^2)	Land Area (km^2)	Migrants (net)	Urban Pop. (%)	National pop. (%)
Bahrain	1,701,575	3.68	60,403	2.239	760	47,800	89	47
Kuwait	4,270,571	1.51	63,488	240	17,820	39,520		50
Oman	5,106,626	2.65	131,640	16	309,500	87,00	87	54
Qatar	2,881,053	1.73	48,986	248	11,610	40,000	96	14
Saudi Arabia	34,813,871	1.59	545,343	16	2,149,690	134,979	84	63
United Arab Emirates	9,890,402	1.23	119,873	118	83,600	40,000	86	11
Total GCC	58,664,098	1.68	969,733	60.49771	2,572,980	302,299	84	49

Source: Worldmeters 2021.
Note: GCC = Gulf Cooperation Council.

FIGURE 1.5. Total Population in GCC Countries, 2016–20



Source: GCC-Stat, Population (2020).

Chapter 2

Distorted Values for GCC Resources Reduce Efficiency of the Water-Energy Nexus

2.1 How and Why Cheap Energy Drives Up Consumption of Water and Demand for Food

The Gulf region's sustainable development rests on the secure provision and efficient use of water, energy, and food. Yet, few may appreciate how closely and deeply these resources are linked. It takes considerable amounts of energy to lift, convey, purify, heat, treat, and distribute water. It also takes substantial volumes of water to extract oil and gas and to produce electricity. Irrigated farms require energy resources to pump water; fertilize soil; and process, ship, and preserve food.

Due to its heavy reliance on desalination, the GCC's water-energy nexus is unique, at risk, and imbalanced. The water sector relies almost entirely on energy while the energy sector only modestly needs water. That dependence makes water vulnerable to prices, impacts, constraints, and availability of energy, all of which will be aggravated by growth and the impacts of climate change. To mitigate these risks, the GCC might consider both supply- and demand-side options.

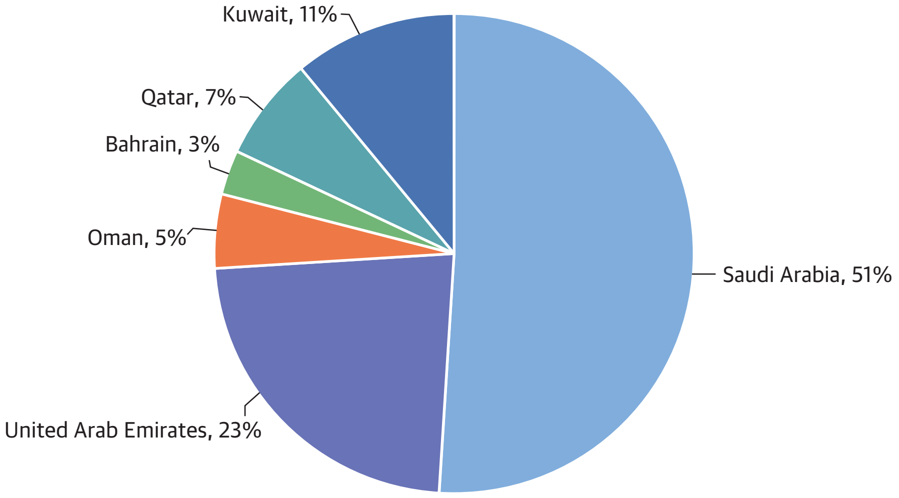
For nearly a century, the GCC's energy—for domestic consumption or global exports—was almost synonymous with fossil fuels. By comparison, in terms of total supply, the use of renewable resources was almost negligible. Yet in recent years these priorities appear to be changing. GCC countries have set ambitious targets to increase their energy reliance on renewables and nuclear energies, as well as enhance the efficiency of the sector.

All GCC countries have set clean energy targets, and several have embraced conservation. Progressive measures include Saudi Arabia's efficiency master plan, Abu Dhabi's comprehensive cooling plan, Dubai's integration of an energy strategy, and innovation in green building standards in the United Arab Emirates and Qatar. Utilities in Oman and Dubai are trying to shift toward customer prices that reflect costs of production. Qatar and the United Arab Emirates have developed comprehensive development strategies that aim at a "low carbon pathway" or "green growth" (Lahn, Stevens, and Preston 2013).

Some GCC clean energy goals and targets aim to reduce electricity demand or adopt efficiency measures. Others set out to diversify electricity production by expanding nuclear capacity in the region, while also deploying four times the amount of power (80 GW) from renewables.

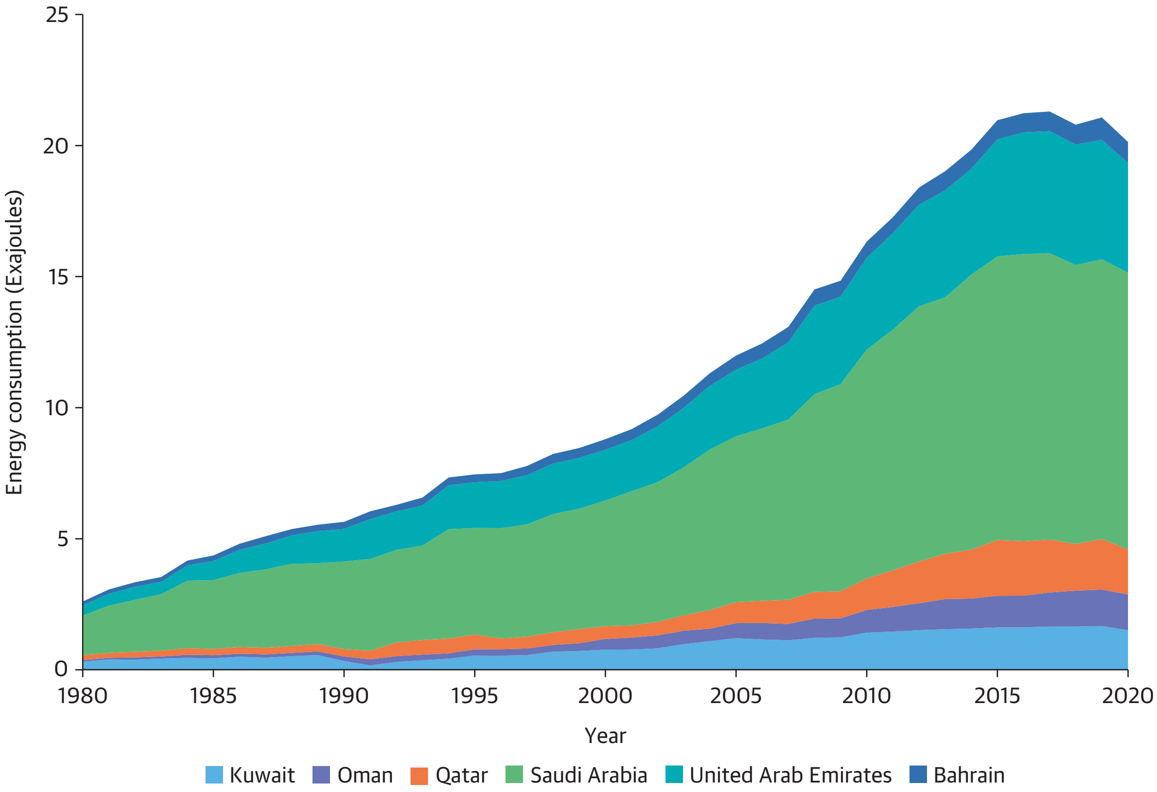
Per capita electricity use in the GCC region ranks among the world's highest (IRENA 2016, See also Figure 2.2). The hot and arid climate demands long hours of air conditioning; keeping the temperature cool at home, in stores, and at work requires substantial quantities of electricity. So, it is difficult to compare the region with Mediterranean countries, or with world averages. Still, electricity consumption in GCC countries is not only high, but projected to rise under a changing climate's longer, hotter, drier summers. This crisis reveals an opportunity to adopt new electricity-saving technologies.

FIGURE 2.1. **Rate of Electricity Consumption, 2016**



Source: GCC-Stat, Energy.

FIGURE 2.2. **GCC Countries' Total Primary Energy Consumption, 1980–2020 (in exajoules)**



Source: BP statistical review of World of Energy, July 2021; and US Energy Information Administration.

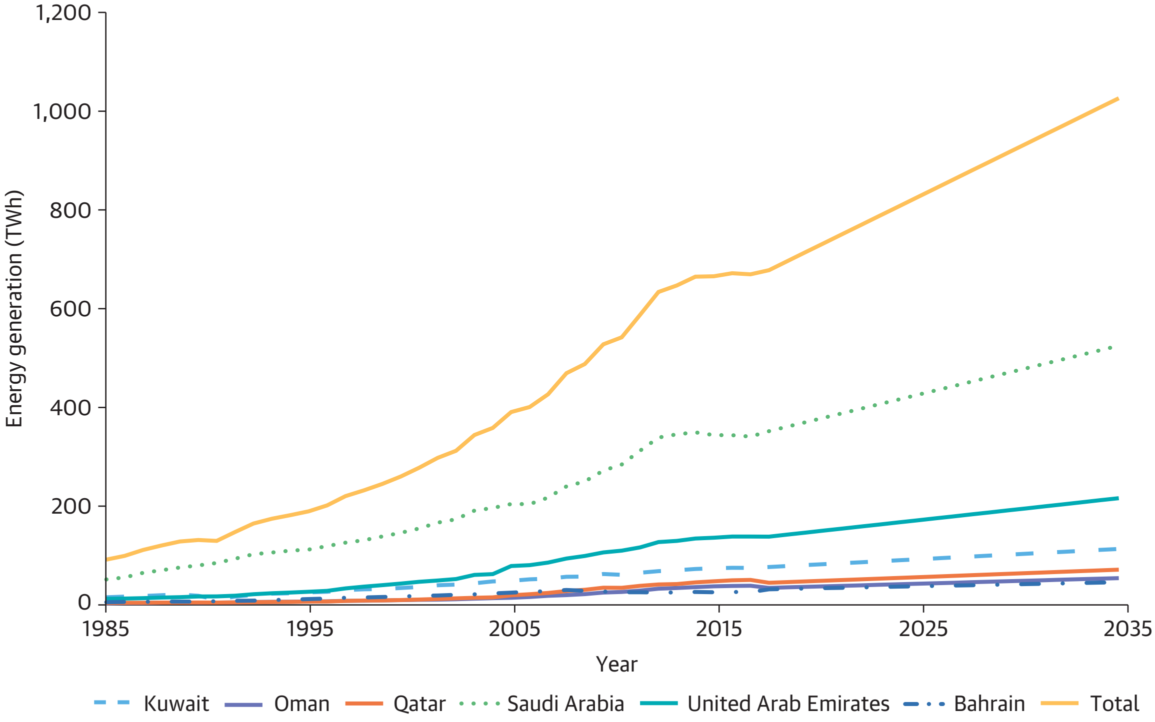
For example, photovoltaic solar energy and green hydrogen can augment electricity to the grid during peak hours and at lower rates. Efforts are being undertaken in the region to implement this going forward. During hot summer afternoons, as air conditioning spikes and drains much of the GCC's electricity supply, solar energy could generate power 13 hours a day right in the 1-5 p.m. slot, when demand and average prices are highest. Since this involves no loss from cooling power plants, renewable energy supports the water sector, lowers costs to users, reduces impacts from GHG emissions, and improves each GCC country's foreign trade balance.

Figure 2.3 projects electrical energy generation through 2040 (Al-Badi and Al-Mubarak 2019)—it shows a steady increase for all the GCC countries. In 2016 Saudi Arabia recorded the highest rate of electricity—54 percent of the total production of electricity in GCC countries—followed by the United Arab Emirates with 20 percent, Kuwait with 11 percent, Qatar with 7 percent, Oman with 5 percent, and Bahrain, 3 percent.

2.2 Electricity Pricing Distorts Household Consumption Patterns

GCC prices for fuel and electricity are among the world's lowest. This has a bearing on the region's desalination, as the various oil-powered de-salting processes mean that these countries are, in a sense, turning oil into water. Such a resource-intensive conversion is projected to grow as water demand rises

FIGURE 2.3. Total Electrical Energy Generation (TWh)



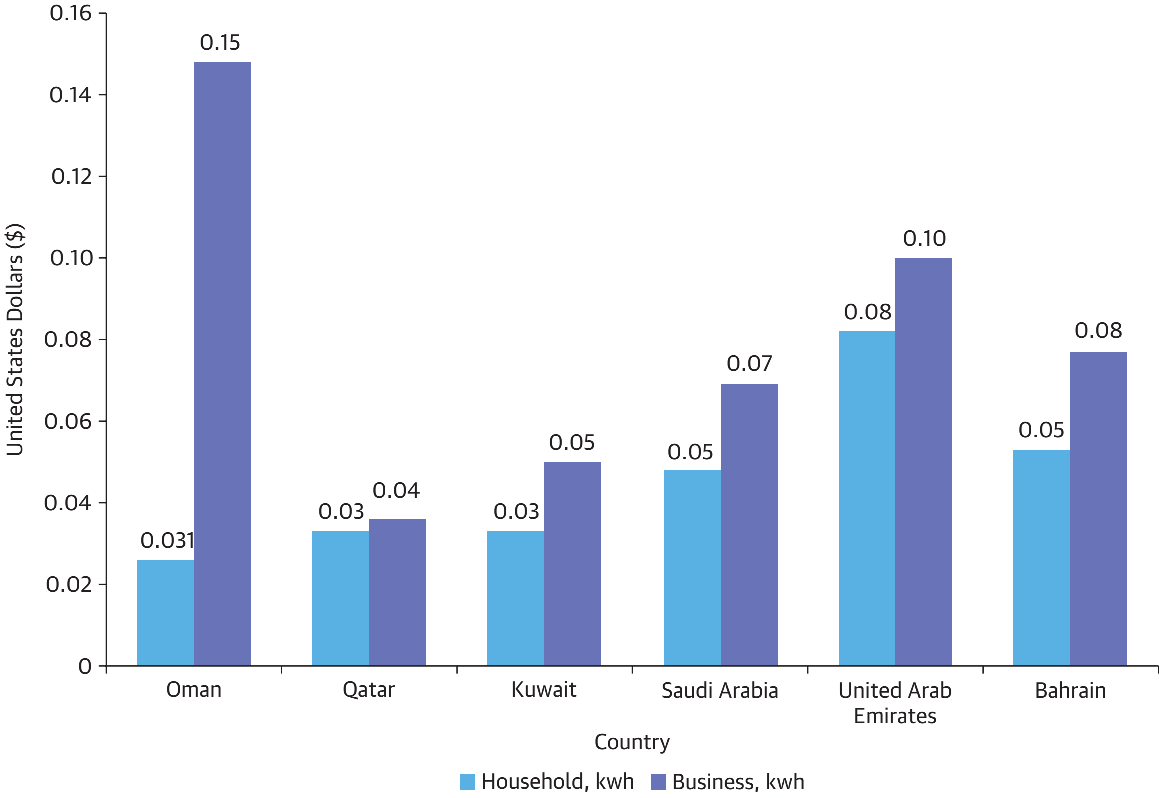
Source: BP statistical review of World of Energy, July 2021; and US Energy Information Administration.

among all sectors of the region's economy. Yet families and firms rarely pay the full costs of their heavy consumption.

Electricity tariffs vary by country and by sector. In 2021, domestic electricity rates were highest in the United Arab Emirates and the lowest in Oman. By contrast, businesses in Oman paid the highest electricity prices. Saudi Arabia's National Water Company subsidizes water along five slabs, whereas its electricity prices are close to its cost of generation. There is no one-size-fits-all strategy. Yet a focus on targeted water and energy rates can lead to substantial savings of both valuable resources.

Subsidies only make sense if they target specific outcomes. Oman, for example, sets several price slabs that consider online records of a household's income and size. This way, registered and eligible low-income families benefit from the lowest and subsidized price, paying the least per unit consumed, while others pay much more. The current system for electricity and fuel prices will soon be extended to water bills, and Oman's affordability criteria can be adapted to all GCC cities to avoid and relieve potential risks of backlash. However, achieving a balance between cost of production and price of consumption requires significant shifts in the way governments intervene in and regulate the energy/water interaction (see Figure 2.4 for detailed electricity pricing for each of the GCC countries).

FIGURE 2.4. **Electricity Prices in 2021 (US$)**



Source: Global petroleum prices.

2.3 The Water-Energy Nexus Is Dominated by Complex Institutional Structures, which Could Be Improved to Simplify and Clarify the Role of Private Sector Partners

GCC resource agencies too often can grow overly complicated and fragmented. Specialized and highly differentiated institutional structures affect performance of the water-energy nexus. Among various ministries and regional authorities, confusion may arise about who is responsible for what outcomes, thus limiting the scope for timely and effective resource decisions.

To better study, plan, and execute initiatives addressing the nexus, government leaders have begun to delegate authority, though a Chatham House report (Lahn, Stevens and Preston 2103) found more coordination among electricity suppliers than those on the water side. Abu Dhabi, Saudi Arabia, Oman, and Dubai, for example, have introduced an independent power sector regulator with responsibility to ramp up energy conservation. To overcome sectoral barriers, Saudi Arabia has pioneered a coordinating body for energy efficiency, as well as an agency to make policy on renewable and atomic energy. The Saudi Energy Efficiency Program (SEEP) was launched by the Saudi Energy Efficiency Center. SEEP is an integrated work program between all concerned parties, whether from the public or private sector, as it seeks to develop and implement programs to raise energy efficiency, and to develop initiatives, systems, regulations, and implementation and financing mechanisms that achieve this. SEEP has focused on rationalizing demand through efficiency across the three key sectors—industry, transport, and buildings—which make up more than 90 percent of domestic energy consumption.

Moreover, strategic and innovative communication tools persuade, educate, and enable consumers to make energy-efficient purchases. Qatar has advanced high-level interministry coordination on climate policy, while Dubai became the first GCC government to establish an entity for integrated energy policy (Lahn, Stevens, and Preston 2013).

Saudi Arabia exemplifies the region's urgent need to simplify and unite complex and fragmented institutions of the nexus (box 2.1). In 2016 the country established the Ministry of Water, Environment and Agriculture (MEWA). Within that ministry, several entities deal with water: the National Water Company, the Saline Water Conversion Corporation, the Saudi Water Partnership Company, the Saudi Transmission and Technology Company, and the Saudi Irrigation Organization. In addition, several Saudi universities have established diverse water and energy departments. Institutional challenges managing linked resources grow even more complex when GCC countries seek to expand the role of the private sector in all components of the water-energy nexus. Businesses can help drive efficiency, but vital resources demand public supervision and transparent monitoring of potential risks to public health or environmental integrity.

2.4 Water Supply Infrastructure Increases Impacts of a Heavy Energy Footprint

Right now, GCC countries meet rising freshwater demand through reuse of treated wastewater (6 percent), desalination (16 percent), and groundwater abstraction (78 percent) (Dawoud 2021a). Each technology or infrastructure brings its own set of risks and impacts due to an increasing strain on energy.

BOX 2.1. Saudi Arabia's New Water Law

On July 7, 2020, the Saudi Royal Court approved a new law that replaced previous regulations with a comprehensive regulatory framework covering all governance of, development rights to, and use of water resources.

Under this law, the Ministry of Environment and Water and Agriculture has the legal authority to ensure the sustainability of water, preserve and develop water resources, and charge water users with a structured tariff. The law identifies the Electricity & Cogeneration Regulatory Authority as an independent regulator for water services.

The law identifies where further measures are needed, for example, to ensure efficient water use, enhance private sector participation in developing water projects, and protect the public interest needs of water consumers.

The law defines what is required to: ensure public access to clean water suitable for health and hygiene, provide adequate water supplies to sustain the agricultural sector, and maintain a high-level continuous service that ensures efficiency and high quality throughout the water sector.

The law seeks to provide consumers a fair, balanced, safe, clean supply at competitive prices, and in accordance with the standards and plans set by the ministry. It further empowers the ministry to establish clear guidelines to develop and improve groundwater resources, plan for strategic water storage, regulate usage for beneficiaries, and ensure short-, medium-, and long-term water treatment.

The law encourages private sector participation and investment in projects to develop, treat, recycle, and conserve water resources, and grants the ministry—in coordination with the National Risks Unit—the power to declare a state of emergency during natural and abnormal disasters that affect the quantity or quality of Saudi Arabia's water resources.

Finally, the new law prohibits property owners from unauthorized explorations, excavations, or diversions of water—as well as the drilling, maintenance, and backfilling of wells—without a license granted in accordance with ministry requirements.

The Royal Decree was published in the official gazette (Umm Al-Qura).

As detailed in a subsequent chapter, the GCC countries are expanding desalination at a rapid pace. In 2000, some 44 plants annually produced 1.7 billion cubic meters (AL Rashed and Sherif 2000). By 2030, the region's capacity will have increased nearly sixfold, with 238 plants desalinating 11,760 million cubic meters. The rate of growth—and energy footprint—extends beyond production. It also goes into conveyance, treatment, and distribution, both to urban communities and industrial zones (see table 2.1).

Meanwhile, some aquifers are pumped to near depletion. Overabstraction from nonrenewable aquifer systems reduces the volume and integrity of groundwater across the United Arab Emirates,

TABLE 2.1. **Present and Future Desalination Capacities in GCC Countries, 2010–30**

Country	Desalination Production (MCM/year)										
	2010	2013	2014	2015	2016	2017	2018	2019	2020	2025	2030
Bahrain	145	156	185	195	215	246	246	250	254	350	450
Kuwait	450	489	546	610	665	702	785	850	1,103	1,850	2,750
Saudi Arabia	1,210	1,350	1,540	1,760	1,910	2,135	2,230	2,380	2,540	3,500	3,950
Oman	120	125	132	145	156	168	174	189	235	350	460
Qatar	210	258	284	320	354	391	401	420	450	560	730
United Arab Emirates	1,450	1,565	1,620	1,650	1,710	1,776	1,820	1,950	2,120	2,850	3,420
Total	3,585	3,943	4,307	4,680	5,010	5,417	5,656	6,039	6,702	9,460	11,760

Source: GCC Cooperation Council, Desalination Statistics 2017.

Bahrain, and Qatar. As water tables fall, salinity rises. This deterioration of quality undermines the region's water security, human health, agricultural development, and environmental ecosystems. In some areas, groundwater has become even more salty than the sea, which if used for irrigation will ruin arable soils. Yet groundwater pumping is often accelerating. At current rates of abstraction, the region will extract 32,350 million cubic meters from wells by 2030 (AL Rashed and Sherif 2000; Dawoud 2021a).

In sum, the water treatment, desalination, and abstraction processes are all energy intensive. Energy production, in turn, needs lots of water. Given this vicious cycle, it is worth quantifying the intersection of these needs.

2.5 How Much Electricity Does the Water Sector Consume?

All six GCC countries have built complex water-energy infrastructures. Each has its own associated policy framework that aims to price electricity, with incentives and subsidies (Zubari et al. 2017). These policies shape domestic consumption of both resources, as illustrated in the next sections.

Energy-intensive desalination consumes 20 percent of the electricity supply in the United Arab Emirates, 13 percent in Qatar, 7 percent in Saudi Arabia, and 8 percent in Kuwait and Bahrain (Siddiqi and Anadon 2011).

Energy is used to:

1. Treat surface water.
2. Abstract and treat groundwater.
3. Desalinate seawater.
4. Pump water through an extensive transmission and distribution system.

5. Collect, treat, and reuse wastewater.

6. Operate irrigation networks.

Conversely, water is used to:

1. Produce fossil fuels (oil and gas).

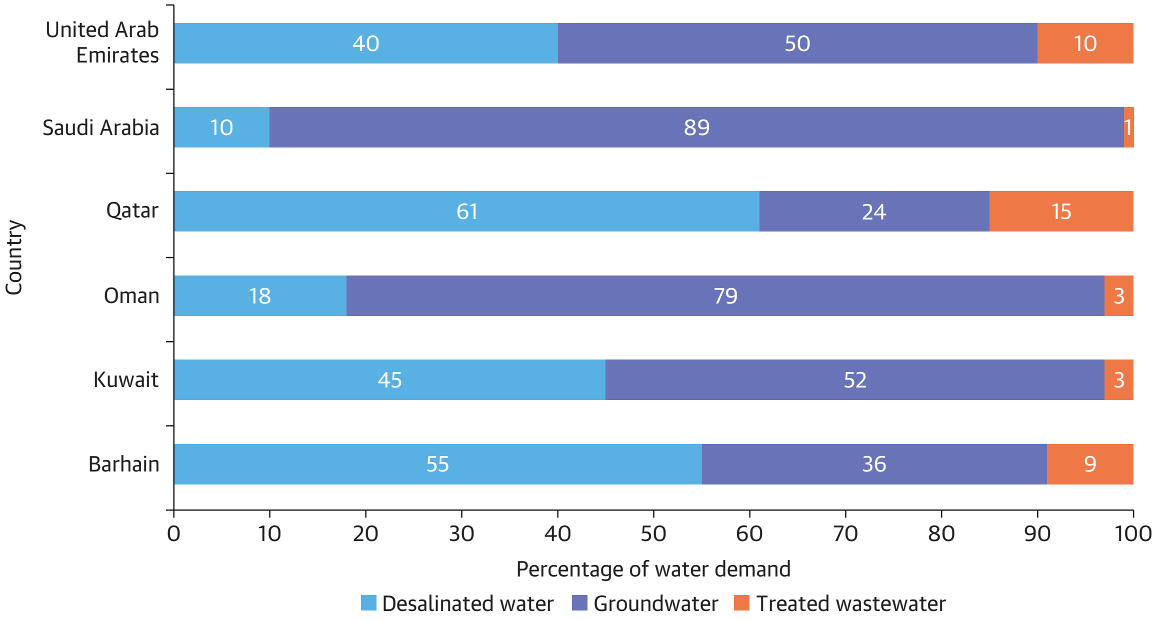
2. Cool power/desalination cogeneration plants.

3. Generate hydropower.

To put the scale of unconventional water supply operations in perspective, each year the GCC region desalinates five times more water than flows down the Jordan River. If one also includes the pumping of deep aquifers, the GCC region consumes as much groundwater (32 billion cubic meters) as flows down the Euphrates River each year (Al-Ansari, Adamo, and Sissakian 2021; Keenan 1992). Producing the equivalent of entire rivers is possible due to advanced water technologies, supported, in turn, by ample supplies of energy. But the technological marvels come at a heavy cost. Each year adds to lost energy opportunities, rising air pollution and GHG emissions, and worsening side effects from dumping 12 billion cubic meters of hypersaline brine into the Gulf (Ibrahim, Xue, and Eltahir 2020).

The climate challenge compounds economic and demographic stress points: rising costs for new and existing water infrastructure and service delivery, resource deterioration, changing consumption

FIGURE 2.5. Water Sources' Contribution to Water Demands in GCC Countries, 2018



Source: GCC-STAT.

patterns, inefficient supply, distorted water prices, low water reuse and recycling, and low energy efficiency in the water sector. As temperatures continue to rise, the intensity of these challenges is expected to increase as well (Zubari et al. 2017).

Groundwater is the primary source for Saudi Arabia, Oman, and the United Arab Emirates. Yet even in these large countries, aquifers are at risk of running low, drying up, being increasingly vulnerable to saline intrusion, and suffering from degraded quality. To mitigate the risks of overreliance on groundwater, GCC countries may consider a reallocation approach that prioritizes desalination for domestic use; groundwater for industry, manufacturing, and indoor food production; and recycled or treated wastewater for industry and agriculture.

Chapter 3

Drivers of the Water-Energy Nexus Are too Important for Distinct Sector Resource Policies

3.1 Water Demands Require Structural Management That Goes beyond Tariff and Pricing

Demand for water in the GCC countries is shaped by multiple pressures (World Bank 2017). These include:

- The world's highest levels of water stress—a withdrawal-to-availability ratio—caused when domestic, agricultural, and industrial demands exceed renewable water supply.
- Per capita residential water consumption is almost double that of high-income countries.
- The world's highest levels of groundwater abstraction, causing depletion of quantity and deterioration of quality.
- A near-total reliance on the energy sector for the production, extraction, treatment, conveyance, and distribution of water.
- The world's largest installed capacity for seawater desalination, an energy-intensive process that has developed and used internationally advanced technology.

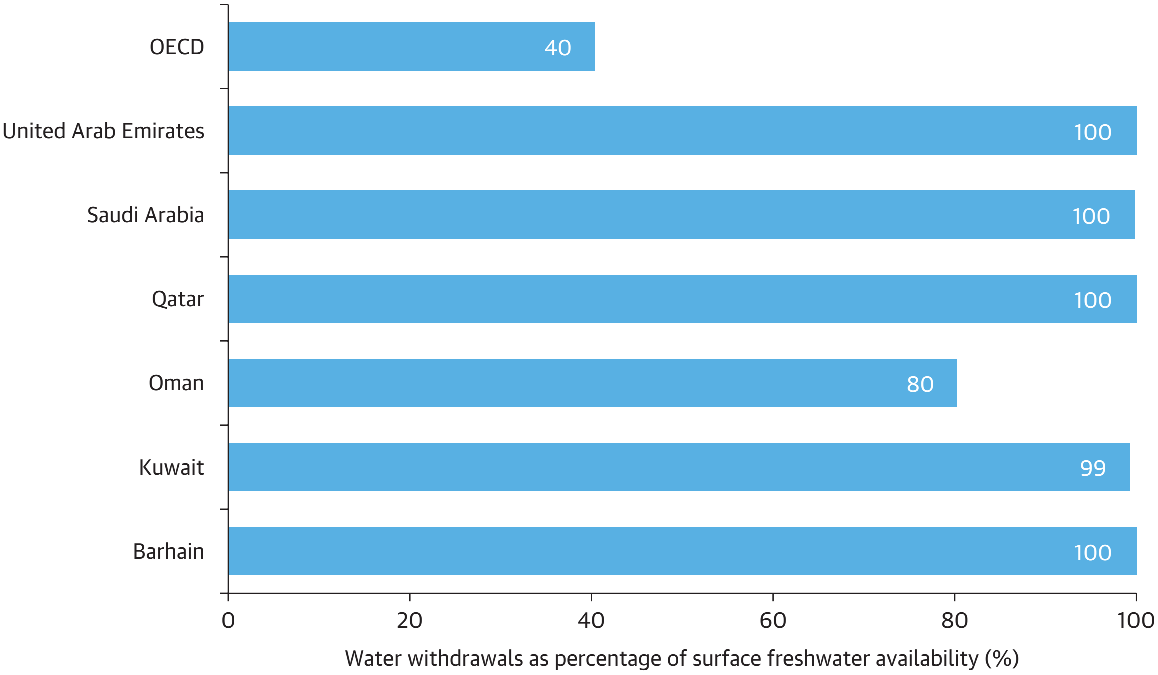
3.2 Water Stress Is a Long-Term Challenge for the GCC Region

The UN Secretary-General and the UN Global Compact define "water stress" as the ability, or lack thereof, to meet human and ecological demand for fresh water (UN Global Compact 2017). According to the European Environment Agency's definition, water stress occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. Water stress depletes freshwater resources (European Environment Agency 2017).

Water stress takes two forms: (1) physical scarcity, or a local shortage of natural resources due to ecological conditions; and (2) economic scarcity, a lack of adequate water supply infrastructure. The GCC countries have built substantial and complex water infrastructure that allows life in the Gulf region to thrive, but nevertheless the region suffers the world's highest levels of water stress (figure 3.1).

High rates of consumption, coupled with rising temperatures, reduce natural water supplies to a trickle. To alleviate stress, expanding water infrastructure alone is necessary but not sufficient. A long-term solution calls for more innovative policies, efficient distribution and usage, and interactive public educational campaigns that engage consumers to reduce demand for water at home, schools, and the workplace.

FIGURE 3.1. Water Stress in the GCC Countries and Average Water Stress for OECD Countries



Source: World Bank 2017.
Note: OECD = Organisation for Economic Co-operation and Development.

3.3 Inadequate Water and Energy Policies Encourage Domestic Water Consumption

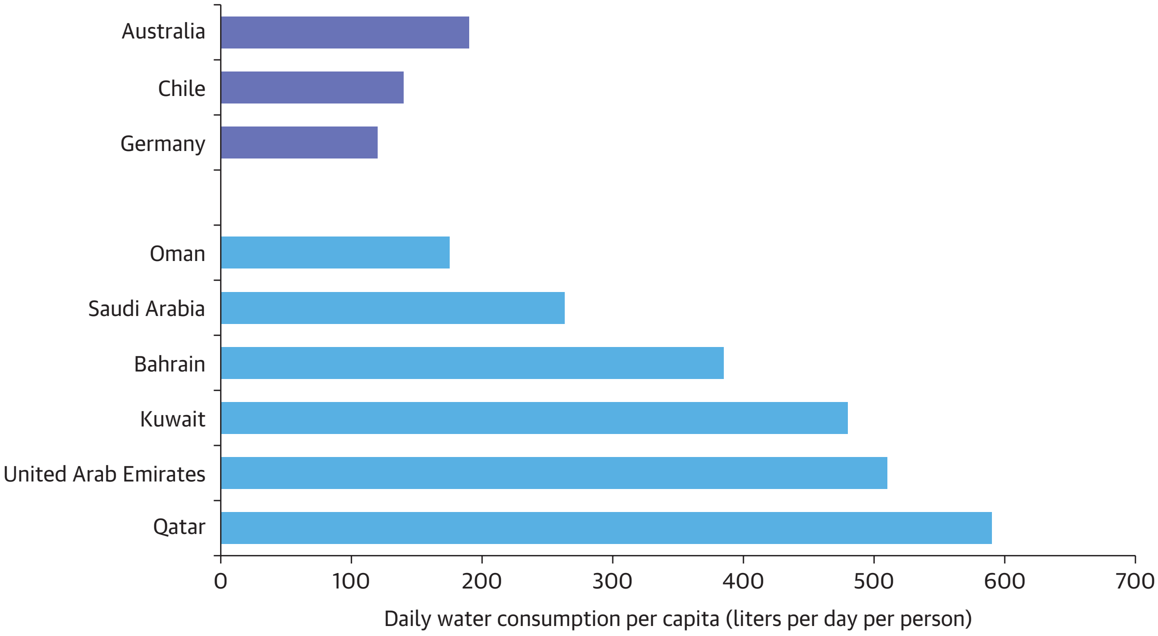
Boosting supply by itself may not relieve pressure if consumption rises even faster. Across the GCC, daily water use by GCC residents is almost twice as high as in other high-income countries (figure 3.2). Even in countries with similar levels of development, or endowed with much greater freshwater resources, people outside the GCC region consume far less than those in the Gulf region. Indeed, GCC citizens use 560 liters/capita/day (LPCD), more than triple the world average of 180 LPCD.

Among GCC nations, Saudi Arabia has the greatest total water consumption, while Qatar consumes the most water per capita. In addition to domestic use, a more accurate and inclusive assessment would factor in the immense volumes of water consumed in fossil fuel production, energy generation, and commercial and industrial uses.

3.4 As Groundwater Gets Depleted, Food Security Depends on Agricultural Imports

GCC countries rank as unsustainable groundwater hotspots. From deep aquifers, wells pump three-quarters (27,850 million cubic meters) of the region's water. Pollution is a concern, as agricultural and industrial waste, landfill seepage, and seawater intrusion degrade groundwater quality (Siddiqi et al. 2021). Yet allocating the bulk of GCC's fossil groundwater to agriculture has proven costly and risky (Dawoud 2021a).

FIGURE 3.2. **Domestic per Capita Consumption (liters/capita/day)**



Sources: Zubari et al. (2017) for the GCC countries; International Benchmarking Network for Water and Sanitation Utilities for Australia and Chile; and Environment Agency for Germany.

Over the past five decades, farms have been abstracting groundwater faster than it can be recharged. As a result, aquifers have fallen more than 200 meters (figure 3.3), and springs and shallow aquifers have dried up. Higher pumping in eastern Saudi Arabia and Bahrain has disturbed the equilibrium between aquifers and could lead to the leakage of poor-quality water from one aquifer to another.

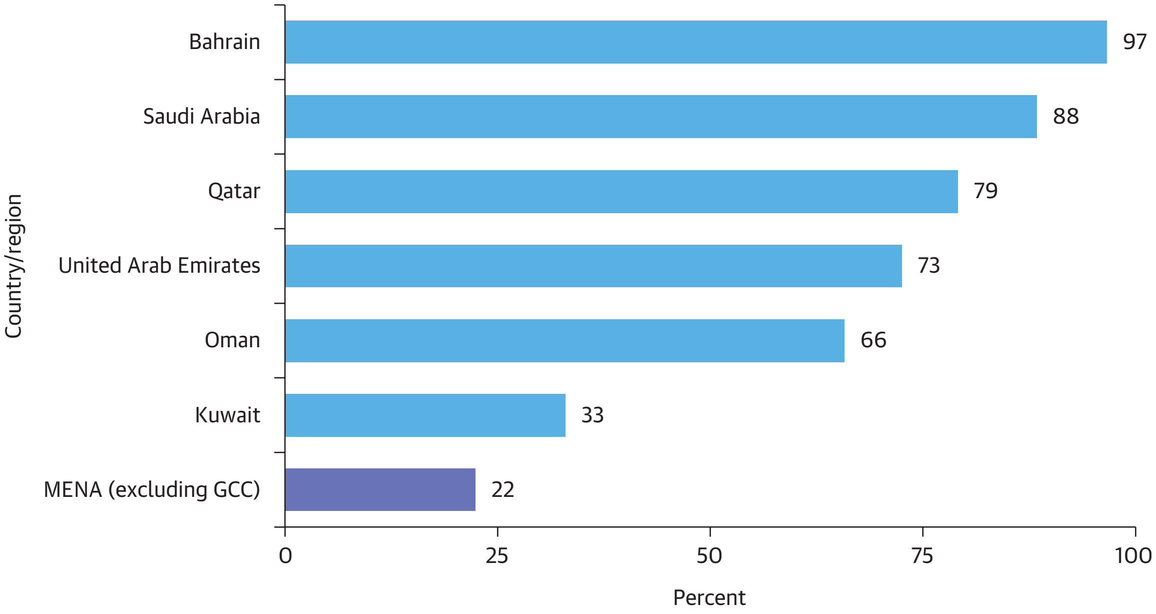
Groundwater pollution is caused by overpumping of wells, seawater intrusion, irrigation runoff, overuse of chemicals, high evaporation rates, and septic tank effluents. Many wells in Bahrain, Qatar, United Arab Emirates, and Oman have been abandoned due to seawater intrusion. GCC countries can better monitor and manage groundwater reserves as a key driver of national water security (Raouf 2009).

Despite decades of unrestricted abstraction of mostly fossil (nonrenewable) groundwater, agriculture only contributes less than 2 percent of any GCC country's GDP. A legacy of free allocations—without water rights, metering, or tariffs—encouraged inefficient practices such as flood irrigation or energy-intensive pivot irrigation that suffer from high evaporation rates. Many irrigation farms cultivate water-intensive cereal and fodder, crops that are more affordably imported.

The results have proven rather predictable:

- Rapid groundwater depletion;
- Heavy mining of deep, nonrenewable aquifers;

FIGURE 3.3. Groundwater Depletion in the GCC Countries: Percentage of Groundwater Abstraction Exceeding Natural Recharge, 1960–2010



Source: World Bank 2017.
Note: GCC = Gulf Cooperation Council; MENA = Middle East and North Africa.

- Escalating per unit energy costs, due to pumping from increased depth from water level to surface;
- Decline in water quality; and
- The loss of vital strategic water reserves.

Countries have noted these challenges and started to advance innovations such as strategic aquifer storage (see box 3.1).

3.5 Food Security Need Not Be at the Expense of Water Security

Most of the GCC region's groundwater—and some 70 percent of all its water resources—gets consumed not by families or industries but by irrigation. GCC members' earlier desire to promote self-sufficiency has led to the production of water-intensive food crops. However, this priority has exacted an extremely high national, economic, financial, and environmental toll.

GCC governments can match realistic strategies with pragmatic solutions. Rather than deplete valuable groundwater resources for a low-value objective, policies might better conserve aquifers as assets, a priority reserved only for national economic outcomes. One step in the right direction is increasing the imports of food grown overseas. According to an analysis conducted by the Food and Agriculture Organization (figure 3.4), the cereal import dependency ratio—of imported vs domestically produced

BOX 3.1. Reducing Supply Risks through Strategic Aquifer Storage and Recovery (ASR)

As GCC populations depend more heavily on desalination plants, urban water supply grows increasingly vulnerable to risks from pollution, malicious sabotage, and emergency accidents. This poses a national security risk.

If supply is interrupted, Saudi Arabia and Kuwait can store only three to five days' worth of clean water in tanks and the distribution network, whereas other GCC countries can last only 24 hours. Also, there is not enough water to cover urban demand during emergencies.

Moreover, water production of desalination plants is largely constant under normal conditions but water demand fluctuates by season, rising during the hot summer months and declining over the winter.

To mitigate these risks, the United Arab Emirates has since 2018 begun advancing innovative technologies to store more drinking water into three secure and confined sand and gravel-covered "gravel-bed" groundwater basins, as an additional distributed reserve.

During the cool winter months, when capacity exceeds demand, Abu Dhabi can inject 25 million cubic meters (m^3) of excess desalinated water through radial perforated pipes to recharge these desert dune aquifers. This system uses 3D technology in 118 wells to monitor the levels of injected freshwater.

The following summer, this clean water can be recovered from 315 wells. The newly available clean water acts as a buffer against potential emergency interruptions, or when demand peaks and supplies run short.

In 2021, Dubai started to inject 45,450 m^3 of water so that it can recover more than 225,000 m^3 by 2025. Other similar projects are under consideration in Saudi Arabia, Kuwait, and Qatar.

Strategic ASR systems seek to reduce exposure to risk, more fully utilize desalinated water, lower production costs, expand storage capacity, build resilience, and diversify sources of water security.

Source: Dawoud 2021a, 2021b.

grains—was more than 90 percent in Oman and more than 95 percent in Kuwait, Saudi Arabia, and the United Arab Emirates (FAOSTAT 2017).

Indeed, for GCC countries food security may rest on a foundation of international trade. Sharpening skills in agricultural imports can reduce the GCC countries' exposure to price risk from volatile prices, as well as supply chain disruptions (Efron et al. 2018). The region's robust fiscal position reduces vulnerability to price risk, and enables it to devise prudent trade policies. In exchange for oil exports, GCC countries can offset and replace most if not all agricultural irrigation needs by importing the same quantities embedded in food commodities, a concept known as virtual water.

Virtual water is a simple but essential concept to improve the nexus. The production of 1 ton of grain, on average, requires 1,000 cubic meters (m^3) of water. Rather than extract or produce all that water to grow that ton of grain locally, or import all that water to irrigate fields, an arid country achieves both water security and food security simply by importing the grain from rainfed regions overseas.

Food security through prudent trade is an increasingly important component of the GCC's water policy. Trade makes sense because it is so much easier, cheaper, and faster to import finished food products than to import all the water required to grow and process them at home. The GCC food security policy can address three main risks:

1. *Availability risk*. Grains cannot be readily traded, due to crop failures in food exporting countries, or physical or political barriers in importing countries.

2. *Counterparty performance risk*. Despite grains being available at an acceptable price, the party who contracted to deliver the grain defaults on the contract.

3. *Price risk*. The risk that the price of imported grains will increase above levels that the importing country considers to be acceptable and/or may be able to afford (Sadler and Magnan 2011).

Scarcity limits agriculture's potential benefits elsewhere. There is simply not enough water or arable land to justify large-scale irrigation, and vast automated farming operations generate very little employment for GCC workers.

From 1960 to 1990, Saudi Arabia set out to quadruple irrigated lands from 370,000 irrigated hectares to 1.5 million. Cheap energy, lavish government subsidies, and modern technology enabled farms to drill deep wells and pump billions of cubic meters of water each year. Unfortunately, Saudi Arabia's massive effort produced few national jobs, little GDP, negligible crops, and insignificant food security. The only lasting measurable outcome was a dramatic decline of nonrenewable aquifers. By 2016, as risks and problems grew, the government changed course. It cut farm subsidies, imported a larger share of its strategic food supply, and ended agricultural production of wheat and other cereals. Even so, many large farms shifted to other water-intensive crops, so the agricultural sector still consumes most of Saudi Arabia's groundwater resources (FAO 2015). The Saudi National Water Strategy 2030 has recommended significant changes in current agricultural practices in the country to help reduce water allocation to the agricultural sector (MEWA 2018).

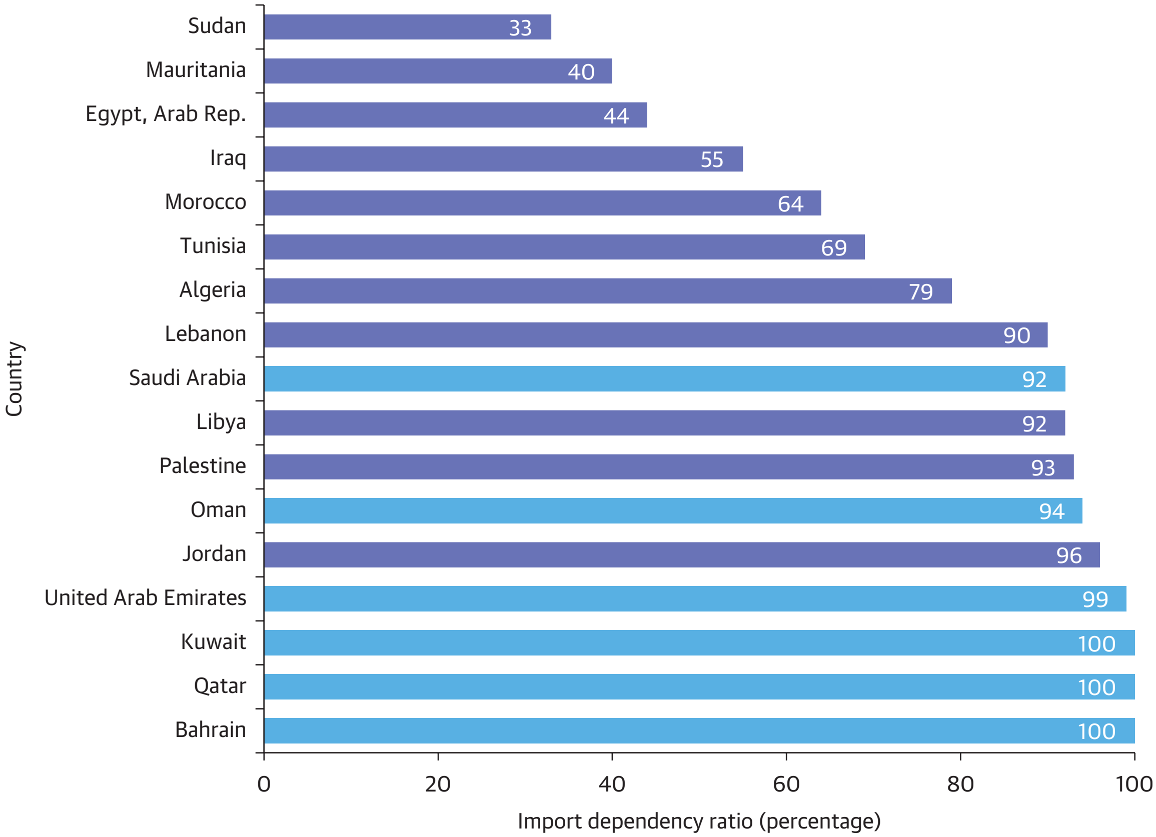
A somewhat controversial variation on virtual water has been to outsource the entire food production process, start to finish. Investors from the United Arab Emirates and Saudi Arabia have contracted with African governments to lease fertile, rain-fed agricultural lands in Sudan, Ethiopia, and Tanzania. Food and fodder will be planted, grown, harvested, and exported back to the GCC countries under contract.

Emerging contractual schemes may be resource efficient, but have political implications. Some critics accuse GCC nations of engaging in a "land grab," taking away opportunities from poor farmers in developing countries for the benefit of rich investors. Perceived risks associated with such investments—this trend to lease and cultivate foreign lands for food exports—have subsided (Elhadj 2004).

Food security fears still vex the water-energy nexus. GCC members struggle to address energy subsidies that deplete groundwater as long as policies favor domestic agriculture. The International Center for Agricultural Research in the Dry Areas analyzed which use of limited water supplies achieves optimal farm yields. It found cereal irrigation to be the least productive; without subsidies, cultivation of cereals in the GCC countries makes very little economic sense.

Many overlook a key element of the nexus: opportunity cost. GCC members may choose to calculate the potential benefits if groundwater resources—now used to irrigate annual or perennial crops—were instead allocated to the urban housing, manufacturing, or service sectors. At US$1.00 per m^3 (the average cost to pump or desalinate each unit), growing a ton of grain has an opportunity cost of US$1,000-US$1,500 for the water alone. That's four to six times higher than purchasing and importing even the most expensive grain (on average trading at ~US$250.00) from Europe or the Americas. Hence GCC countries rank among the world's largest grain importers (see figure 3.4).

FIGURE 3.4. **Cereal Import Dependency Ratio of Select Arab Countries, 2017**



Source: FAOSTAT.

Note: Cereal import dependency ratio is defined as the share of imported cereals in domestic consumption. It is calculated using the following formula: Imports/(imports + domestic production – exports).

3.6 Alternative Commercial Farming Options for the Water-Scarce Region

For water allocated to agriculture, the GCC can ensure food is grown more intensely. One water-smart way for small farmers to grow fresh local vegetables for domestic or export markets is hydroponics. This subset of "hydroculture" refers to growing plants without soil. Instead of farmland, hydroponics uses nutrient-rich solutions in a water solvent. A recent World Bank report highlights the potential relevance of this opportunity to improve food security in the GCC region (Verner et al. 2021).

Growing typically takes place indoors, in a controlled environment free from weeds, pests, disease, and hostile elements. Root mass is much smaller in hydroponic systems, where plants are given nutrients directly and in precise proportions. Proximity to urban buyers brings down transport costs. The green, clean, cost-effective aspects of hydroponics can generate higher yields than conventional farming, an increase of three to ten times in the same amount of space. It can take place year-round, allowing several growing seasons instead of just one.

Above all, hydroponic systems are up to 90 percent more water efficient than traditional irrigation methods. The high "crop per drop" ratio inherent to hydroponic systems is achieved by capturing, recovering, and reusing water runoff. It also limits water loss associated with transmission, evaporation, transpiration, and percolation.

To drive efficiency in the water-energy nexus, GCC countries benefit from policies that:

- Promote controlled farming in greenhouses, using hydroponic technology in established farm networks and targeted communities;
- Bridge the gap between traditional agricultural knowledge and hydroponic systems through educational material and training exercises; and
- Explore, test, demonstrate, and scale the feasibility of hydroponics through field work in partnership with the private sector.

The private sector plays an important role in the logistics for both international trade imports of strategic food commodities, as well as the efficient production, storage, and marketing of domestic food. Conversely, the public sector can more carefully define governance and public procedures in ways that ensure high environmental standards and consumer protection.

Governments, businesses, and local communities may strive to reach consensus on difficult decisions about water allocation, crop selection, domestic production, and foreign food imports. Balanced policies understand and take a multisectoral approach to the water-energy-food nexus. This approach incorporates views of government officials from the water, energy, agriculture, environment, tourism, industry, finance, health, and even trade sectors. The optimal policies are based on reliable market intelligence and guided by transparent and qualified analytical tools.

FIGURE 3.5. Components of Food Security

- Demand for Strategic food commodities
- Local production or imported

- Storage and logistics of international trade
- Food local productivity, storage, and market

- Risks of international trade and constraints in domestic production
- Public policy to manage strategic food commodities in partnership with the private

- Trade policies to encourage import of food as virtual water
- Incentive to export high value and water efficient crops

Based on the above analysis, GCC governments may choose to value aquifers not as a source for elusive food security, but rather as a cornerstone of national and regional water security. A water security policy is best informed by timely analysis of energy, opportunity costs, international trade, and storage of strategic food commodities (as outlined in figure 3.5).

Chapter 4
Policy and Technology Shape the Water-Energy Nexus in the GCC Countries

The water-energy nexus presents the GCC region with significant risks, as water relies on energy far more than energy needs water. In the years ahead, risks from this heavy dependence are only projected to escalate.

4.1 Water Requirements for Energy Production Are Limited but Important

The energy sector does need some water to (1) produce fuel and (2) generate electricity. Both processes employ diverse technologies that require very different levels, qualities, and uses of water. While traditional oil extraction does not use much water, the more sophisticated modern techniques of enhanced oil recovery can prove surprisingly water intensive. Refineries consume large amounts of water for steam and for cooling.

Researchers measure and manage the interdependence of water and energy systems in the GCC countries by quantifying the relative intensity of use in each sector. Water consumption in oil extraction, for example, is much lower than what is lost to evaporation from the cooling processes in power plants. Still, because GCC countries produce so much energy, the toll on water can be heavy. What's more, the water needed by the energy sector can only be secured through earlier consumption of energy to pump groundwater and desalinate seawater, making it a vicious inward cycle.

Water use in electricity generation varies by location. No GCC members use freshwater in once-through cooling systems, while most steam turbine plants use seawater (if located on the coast) or brackish groundwater (if inland). While electricity production in the GCC countries rarely depends on freshwater cooling (Siddiqi and Anadon 2011), there are exceptions. A 2013 study estimated that in eastern Saudi Arabia, electricity's freshwater footprint was 739,308 cubic meters (m^3), or 0.125 m^3 per kilowatt-hour (kWh). Taken from a shallow local aquifer, this dependence was relatively high by global standards, and posed a significant risk for such a water-scarce country (Al-Mutrafi et al. 2018).

4.2 Energy Requirements for Water Are Expanding at the Expense of Exported Energy

By contrast, energy is required at every segment of the water value chain. It takes energy to gather, desalinate, pump, heat, treat, transmit, clean, reuse, and/or dispose of water.

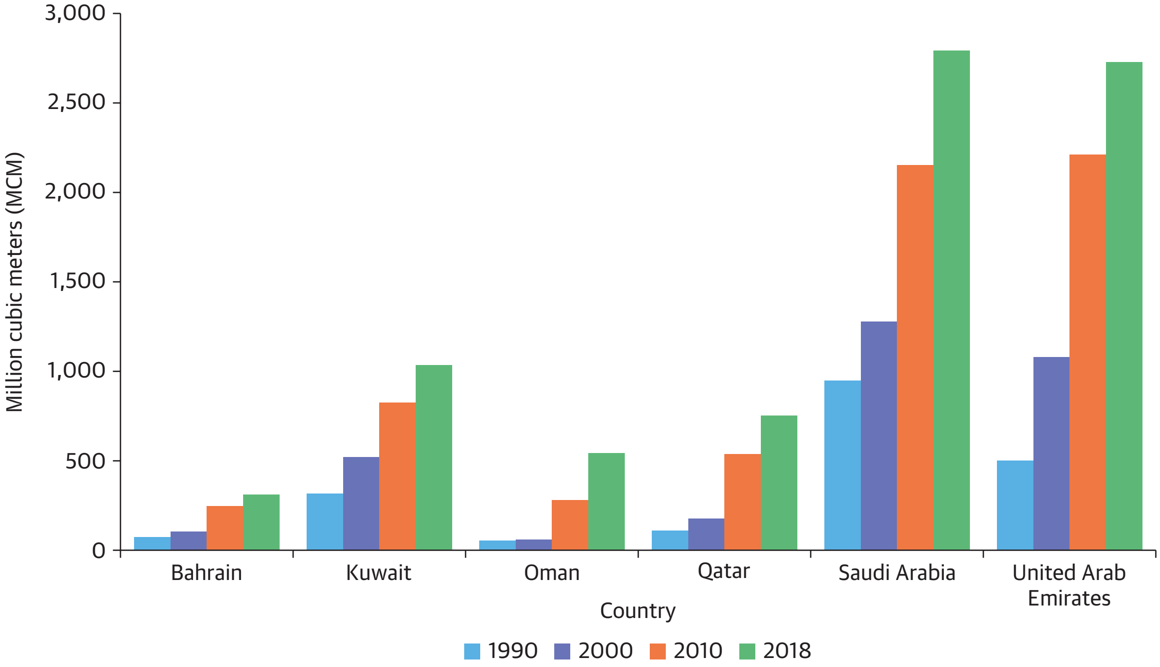
Energy consumption in the water value chain is case specific, but intensity can vary depending on geography, technology, infrastructure, and use. Analyses estimate that the three primary components—groundwater, desalination, and wastewater treatment—consume 5-12 percent of total annual electrical energy consumption in the GCC countries (Siddiqi and Anadon 2011).

The magnitude of energy consumed to extract groundwater is influenced by the depth of the pumped zone, the volumes abstracted, and pumping efficiency. These factors change over time, as aquifers decline, water is lifted a greater distance, and technology grows more efficient. Eastern Saudi Arabia, on average, requires 0.1 kWh to lift each cubic meter of water up 218 meters at 77 percent average pump efficiency (Al-Mutrafi et al. 2018). Scaled up, a 2000 study estimated that Saudi Arabia consumed more than 5 percent of its electricity just to pump groundwater (Al-Mutrafi et al. 2018).

To meet urban demand, desalination and conveyance have become two of the most energy-intensive processes per unit volume. The initial purification technology began in 1907 on the Red Sea coast to support Jeddah. It then spread to Kuwait and Qatar in 1953 with a combined output of 5,000 m^3/day. But Saudi Arabia has a higher cost of energy for water, estimated at 4.2 kWh/m^3, because water needs to be transported long distances—400 kilometers inland and 600 meters uphill from the Gulf to Riyadh (Al-Mutrafi et al. 2018).

Desalination has always consumed the lion's share of energy allocated to the water sector. In the twenty-first century that share is projected to increase even further.[1] Indeed, today the Middle East and North African countries (mainly GCC members and Israel) account for half the world's installed desalination capacity (see figure 4.1). Hence, in GCC countries desalination is caught between energy consumed (which raises costs of water production) and technological innovations (which lower them).

FIGURE 4.1. Trends in Desalination Capacity in the GCC Countries, 1990–2018

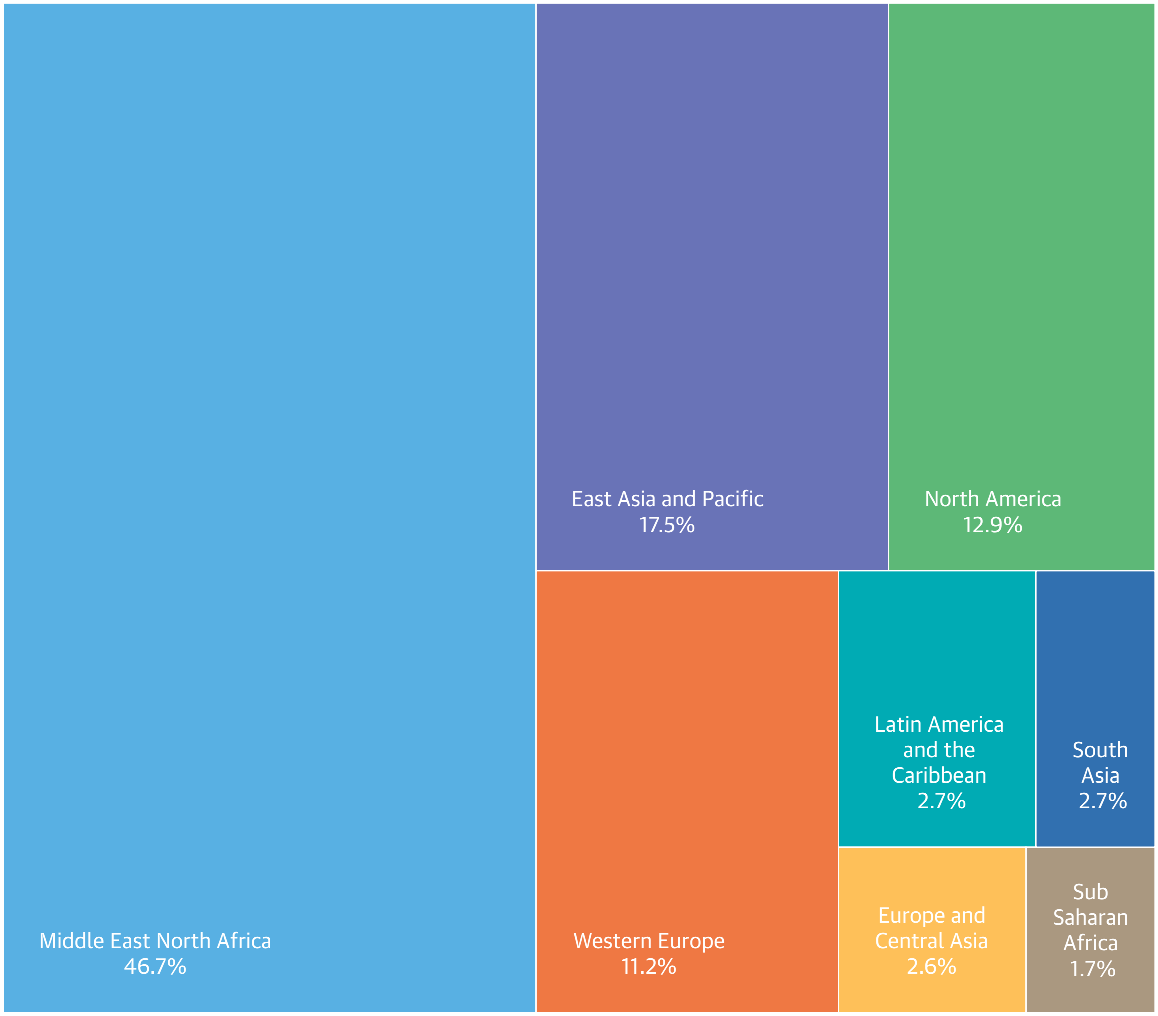


Source: GCC-STAT.

To meet rising demand in hyperarid conditions, total seawater desalination nearly tripled from 2,000 million m^3 in 2000 to about 5,900 million m^3 by 2018 (figure 4.1), and may exceed 9,000 million m^3 by 2030. Desalination now provides a fifth of all water used in the GCC countries, and more than half the water used in Bahrain, Kuwait, Qatar, and the United Arab Emirates.

Gulf cities in particular stand on a foundation of desalination. In the GCC, desalination supplies 75 percent of urban water, either directly or blended with groundwater. This dependence is projected to grow (figure 4.2), since all GCC countries are embarking on major desalination projects (Zubari et al. 2017). These expanding investments are part of deliberate policies to wean drinking water supplies away from a dependence on groundwater.[2] In 2016, desalinated water grew over the previous year by 3.9 percent, while the number of desalination plants increased by 9.5 percent.

FIGURE 4.2. **Global Desalination Production, 2017**



Source: World Bank 2017.

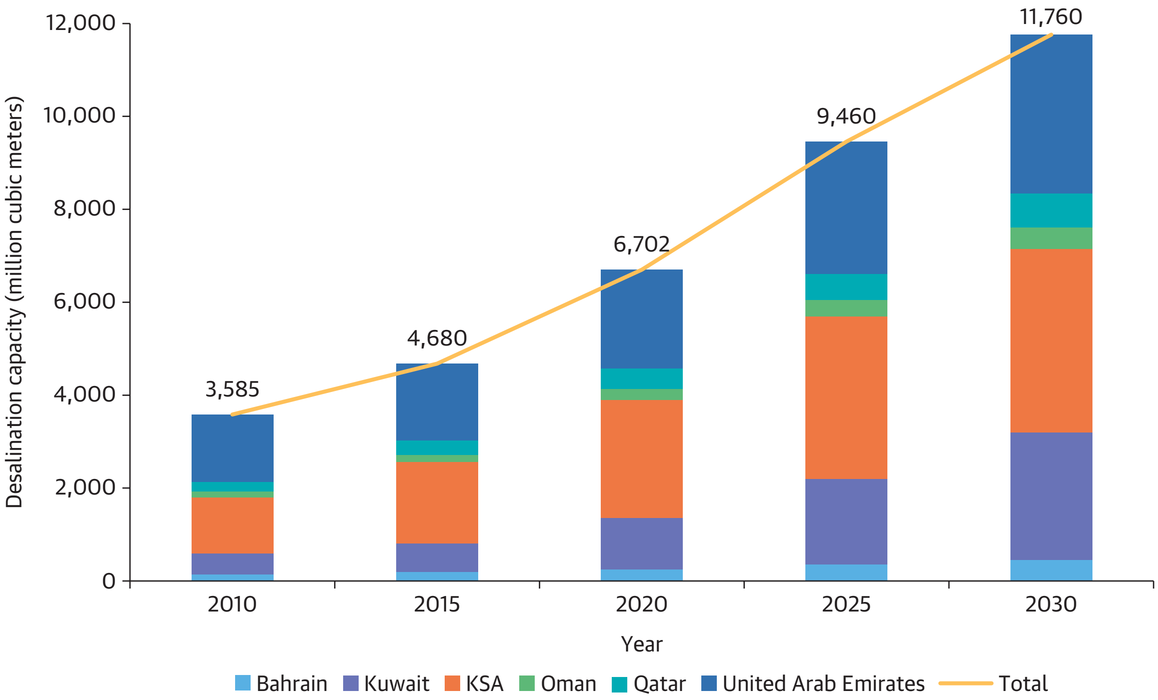
As GCC countries continue to deplete groundwater sources, desalination often becomes even more the default option (see Figure 4.3). From 2014 through 2018, the volume of water desalinated in the GCC increased 18.7 percent, to reach 8.4 billion m^3. More than half (56 percent) of the region's production comes from Saudi Arabia; the remainder, by country, varies based on the availability of groundwater, the size of the population served, and the level of industrial development.

4.3 Desalination Is an Expensive Process That Puts the Environment at Risk

Technology's benefits come at a high price. There are several enormous costs associated with desalination. First, consider the oil and gas consumed in production have both opportunity costs and in-situ value. Next, calculate the financial resources and electricity cost at every stage in the operation of the water system—filtering, production, transmission, treatment, distribution, and reuse—most of which involves subsidies. Not least are the environmental costs of pollution, whether at sea, in thermal and brine discharge into coastal ecosystems, or in the air, as emissions from the burning of fossil fuels impact human health and destabilize the climate.

Yet energy intensity and related costs vary by desalination technology. The GCC deploys both thermal types, multi-stage flash distillation (MSF) and multi-effect distillation (MED), as well as membrane reverse osmosis (RO). Thermal desalination technologies are designed as part of cogeneration power desalting plants, which are characterized by high energy intensity. One robust analysis in the eastern region of

FIGURE 4.3. **Present and Future Desalination Capacities in GCC Countries, 2010–30**



Source: GCC Cooperation Council, Desalination Statistics 2017.

SaudiArabia (where desalination capacity is high) estimated MSF plants to be by far the most energy intensive among other desalination technologies, consuming 74 percent of total energy input (table 4.1).

Historically, thermal technologies (i.e., MSF and MED) have dominated the water sector, and are used in 77 percent of all plants across the GCC region. More recently, the region has been shifting to embrace 200 less-energy-intensive RO technology plants[3] with plans to add 38 more by 2030. RO will then comprise more than 35 percent of capacity. Decoupling electricity production from water production not only reduces operational and opportunity costs, but can also relieve energy intensity, cut GHG emissions, and encourage renewable and nuclear technologies as a cleaner alternative to fossil fuels in desalination.

Energy consumption can be broken down by the water cycle's components. Recent studies calculated the energy used in Bahrain's municipal water supply sector. The analysis used a bottom-up approach to collect data at the main stages: water production, transmission, distribution, as well as wastewater collection, treatment, and reuse (Alsabbagh et al. 2021). It found (figure 4.4) that water production, that is, desalination,[4] consumes 88.5 percent of all energy required, or eight times all the other stages combined.

A benchmark comparison against global best practices led Bahrain (and by extension other GCC members) to focus on energy efficiency at the production stage, since that is where most losses occur (Marzooq, Alsabbagh, and Al-Zubari 2018).

For the remaining stages, energy consumption depends on the length and diameter of the pipeline. As noted earlier, long before Riyadh can pump water through its extensive distribution network serving 7.5 million people, the city would first need to lift the desalinated water 600 meters above sea level and 500 kilometers inland from the coast. The cost and energy required for that journey (5 kWh/m^3) is five times higher than conveyance to nearby cities in the Eastern Province, like Dammam (0.87 kWh/m^3), which lie at the same elevation (see table 4.2).

4.4 Treated Wastewater Is an Underutilized Resource

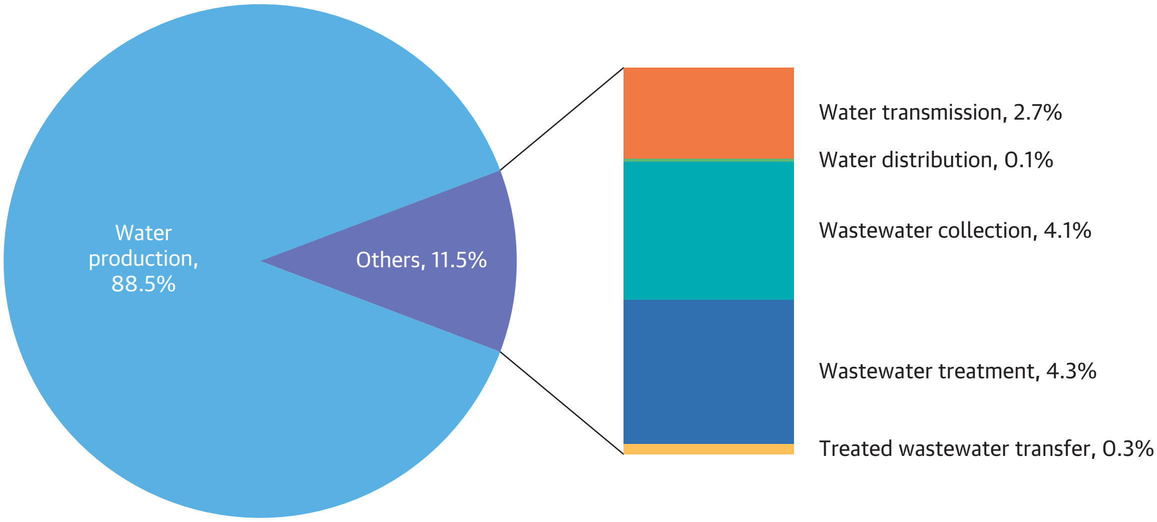
The high cost of water's energy footprint also reveals a large opportunity. Wastewater treatment and reuse are environmentally friendly and financially sound. They are also becoming indispensable for meeting the staggering water demand in certain regions, especially under conditions of alarming water scarcity.

TABLE 4.1. Electric Energy Consumption of Water Production through Desalination at Saudi Arabia's Eastern Province, by Technology (GWh)

Desalination technology	Gigawatts (% of total)
Thermal technology: multi-stage flash (MSF) distillation	19,339 (74.4%)
Thermal technology: multi-effect distillation (MED)	6,458 (24.8%)
Membrane technology (MT): reverse osmosis (RO)	211 (0.8%)
Total	25,008

Source: Zubari 2021.

FIGURE 4.4. Electricity Consumption for Water Supply in Bahrain



Source: Alsabbagh et al. 2021.

TABLE 4.2. Electric Energy Consumption for Desalination and Transmission in Eastern Saudi Arabia (year 2013)

Process	Gigawatts	kWh/m³
Desalination operation	25,977	41.5, 39.5, 7.4 (MSF, MED, RO)
Desalinated water transmission to Eastern Province cities	281	0.87
Desalinated water transmission to Riyadh	1,407	4.2
Total transmission (to Eastern Province cities and Riyadh)	1,688	5
Total desalinated water production and transmission	27,665	

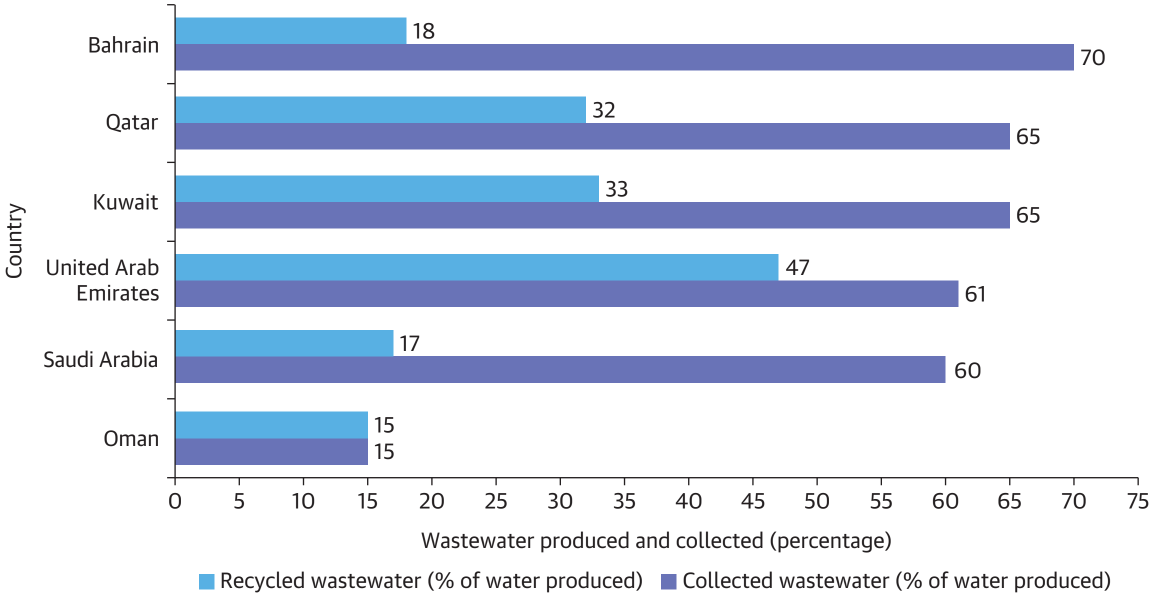
Source: Al-Mutrafi et al. 2018.

Reused and treated wastewater will relieve costs of, and harmful pressures from, both desalination plants and groundwater extraction. The GCC countries have long made wastewater treatment a priority research area, especially if applied to agriculture. Yet when it comes to actual implementation, reuse of treated wastewater is still in its early stages. Only half of the tertiary treated water is recovered and reused on land; the rest still flows out to sea.

Behind the Lost Opportunity

Failure to recycle wastewater (see figure 4.5) is puzzling given the region's high potential (Ouda 2015). Indeed, the gap between wastewater treatment and its productive reuse is unrelated to capacity. Treated wastewater was introduced four decades ago. All six GCC countries have achieved commendable rates for sanitation services, and cities have built sewage water treatment facilities and networks. As a result, relatively large volumes of treated wastewater are available. Some have been treated completely or

FIGURE 4.5. **Collected and Recycled Wastewater (% of Wastewater produced)**



Source: World Bank 2017.

Note: Failure to collect wastewater results in contamination of aquatic environments and freshwater supplies. Failure to recycle wastewater is a missed opportunity to augment water supplies.

partially regardless of their utilization. Yet of all the treated wastewater that is available for reuse, very little is being recycled to its full potential.

Constraints include lack of policy, inadequate investment, and the cost of technological uptake. The GCC region's comparatively low rate of wastewater treatment is due to the limited coverage (60 percent) of the sewage network in the main cities. GCC countries have begun planning but can more rapidly scale up efforts to meet water requirements, starting with green cover, public landscaping, and agricultural options. Overall, treatment has not kept up with high urban growth rates (Aleisa and Al-Zubari 2017) (table 4.3).

Much of this gap is due to lack of demand. Most recycled wastewater goes toward urban landscapes, to irrigate gardens, parks, and roadway margins and dividers. More than a third of the treated wastewater irrigates nonfood crops and livestock fodder. Given the long-term potential, this represents a modest start. To reach zero discharge, with full use of all produced treated wastewater, the GCC would have to invest $2.2 billion into infrastructure for the wastewater transmission (pipes, pumping stations, and storage tanks) and distribution network. The estimated cost for annual operation and maintenance across the GCC region (table 4.4) is about 10 percent of the capital cost (Dawoud 2021a).

Energy needed for wastewater treatment:

Wastewater collection, treatment, and reuse and/or disposal also require energy. Energy consumption for these efforts will again vary by location, volume, and system design. Most wastewater treatment

TABLE 4.3. Treated Wastewater Production and Use in GCC Countries

Country	TSE production (MCM)			Reused	Discharge to environment
	2010	2015	2025 (plan.)	2015	2015
Bahrain	81	102	150	31	72
Kuwait	254	290	420	189	102
Oman	39	84	125	67	17
Qatar	104	160	230	64	96
Saudi Arabia	712	812	1,200	487	325
United Arab Emirates	352	587	900	264	323
Total	1,542	2,034	3,025	1,101	933

Source: Dawoud 2021a.
Note: TSE = treated sewage effluent; MCM = million cubic meters.

TABLE 4.4. Estimated Costs to Fully Utilized TSE in GCC Countries

	TSE volumes, 2015 (MCM)			
Country	Production	Reused	Discharge to environment	Estimated Cost for 100% Utilization ($ millions)
Bahrain	102	31	72	113
Kuwait	290	189	102	320
Oman	84	67	17	93
Qatar	160	64	96	176
Saudi Arabia	812	487	325	895
United Arab Emirates	587	264	323	647
Total	2,034	1,101	933	2,243

Source: Dawoud 2021a.
Note: TSE = treated sewage effluent; MCM = million cubic meters.

plants need energy for pumping the effluent with air, as well as for mixing and chemical dosage. Energy intensity values also depend on plant size, treatment level, and technology (see table 4.5).

Costs of renewable energy also depend on the rate structure for electricity tariffs. At current transmission and distribution costs (US$0.08/kWh), renewable energy could meet one-third of this need. Accounting for costs to build and operate (US$0.016/kWh), renewables meet more than half of this need; including a feed-in tariff (US$200/megawatt-hour), renewables would cover three-quarters of this need.

One constraint on the reuse of treated wastewater is the distance between urban supply and rural demand (Zekri 2020). If a densely populated city is relatively close to large, irrigated areas, the performance outcome will improve, sometimes dramatically. Here, the potential water-energy nexus opportunity is too high to ignore.

TABLE 4.5. Wastewater Treatment Plants' Energy Consumption by Plant Size

Plant size (m^3/d)	Electric energy consumption (kWh/m^3)		
	Primary	Secondary (activated sludge)	Tertiary (advanced wastewater treatment)
3,785	0.479	0.59	0.686
18,925	0.258	0.362	0.416
37,850	0.255	0.318	0.372
75,700	0.198	0.294	0.344
189,250	0.182	0.278	0.321
378,500	0.177	0.272	0.314

Source: EPRI 2002.

Another consideration is technology. If less capacity is required, simpler treatment technologies are more cost-effective. Low-energy, low-cost technologies for domestic wastewater treatment include intermittent sand filters and rotating biological contractors. In sum, proximity, capacity, technology, and irrigation usage all shape the contours of treatment and reuse (Zekri 2021).

Finally, there are economies of scale. Studies estimate total electricity consumption by all wastewater treatment plants adds up to 117.4 gigawatts. When possible, larger plants are better. Based on studies of activated sludge for secondary treatment, expanding plant capacity tenfold can halve energy requirements per unit.

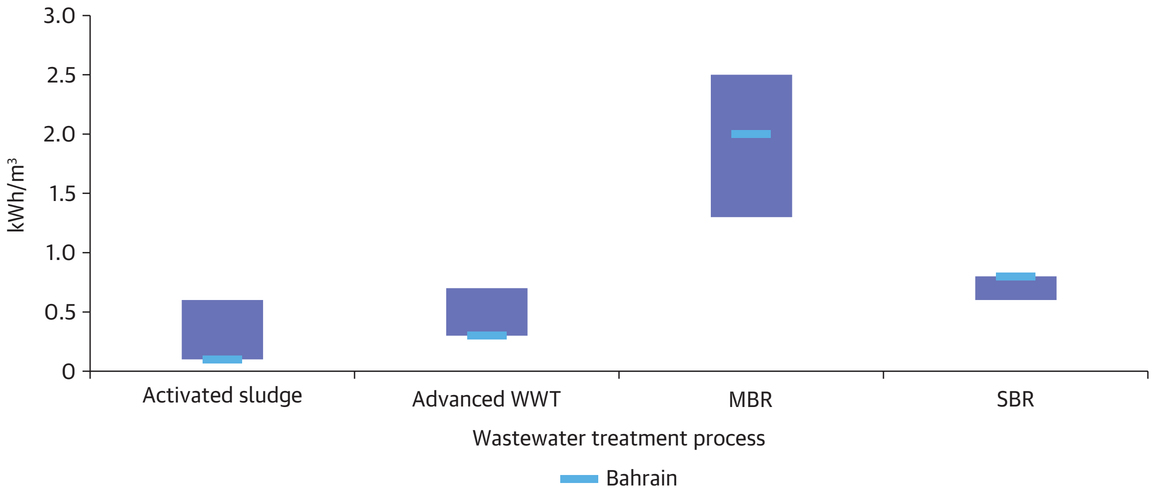
It also helps to consider energy demand across alternative uses in the water sector. The energy consumption from treating wastewater represented only 0.42 percent, while energy consumption for desalination represented more than 92 percent. When benchmarked against the global best practice, both values were equal, and in some cases better (figure 4.6). However, there were variations among the GCC members, and between technologies. In Bahrain, comparing membrane bioreactor (MBR) and sequencing batch reactor (SBR) technologies, energy intensity is at the higher end of the international best practice. This emphasizes the need to include energy intensity as an important criterion in the technology selection process for wastewater plants.

4.5 Actions Needed to Expand the Use of Treated Wastewater

Given the high energy costs of desalination, and its other negative impacts, GCC countries may choose instead to prioritize wastewater treatment and reuse as an indispensable alternative (Aleisa and Al-Zubari 2017). Customized, effective policies for wastewater treatment and reuse have been shown to alleviate both groundwater depletion and degradation due to saltwater intrusion.

In the GCC's agricultural sector, the ratio of treated wastewater to freshwater withdrawals averages 9 percent. Low utilization rates are often blamed on physical constraints: fluctuations in the effluent quality, overloaded plants, contaminated inflows, and insufficient distribution infrastructure. Yet human taste and public policy also play a limiting role. Needlessly restrictive reuse standards and

FIGURE 4.6. Comparison of Specific Electrical Energy Use in Wastewater Treatment Plants in Bahrain with Existing Wastewater Treatment Related Processes in Countries Worldwide



Source: Zubari 2021.
Note: WWT = wastewater treatment; MBR = membrane bioreactor; SBR = sequencing batch reactor.

people's repugnance inhibit widespread adoption of wastewater reuse. So, despite commendable efforts to promote efficient energy consumption, the most important barrier by far to advancing sanitation, wastewater treatment, and services is the absence of legislation.

To overcome that shortcoming, the GCC might consider further recommendations to:

a. Galvanize political support and legal frameworks

Governments can secure broad political and social support for the reuse of treated water through a robust legal and regulatory framework. Specific responsibilities may focus on planning, financing, implementation, operation and maintenance, and monitoring of sewage plants.

b. Analyze the most effective policies

Sustainable investments will design, construct, operate, and maintain sewage infrastructure using the most water efficient and environmental technologies. Decision-makers can prioritize treated water redistribution projects, given their positive impacts on economic productivity as well as on water and food security, and incentivize privatization of wastewater treatment loans, credit guarantees, tax exemptions, and other financial benefits.

c. Enforce rules and regulations

Governments may also choose to increase penalties and crack down on illegal discharge of untreated wastewater into coastal waters, valleys, and deserts.

d. Reduce municipal consumption

Officials might gradually increase municipal water supply tariffs or penalize users who refuse to pay overdue bills. They may introduce and raise sewage collection charges in proportion to consumption, an approach that has proven to reduce demand in Oman, or expand advanced farming technologies, such as drip irrigation, which can dramatically lower agricultural consumption. Incentives can encourage installation of water-saving toilets, faucets, showerheads, timers, and nozzles.

e. Launch public awareness campaigns

The most effective outcomes involve many stakeholders. Water conservation, tariff increases, and recycling require broad-based acceptance. This means educating families and firms about health benefits, energy gains, or environmental impacts. Public outreach campaigns work best when they are designed to be interesting, enriching, interactive, and fun.

f. Invest more in wastewater research and development

Change rarely happens in a research vacuum, and knowledge-generating activities deserve support. Officials may assess and evaluate regional standards for wastewater treatment and reuse, and conduct field studies to select the most suitable sites for water treatment, based on availability, population density, wind direction, and distance from service areas to the aquifers that could be recharged. To expand reuse options it is important to upgrade efficiency of the tertiary treatment and quality of the RO technology, update standards of reclaimed water for agriculture, and test wastewater inflows to treatment plants to ensure compliance with chemical and biological standards.

g. Reevaluate sludge as a potential resource asset

Sewage sludge can become an asset, with energy recovery rates of 60–80 percent. By deploying microbial technology, wastewater treatment plants can generate power or at least recover energy from sludge. Clean technologies allow plants to exploit bacteria to produce electricity that could help operate the sewage plants themselves, closing the loop.

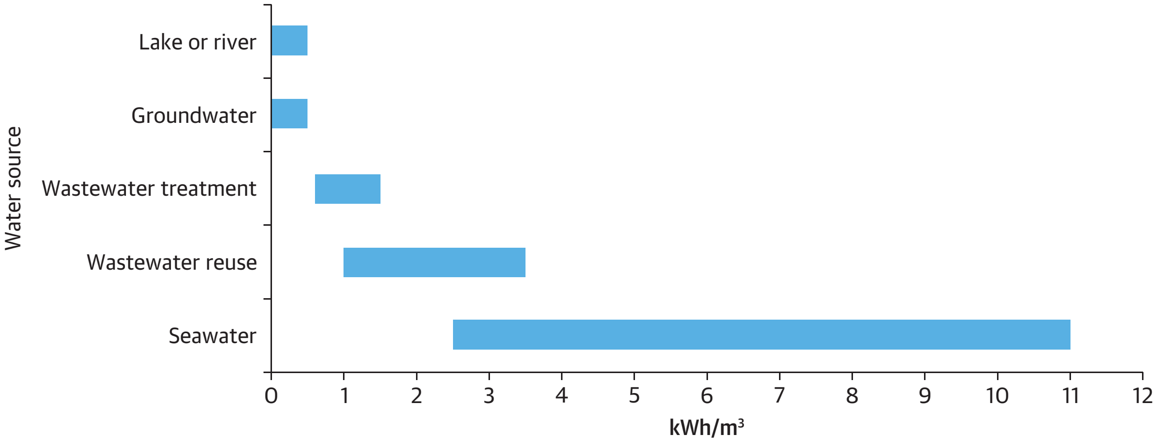
4.6 Summary of Energy Consumption, by Water Cycle Phase

Production of any source of clean water requires energy. But seawater desalination (figure 4.7) demands far more energy than others. In the coming decade, GCC countries are on track to desalinate 9 billion m^3 of water from the Gulf and the Red Sea. Doing so will significantly elevate energy needs and financial investments, as well as costs of mitigating air and water pollution, and of adapting to the climate change risks that are already underway.

4.7 Advances in Renewable Energy Hold Potential for Large-Scale Clean Desalination

The International Renewable Energy Agency (IRENA) is promoting the adoption of renewable technologies for desalination. A recent report by IRENA describes limited progress in achieving this objective, but the high costs of energy could shift the equation (IRENA 2016).

FIGURE 4.7. Energy Required to Provide One Cubic Meter of Water Safe for Human Consumption from Various Water Sources



Source: UN Water 2014.
Note: This does not consider the distance the water is transported.

To meet rising water demands, GCC countries will ramp up their desalination infrastructure by 6-10 percent annually till 2040. If powered entirely by hydrocarbons, long-term desalination production could eat into the share of domestic energy, reduce oil and gas exports, and require costly imports.

Each day, Saudi Arabia burns 300,000 barrels of oil for thermal desalination alone; Kuwait suffers the same dependency, albeit on a smaller scale. Modern desalination also burns natural gas. Qatar's desalination energy needs, combined with its domestic electricity generation, redirects larger shares of natural gas away from exports and to domestic use. Among natural gas importers, such as the United Arab Emirates, desalination raises costs and concerns about energy security.

These realities elevate two pillars of an emerging long-term desalination infrastructure strategy. The first is to consider adoption of energy-efficient technologies like RO. The second suggests a transition toward renewable energy resources. Abundant sunlight, combined with falling costs, make renewable energy technologies a reliable, affordable, and sustainable energy source. Adopting renewables in the Gulf would decouple water supply from fossil fuel availability and price volatility. In the long term, solar and wind energy could supply all the energy required to run the Gulf region's entire desalination infrastructure.

For more than a decade, researchers have evaluated new tools and efficient technologies to reduce energy consumption required for desalination. Many options hold potential, but few are ready for full-scale commercial adoption. Yet in off-grid and remote areas, renewable-energy-based desalination solutions are cost competitive with diesel-based water production, accounting for the fuel's opportunity costs. For round-the-clock operations, photovoltaic (PV)-diesel hybrids are 10 percent more cost effective (USD 2.0/m3) than systems powered by diesel alone (USD 2.2/m^3).

Of course, renewables thrive only on a level playing field. Benefits from solar assume a diesel price of US$0.70/liter and a levelized cost of energy from solar PV at US$0.9/kWh. To put these numbers in context, Saudi Arabia prices diesel at US$0.17/liter and the United Arab Emirates charges US$0.50/liter. Saudi Arabia started the Energy Price Reform (EPR) program in 2016 to stimulate a rational consumption of different energy products, encourage energy mix optimization, and redirect incentives. The EPR program also focuses on fostering innovation in productivity and implementing demand-side management practices. The reform has been implemented gradually according to a long-term plan, which is continuously evaluated and monitored on a periodic basis to ensure balanced socioeconomic conditions. However, and as a global comparison linking back to benefits from solar power, diesel in European countries runs to more than US$1.0/liter. While reforms are ongoing, the GCC's artificially low energy prices delay or prevent investments in scaling up the most cost-effective renewable energy technologies.

Given low regional diesel prices, the GCC is unlikely to adopt solar desalination as a purely market-driven rationale. But as Oman has demonstrated, market dynamics shift as countries reform energy pricing, and as public utilities seek small-scale, off-grid solutions for remote communities and special zones. Under these conditions for rural locations, wind and solar offer a competitive alternative to, combination with, or substitution for diesel. Renewable-energy-based desalination remains early stage. Further cost reductions from technological innovations—advances in generation of energy and of water—may elevate the potential for solar desalination even at larger scales.

Saudi Arabia has embarked (box 4.1) on the world's first large-scale solar desalination plant. GCC members will continue to lead all nations in design and capacity to better integrate renewable energy technologies with water production. Further, the GCC region has invested in a series of small-scale pilot projects, which test and enhance the overall reliability of the grid through improved demand response. Seizing this opportunity, Masdar in the United Arab Emirates has been working with industrial partners to develop more sustainable desalination technologies (IRENA 2016). It is far from alone.

4.8 Water Pricing Distorts Consumption and Hinders Efficiency

All GCC countries base domestic water bills on metering and volumetric usage. But within the region, the tariff structures, value, and prices charged for water vary by country (see table 4.6 and box 4.2)). Bahrain, Oman, Saudi Arabia, and most of the United Arab Emirates have adopted a progressive block price system (see box4.1 on Oman's reformed tariff system), whereas Kuwait, the Abu Dhabi emirate, and Qatar use flat rate structures.

Further, the United Arab Emirates and Qatar exempt 11 percent and 14 percent (respectively) of national citizens from municipal water charges. These 1.5 million water users—who tend to be the wealthiest segment—are provided free access to limitless water. Free water combined with high income results in the world's greatest water usage—exceeding 500 liters/capita/day in Qatar, the United Arab Emirates, and Kuwait. It is also difficult to address. Yet a recent Abu Dhabi demand management study found that raising the water tariff on all categories of consumers was less efficient than offering targeted subsidies.

BOX 4.1. Public-Private Partnerships with Well-Defined Targets Can Achieve Environmental Guidelines

While several GCC countries are investig in solar desalination, few have gone further than Saudi Arabia.

In January 2009, the King Abdullah City for Science and Technology (KACST) officially launched the initiative and began working with IBM to develop nanotechnology that would use solar energy in the operation of desalination plants. Three years later, Saudi Arabia's Saline Water Conversion Corporation (SWCC) agreed to research solar desalination with the Hitachi Zosen Corporation. It also signed a memorandum of understanding with the Dow Chemical Company to jointly pursue research and development in desalination technologies, following Dow's plans to start manufacturing reverse osmosis membranes in the country.

To expand water sufficiency in 2018, the KACST's subsidiary Advanced Water Technology (AWT) embarked on a large-scale, $130 million solar desalination plant. Located in the northeastern city of Al Khafji, this 15 megawatt plant aims to quench the water needs of 100,000 people and yield up to 60,000 cubic meters of water each day. This emissions-free source of water production would also be free from volatile oil price spikes (US Saudi Business Council Report 2021).

Looking ahead, Saudi Arabia has signed power purchase agreements with seven more solar projects, which will provide electricity to more than 600,000 households.

These and other renewable energy projects demonstrate the country's priorities to optimize its energy mix and its plan to meet half the kingdom's electricity needs with renewables by 2030 (Saudi State News Agency SPA 2021).

Only in 2016 did Saudi Arabian authorities reform tariffs, which until then provided water almost for free. In fact, it cost less to receive 1,000 liters delivered to the home than to buy a one-third liter bottle of the same water from a store. Still, even after reforms, the price of domestic water remains among the world's lowest and covers only a third of the actual estimated production costs (US$3.1/m3) for water and sewage services (KSA 2018). Domestic water's below-cost price resulted in excessive urban consumption (GWI 2017) of 263 liters per capita each day (KSA 2017).

Low water rates can allow or encourage waste on both sides of the meter. Beyond end user consumption, leaks in the distribution system reached 25 percent with few efforts to recover the lost water (KSA 2020). The situation is hardly unique to Saudi Arabia. Throughout the GCC, low and below-cost water prices lead water utilities to finance operations through high government subsidies. In 2015, Saudi Arabia's revenue from domestic water bills covered only 7 percent of the estimated marginal cost of the domestic supply. Cheap water encouraged careless habits and a level of comfort with high consumption. When the country tried to reform water pricing, it proved unsuccessful (Ouda 2013).

TABLE 4.6. **Fresh Water Prices and Structures per Country**

Country/price structure	Blocks/category	Block per month (m^3)	Price (US$/$m^3$)	Remarks
Bahrain				
Progressive Block	1	<60	0.07	Different price is applied for nondomestic users: restructured in 2013 to reflect energy prices to recover the full cost of water supply.
	2	61–100	0.21	
	3	>100	0.53	
Kuwait				
Flat Rate	n.a.	n.a.	0.626	For piped residential, government, and commercial users; tankers US$0.22/$m^3$ and industrial US$0.18/$m^3$.
Oman				
Progressive Block	1	1–23	1.43	Different price for commercial (US$2.34/$m^3$), industrial (US$2.57/m^3), and government (US$2.34/$m^3$) users.
	2	>23	1.72	Prices do not include wastewater treatment and fixed monthly fees.
Qatar				
Flat Rate	Nationals	No limit	Free	Different price for commercial (US$1.42/$m^3$), industrial (US$1.64/m^3), and government (US$1.92/$m^3$).
	Nonnationals	Flat	1.2	
KSA				
Progressive Block	1	1–15	0.03	The same price structure applies for industries using the network.
	2	16–30	0.26	
	3	31–45	0.80	
	4	46–60	1.07	
	5	>60	1.6	
United Arab Emirates				
Flat Rate (Abu Dhabi Emirate)	Nationals	No limit	Free	Price for nonnationals is also applied for commercial and industrial consumers.
	Nonnationals		0.6	

Source: United Environmental, Unified Water Sector Strategy and Implementation Plan for the Gulf Cooperation Council of Arab Member States (2015–35); and Zekri (2021) for Saudi Arabia the data comes from: https://www.nwc.com.sa/Arabic/Pages/NewTarrifCalculator.aspx.

Perhaps reforms came too fast and too steep. Suddenly, monthly water bills spiked tenfold, generating an unprecedented public backlash until their repeal (Mcilwaine and Ouda 2020). Even so, these modest reforms were hardly onerous. The first water rate block/slab still charged no more than US$0.04/m3, and the second (up to 30 m3/month) was only US$ 0.4/m3. That meant the average household (6.4 people) could still consume up to 156 liters/capita/day with almost no incentives to conserve.

Even with higher rates, utilities still recovered only 30 percent of the costs of production. Moreover, since prices remain level throughout the country, Riyadh families enjoy even higher subsidies than those in the coastal areas, due to the much higher cost of pumping water 500 km inland, and 600 meters uphill (Zekri 2021).

BOX 4.2. Oman's Reformed Tariff System, Supported by Targeted Subsidies, Ensures Efficient Use and Equitable Access for Vulnerable Households

GCC governments face a difficult challenge of how much to charge for natural monopolies such as water, fuel, and electricity. If priced too low, these essential resources are all too often wasted and depleted; priced too dear, low-income families will struggle to afford access, and protest.

Oman has developed an advanced online National Subsidy System (NSS) that offers the region a creative new approach that ensures provision is both economically efficient and socially equitable. The NSS establishes three bands, or tiers, in which prices correspond directly to electricity consumption. So, rising demand translates to higher charges per unit. This efficient billing structure is combined with targeted subsidies that lower electricity bills for needy families, based on a household's income and size.

Households become eligible if they earn less than $1,300/month (regardless of family size), or support nine or more people (and earn less than $3,250/month). Similarly, eligible families receive fuel cards that allow households to purchase 400 liters per month of fuel for approximately 25 percent below current prices, saving up to $50/household/month.

The single-point registration process is simple, fast, and transparent. Households must register for these targeted subsidies by entering their name, ID number, address, job, household size, and car plate number into the website. The NSS checks eligibility, and links to the corresponding meter.

While currently limited to fuel and electricity, the Omani government plans to extend the NSS to water bills once new prices have been established. By identifying eligible Omani nationals who meet the eligibility criteria, the NSS offers deserving households a protective cover against rising costs of essential resources.

The government connects data sets shared among the Royal Police, Social Development Ministry, Authority for Public Services Regulation, and the electricity distribution company (Oman Water & Wastewater Services Company).

Low-income expatriate and foreign households deserve equally fair treatment. Going forward, the system unifies the electricity bands to include all residential category accounts for citizens and nonnationals alike, eliminating any differences in pricing. Oman's experience can be generalized and replicated by all GCC members to relieve criticism of the rising price of essential resources.

Source: Zekri 2021.

Notes

1. The municipal sector refers to water supplied through the municipal water distribution network; it includes domestic (i.e., household), commercial, and tourist venues, as well as government buildings, etc. In the GCC countries, the domestic sector is the major consumer of municipal water supply.
2. In many GCC countries, groundwater cannot be used directly for municipal/drinking water supply. Groundwater quality either does not meet the quality standards for drinking water or is deteriorating due to overexploitation.
3. Thermal technologies include multi-stage flash distillation (MSF), multi-effect distillation (MED), vapor compression distillation (VCD), membrane technology (MT), reverse osmosis (RO), and electrodialysis (ED).
4. Groundwater utilization in in Bahrain's municipal water supply is negligible.

Chapter 5
How Environmental Risks Undermine the Water-Energy Nexus in the GCC Region

5.1 Desalination Negatively Impacts Marine Ecology and Water Quality

The GCC can improve the sources, intensities, and efficiencies of energy that go into the desalination process. But it can also mitigate environmental threats by the byproducts that come out of it. While desalination pumps clean drinking water into one pipe, toward cities, it discharges hypersaline waste effluent through other pipes into the Gulf, where it impacts marine ecosystems.

The quality and quantity of brine discharge vary by source and technology. From every cubic meter (m^3) of seawater that goes in, reverse osmosis (RO) recovers 42 percent potable water, and the 58 percent of brine discharged is saltier and cooler. Thermal technologies recover just 22 percent, generating more and hotter but less saline brine waste. Both impact marine species' composition, density, and abundance (Ihsanullah et al. 2021).

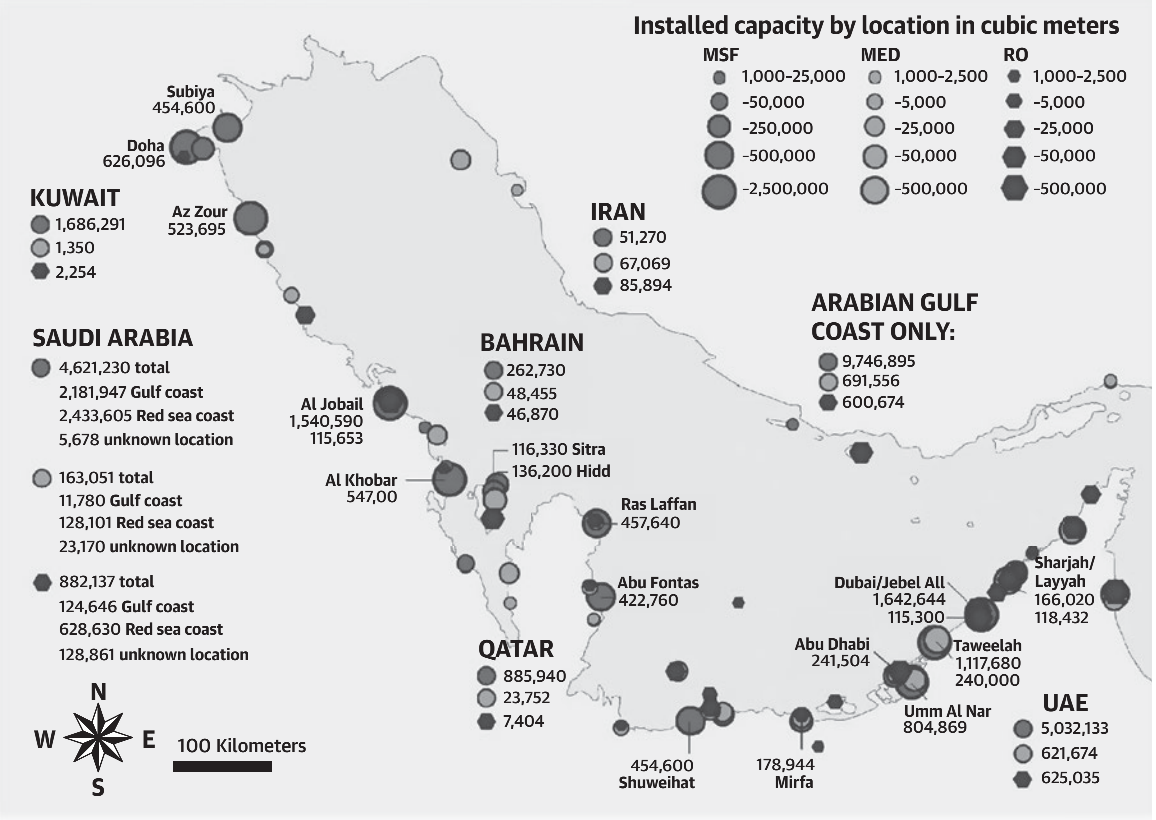
Desalination is not the only threat to marine ecosystems. Oil and gas production also empties effluents into the Gulf. Local industrial discharges exacerbate larger geographic threat multipliers to this comparatively warm, shallow, and semi-enclosed saline water body. It is difficult to dilute or disperse waste discharges, especially upstream; irrigation and dams on the Tigris and Euphrates (historically the Gulf's only meaningful freshwater source) slow inflows to a trickle.

All these stressors make the Gulf about 15 percent saltier than other ocean bodies (World Bank 2019), and local hotspots double or triple the average salinity. One or two small plants might have a negligible impact, but today more than 220 desalination plants ring the Gulf, producing about 6 billion m^3 of water each year (see map 5.1). Assuming an efficiency ratio of 0.040, the Gulf absorbs the influx of approximately 10-12 billion tons of brine each year (Dawoud and Al Mulla 2012).

Hypersaline brine harms the living biodiversity of marine ecosystems in subtle but lasting ways. Basin buildup of the salt in brine threatens potable water supply. As a rule of thumb, rising salinity makes desalination more difficult, requires additional effort, consumes more energy, and drives up costs. Several studies have raised concerns about the sustainability of seawater desalination and its future impact on the salinity and marine ecosystem of the Gulf basin (Elimelech and Phillip 2011).

To safeguard future water supplies and marine life, the region may seek to manage brine in ways that limit the negative environmental impacts and reduce the economic cost of disposal. New and existing water and energy infrastructure projects can be evaluated for potential environmental impacts of discharge, with adverse effects mitigated as far as possible (Jones et al. 2019).

MAP 5.1. **Desalination Capacity in the Shallow Gulf**



Source: Dawoud and Mulla 2012.
Note: MED = multi-effect distillation; MSF = multistage flash; RO = reverse osmosis.

5.2 How Regional Policies Can Address Mounting Environmental Risks of the Water-Energy Nexus

The volume of water produced by the Gulf's desalination plants has ramped up sharply, from 40,000 m^3/day in 1970 to 21 million m^3/day in 2018. This rapid rise has negatively impacted ecosystems on land, at sea, and in aquifers, while raising greenhouse gas (GHG) emissions in the air.

The Gulf's coast is characterized as sedimentary. That territory provides a natural habitat for plant and animal species of high concern for international conservation such as mangroves, coral reefs, and seagrasses. These habitats provide shelter and food source for fish and marine mammals. Sensitive to sudden shocks from desalination, many species are in decline, while others face extinction.

Desalination impacts vary by timing, cause, species, and location (Zekri 2021). Brine discharge causes more damage in summer than in winter. Mass bleaching of coral reefs is observed whenever seawater temperatures are 1.5–2.5°C above current normal summer conditions. The combination of higher salt, heat, chemicals, and climate change bring a cascade of damage to the Gulf's marine environments. Elevated temperatures lower the capacity of seawater to hold oxygen, causing mass fish die-offs above 35°C and seagrass reduction above 37°C, driving off even cold-blooded sea turtles.

Brine discharge mixing zones can be literal "hotspots," where salt levels concentrate another 3-6 parts per thousand (ppt). Gulf salinity averages 40-41 ppt (Ibrahim, Xue, and Eltahir 2020), rising along Qatar's east coast to 45 ppt and reaching 57 ppt on its west. Reports project salinity will reach 70 ppt in low-flushing and shallow embayments. A study by 24 authors documented the extent to which stress caused by rising heat and salt result in multiple and complex disruptions that deteriorate all natural benthic habitats, and the food web that depends on them (Sheppard et al. 2010).

5.3 The Desalination Industry Can Monitor Brine Disposal and Develop More Innovative Solutions to Its Waste Effluent

Damages from elevated salt levels are not confined to the sea. Threats to marine species offshore raise concerns about sustaining the needs of our own species on land. GCC members can ramp up efforts to monitor and solve the challenge of brine disposal.

The search for more responsible solutions has led researchers to weigh two options: zero liquid discharge and brine mining. Both seek to recover large volumes of fresh water and produce different solid salts. Zero liquid discharge technology involves a combination of multi-effect distillation and evaporative crystallization to brine treatment. The system can desalinate water at higher salinity levels and eliminate effluents. That is a positive development for the marine environment, but its more intensive use of energy drives up costs to an estimated US\$4.17/m^3 (Zekri 2021).

Still, hybrid systems that use larger membrane areas reduced brine concentrations from 41 to 34 percent. Technological progress—in reverse osmosis, electrodialysis, and nanofiltration—may bring down costs over time, yet economies of scale also play a role in determining which technology to adopt in new locations. A recent study reviewed the costs, impacts, needs, and benefits of existing technologies that could mitigate the environmental damage from brine discharge (Panagopoulos and Haralambous 2020). The results ranged from the lowest cost (ongoing discharge of brine into the sea) at US\$0.05-0.30/m^3, to the highest (brine evaporation on land ponds with salts recovery) at US\$3.28-10.04/m^3. Each method has risks, and causes different kinds of environmental impacts, to air, land, soil, aquifers, or marine life (Cipolletta et al. 2021. See also table 5.1 and box 5).

Such analyses help internalize hidden costs and push reforms and experimentation. Today, desalination technologies too rarely consider brine treatment, let alone seek zero or minimum liquid discharge. Still, possibilities are arising.

One near-term solution combines energy-intensive RO (forcing saltwater through membranes) with forward osmosis (using natural osmotic pressure to induce the flow of water through membranes by running a highly saline draw solution on the other side). Other innovations recover resources from brine at early stages. All these hold promise but require more research and trials before scaling up.

TABLE 5.1. Summary of Brine Disposal Methods and Costs

Method	Principle	Cost of Brine Rejected (US$/m^3)	Environmental challenges
Sewer discharge	Brine is rejected in a sewage collection system	0.32–0.66	Inhibition of bacterial growth in the wastewater treatment plant
Evaporation pond	Brine is evaporated in a pond and the residual salts are gathered	3.28–10.04	Groundwater pollution and soil salinization
Surface water discharge	Brine is rejected into the surface water	0.05–0.30	Marine environment pollution
Deep-well injection	Brine is injected into porous subsurface rock formations	0.54–2.65	Groundwater pollution and soil salinization
Land application	Brine is used in irrigation of salt-tolerant crops and grasses	0.74–1.95	Soil salinization

Source: Panagopoulos and Haralambous 2020.

BOX 5.1. Methods for Treatment and Management of Brine

Management of the Desalination Brine Solution

Surface water discharge: The brine, after being transferred to a disposal site, sheds into the desired aqueous medium through a special structure.

Discharge to the sewage system: The brine that is discharged into the nearby sewage collection system is called sewer discharge. Most of the small-scale brackish water desalination plants are using this method of discharge as the high total dissolved solids (TDS) content available in the brine can have a potentially negative impact on the receiving wastewater treatment plant.

Deep well injection: When the brine is injected into a deep aquifer beneath the groundwater layers, it is called deep well injection. The most important matter to be considered before the injection is to ensure that wastes are not leaked to other locations, and the capacity of the target aquifer is consistent with the plant life. Also, this aquifer should be hydraulically isolated from the surrounding porous media.

Application for land: The brine can be used for vegetation such as parks, golf courses, and lawn irrigation, and land application of the brine can be suitable to reuse water for these purposes.

Evaporation ponds: The brine slowly evaporates in shallow, arrayed earthen basins directly under the sunlight. When the freshwater available in the brine has evaporated, the solutes in the brine are precipitated and periodically removed from the site.

Conventional crystallizers: The brine contains some metals that can be recovered (an additional economic advantage), which is an attractive solution to avoiding disposal problems.

Source: World Bank 2019; Katal et al. 2020.

Knowledge of impacts and mitigating solutions is insufficient to mandate change. The GCC countries cannot continue to dump salty effluents into the sea at current rates; nor can the region curb brine disposal's environmental impacts without pain. Given available technologies, a policy requiring zero/minimum liquid brine disposal would substantially raise desalination costs.

5.4 Climate Change Is Disrupting the Habitats of All Gulf Species—Including Ours

A series of recent global and regional studies document how and where climate change will intensify impacts of and risks in the GCC region from the water-energy nexus.[1] The common denominators of these reports include escalating temperatures, falling precipitation, higher evapotranspiration, increased demand from families and firms, and rising frequency and intensity of extreme weather events, such as protracted droughts punctuated by flash floods.

More specifically, escalating heat and aridity in the region will increase demands for desalination, which in turn will further increase the water sector's utter reliance on energy. Higher temperatures elevate demand for freshwater from people and crops. Heat also reduces the efficiency of membranes in RO desalination. Lower precipitation will reduce the already limited groundwater recharge, while rising sea levels will intrude on and contaminate freshwater aquifers near the coasts.

As these factors worsen the current high levels of regional water scarcity, GCC members will be forced to meet demand through desalination and wastewater treatment, with negative impacts on the energy sector. In addition, as groundwater levels fall, water—weighing one metric ton per cubic meter—will have to be lifted from greater depths. Maxed-out well pumps working at full capacity will strain energy supplies even further (Zubari 2021).

To moderate risks and avoid the worst projected impacts, the GCC was urged to embrace long-term adaptation strategies. Climate adaptation goes beyond enhanced desalination capacity to advance wastewater reuse, develop strategic reserves, and aggressively pursue efficiency and water-demand management programs.

In 2017, the comprehensive Arab Climate Change Assessment Report was the first study to consider climate change impacts on water resources in the Arab region as a single geospatial unit. Based on two IPCC scenarios,[2] the report carried out regional climate modelling and regional hydrological modelling projections for the Arab region through 2100. It found that by the end of the twenty-first century, mean regional temperatures are expected to increase by up to 2.3°C (under the UN's low-end scenario) to 4.8°C (at the upper end). Mean temperatures will rise highest in noncoastal areas such as the central and western Arabian Peninsula. To provide greater insight into these implications, peak projections indicated that the number of very hot days of over 40°C will increase significantly across the Arab region.

For most of the GCC region, rising heat is unlikely to bring more rainfall. With a slight exception in the southeastern Arabian Peninsula, the report projected that precipitation trends will further decrease across the region. Again, this general precipitation trend is better understood by looking at projections of extreme climate indices, and at smaller scales of analysis. Such investigations of the Wadi Diqah River basin in Oman, among other basins,[3] suggest longer consecutive days of drought broken by a few days of intense precipitation.

Less rainfall will reduce surface runoff. Groundwater depletion will suffer from seawater intrusion. Yet the United Nations Framework Convention on Climate Change's vulnerability assessments of the region do not occur in a vacuum (box 3.1). GCC countries face a critical outlook of enormous stresses that go beyond climate impacts. Rapid population growth, urbanization, wasteful agricultural policies, inefficient distribution, rising costs, and irrational consumption patterns take place in a hotter, drier climate. The combined human and natural pressures are threat multipliers that undermine water security in the GCC.

The climate assessments do offer more than dire projections. Each report, taken together, calls on the GCC nations to prepare for severe impacts and adapt to the changing climate through a focus on water. Adaptive interventions encourage not just supply-side production (desalination, treatment, dams, wells, and aquifer recharge) but demand-side reductions. To ease the pain of scarcity, GCC members can design and develop more integrated water management plans, with a priority on efficiency. One measure of progress is the reduction of per capita water consumption; another, the reduction of leakage in the municipal distribution network. Outside cities, well owners can better control agricultural water consumption through irrigation efficiencies. Still other producers may choose to reuse treated wastewater, where appropriate.

BOX 5.2. The Climate Change National Communication Reports

In 1992, the United Nations adopted the Framework Convention on Climate Change (UNFCCC). Implemented two years later, this environmental treaty set out to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

Two decades later, the 2015 Paris Agreement established a global framework, timeline, and support mechanisms to strengthen countries' abilities to deal with climate change impacts already underway. As signatories to both the UNFCCC and to the Paris Agreement, all six members of the Gulf Cooperation Council can prepare "The Climate Change National Communication" reports, and submit their nationally determined contributions to reduce greenhouse gas (GHG) emissions.

These reports comprise four sections: (1) GHGs inventory, (2) GHG mitigation, (3) vulnerability, and (4) adaptation. The last two sections, vulnerability and adaptation, include the water sector. They describe how climate change threatens the water sector and how governments plan to alleviate these impacts and enhance resilience. The reports also reflect, in general, how countries prioritize the water topics and issues they have chosen to address.

Vulnerability assessments in the GCC countries may not address the water-energy nexus explicitly. Yet the nexus's presence, and implicit risks, are felt everywhere. A robust study by the Abu Dhabi Global Environmental Data Initiative (AGEDI) did investigate the water-energy nexus and found that climate change in GCC countries will bind linkages between the two resources even tighter. To project regional outcomes, AGEDI's assessment used two models. Water Evaluation and Planning (WEAP) modelled drivers of water demand and water supply by simulating policies, priorities, and preferences. Long-range Energy Planning (LEAP) modelled both energy supply and demand to capture the impacts of low-carbon development strategies. A combined WEAP-LEAP model was then used to evaluate the future performance of the integrated water-energy system under four climate change and policy scenarios. Each future yields different resource management options through the year 2060:

1. Under current management practices, given today's and future climate projections;
2. A "high efficiency" scenario in which each country gradually implements policies to reduce the consumption of water and electricity;
3. A "natural resource protection" scenario that secures resource efficiency, phases out groundwater extraction, and drastically reduces fossil fuel usage in favor of renewable energy; and
4. An "integrated policy" scenario that combines the second and third policy scenarios.

Most water demands can be met under any scenario that combines supply-side desalination and wastewater reuse, and that draws down regional fossil groundwater basins to extinction by 2060. Yet, to ensure sustainable development into the second half of the century, the region will grow more resilient if it pursues both demand- and supply-side policies in symbiosis.

Notes

1. For a detailed summary of the results of these reports, refer to Zubari and Alajjawi (2020).
2. Representative concentration pathways (RCPs) are GHG concentration trajectories of CO_2 equivalent (not emissions) in parts per million by volume, adopted by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5) in 2014. AR5 has four projections, titled RCP2.6, RCP4.5, RCP6.0, and RCP8.5.
3. See footnote 2.

Chapter 6

The Business Case for Nexus Research, Innovation, and Knowledge Systems

As GCC countries seek resource security and resilience, few options may drive higher yields than investing in technology and scientific inquiry. Recent World Bank studies (Cirera and Maloney 2017) have shown the value of new knowledge as a long-term national asset. Public investment in applied research and development (R&D) has evolved into a major component of any GCC country's intellectual infrastructure, which informs policy, guides decisions, and sparks innovation.

But investment in knowledge can selectively target and nurture regional issues at their root, rather than simply import generic institutions or policies from elsewhere. Several studies (Cusolito and Maloney 2018; Goswami, Medvedev, and Olafsen 2019) found that certain factors affect the accumulation of all types of capital—physical, financial, human, and knowledge—whereas underinvestment in R&D can erode or dissipate capital just as quickly.

Over decades, GCC countries have invested the bulk of funds for water and energy into pumps, pipes, dams, and desalination plants. Looking ahead, they can leverage existing "hard" infrastructure by investing in "soft" policy foundations, organizational structures, and institutional performance of the water-energy nexus on which the Gulf's regional economy depends.

6.1 Regional Cooperation in Supporting Field Research Is Urgently Needed, Especially to Monitor Water Quality in the Gulf Sea

To jumpstart knowledge investments, GCC leaders might choose to increase funding for cooperation among academic institutions, applied research, and robust field studies. Possibly the best starting point is the source of the water-energy nexus shared by all GCC countries: the Gulf itself.

Monitoring water quality along the shared coastline can inform local, national, and regional policies. Doing so may also limit or expand options for energy efficiency, and guide decisions about water allocation and delivery. And it could help prioritize the ultimate uses of the resource, for clean drinking water, tourism, service industries, manufacturing, or irrigation to produce food.

The GCC can support interdisciplinary regional research programs that assess these priorities in the context of water prices and subsidies, of food security and international trade, of efficient reuse, and of using recycled water to extract oil. Efficiency does more than save money. Reduced waste has environmental benefits and helps mitigate the oil industry's carbon footprint.

6.2 Allocate and Pool Funds for Water and Energy Programs

Too often, the region's current bureaucratic realities lack perspective. Working within silos, institutions cannot always capture how much each resource sector depends on the others. Climate change complicates this situation, skewing components of the water-energy-food nexus. More analytical work is needed to assess the costs involved in monitoring shared natural resources.

The analytical work would optimally engage public institutions, private investors, and beneficiaries at local and national levels. Regional integration hinges on scale. Lasting institutional cooperation can grow from and build on government coordination. It is important to monitor, respect, and integrate existing water and energy laws, policies, regulations, and institutional arrangements.

To reform resource sectors and drive efficiency, GCC governments could invest in regional facilities that exchange knowledge, share best practices, and integrate information on the water-energy nexus with that of the larger economy. Rather than see this undertaking as an expense item, governments could recognize it as an investment. After all, water and energy efficiency will drive up GDP and economic diversification, which in turn will expand sources of fiscal revenues for the state.

Indeed, intersectoral coordination lets governments advance on two symbiotic fronts. First, programs will increase sustainable supply through more efficient resource production. Second, demand reduction will eliminate wasteful consumption and end unsustainable practices in the water, energy, and food sectors. To scale up through well-planned analyses, GCC programs would:

1. Establish a time-bound research agenda that delivers solutions to water problems through applied research and field studies.
2. Support and inform the decision-making process of both public and private water entities.
3. Update water information, integrate data services, ensure open access research, and expand systems of knowledge, analytics, learning, and outreach.
4. Establish locally tested adaptation of advances in “smart” information technologies.
5. Work with stakeholders to deliver, train, incentivize, educate, and communicate the public benefits of adopting technological and policy solutions.
6. Focus research on the design of governance, incentives, regulations, and policies that will ensure smart water resource decisions.
7. Evaluate the performance of water sector interventions (investments, policies, tools), with a rigorous emphasis on stakeholder experience and user feedback.

6.3 A Regional Data Bank of Information on the Nexus Would Be a Valuable Asset

The Gulf is more than the source from which GCC nations secure most of their urban water supplies. Its coastal zones also lay the foundation for expanding the transport, service, and tourism sectors. How these activities grow in each country—calibrated by substantial investment in the energy and water nexus—will determine the health of the Gulf.

The Gulf's water quality is also under pressure from riparian countries upstream. Turkey, the Islamic Republic of Iran, and Iraq all extract and divert freshwater from rivers for their own use. In doing so, they reduce the historic influx of freshwater entering the Gulf, further elevating salinity.

Looking ahead, the GCC members might do well to pool resources to establish a special joint facility that collects and shares timely data related to the source of the water-energy nexus. This information will help the GCC anticipate and respond to impacts on marine ecology and water quality in the sea that all six countries share. By sharing knowledge, and highlighting best practices, the regional facility could play an instrumental role in forging synergies in the water- energy-food nexus.

A rapid, effective response demands a clear understanding of the nexus. That understanding, in turn, depends on the availability of rich and timely data, information systems to manage data, and robust models to leverage data. To that end, the region would not be starting from scratch. Collaborative research can build on a long tradition of local studies and investments.

Saudi Arabia's experiences in advanced desalination technologies are second to none. One important case study draws on extensive field research into efforts to deliver water services to households and farms in the Assir Region. Also, leading regional universities and public water agencies like the Saline Water Conversion Corporation have established robust R&D programs that assess the performance of policies, technologies, and other components of the nexus. Next steps would be to establish a reliable and transparent data acquisition and disclosure system for water and energy data, including real-time geographic and demographic-system-based monitoring.

6.4 Establish Regional Public Information and Educational Programs

Knowledge need not be confined to a few elite experts and decision-makers in GCC capitals. The quality of information often improves through vigorous and widespread discussion. Central governments can engage local municipalities, schools, public think tanks, and private businesses; work with urban and rural communities to update, inform, and engage the public; discuss rationales; and explore incentives for conserving water and energy resources from below.

For example, the overabstraction of groundwater beyond safe yield levels has caused saline intrusion into and pollution of existing groundwater aquifers. This "tragedy of the commons" poses a thorny challenge to central governments. It needs a concerted response that engages all stakeholders. So, one public outreach campaign may work with communities to draft legal rules and economic rewards that encourage well owners to reduce pumping of groundwater. Another might educate the public about newly approved water laws and associated restrictions on usage. A third might explain the risks of energy subsidies within a complex framework seeking to reduce waste, excessive use, and pollution. New tools, including smartphone apps, allow more people and institutions to participate in resource governance and efficiency. Many of these can enhance long-term monitoring of the quality and quantity of local and regional aquifers and regulate development and abstraction.

6.5 Establish a Regional Framework for Broader Collaboration on Water Conservation in the Gulf

To unlock broad collaboration, however, the GCC needs a framework of goals and incentives. Right now, the criteria for establishing rights and equity in sharing groundwater resources is neither clear nor well defined. A regional facility for sharing knowledge could change this dynamic, for the better. In addition, a regional framework would allow the GCC countries to agree on measures on the management of the Gulf—much needed for long-term sustainable development. Again, the region can learn from regional precedents.

In March 2019, as part of its Vision 2030 plan, Saudi Arabia launched the National Program for Water Conservation, also called Qatrah, Arabic for "droplet." Qatrah's goal is to reduce the country's average per capita daily water consumption from 263 liters to 150 liters by 2030. The initiative engages with private and public partners to detect and plug leaks, but also encourages cooperation at the family or individual level to reduce wasteful consumption.

While building on all these regional insights into the nexus, GCC governments can also turn outward and learn from international experiences in the effort to secure more sustainable and efficient use of water and energy.[1] Two European precedents—in the Mediterranean and Baltic Seas—offer strong, useful parallels for the Gulf region, wherein diverse countries united to accomplish far more together than they could acting alone.

In 1975, 16 Mediterranean states and the European Community established the earliest framework for intergovernmental cooperation. The Mediterranean Action Plan (MAP) set out to address common challenges of marine environmental degradation. The MAP endorsed and prepared an institutional framework convention, with two related protocols that provide a legal basis for coordinated action. The MAP's initial objectives were to help Mediterranean governments to assess, control, and prevent pollution of shared natural resources; it also aligned national marine environmental policies, standards, and protections. Through the MAP, governments could better identify options for development, and make sound decisions over resource allocation.

The second and perhaps closer parallel, as a framework for regional cooperation, is the Baltic Sea Commission, which is responsible for the design and implementation of an action plan to protect that vital shared saltwater body (see box 6.1).

The international examples of regional frameworks underscore how countries can come together with a view to achieve more than what would be possible under unilateral management. The coordination and agreement around core principles and goals necessary for a regional framework promise tremendous benefits, now and in the future.

BOX 6.1. The Baltic Marine Environment Protection Commission

Also known as the Helsinki Commission (HELCOM), this is an intergovernmental organization and a regional sea convention in the Baltic Sea area.

A regional platform for environmental policy making, HELCOM was established in 1974 to protect the marine environment of the Baltic Sea from all sources of pollution.

HELCOM has 10 contracting parties, namely Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, the Russian Federation, and Sweden. They are the signatories to the Helsinki Convention. The contracting parties form the HELCOM and are represented by a head of delegation. In addition to an annual commission meeting, the heads of delegation meet at least twice a year.

Guided by the HELCOM vision of "a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable economic and social activities," the updated Baltic Sea Action Plan is divided into four segments with specific goals:

- Biodiversity, with a goal of a "Baltic Sea ecosystem that is healthy and resilient";
- Eutrophication, with a goal of a "Baltic Sea unaffected by eutrophication";
- Hazardous substances and litter, with a goal of a "Baltic Sea unaffected by hazardous substances and litter"; and
- Sea-based activities, with a goal of "environmentally sustainable sea-based activities."

Each of the four segments is structured around HELCOM's updated ecological and management objectives and contains concrete measures and actions to be implemented by 2030 at the latest.

The division of the segments seeks to reflect the pressures stemming from land ("eutrophication," and "hazardous substances and litter") and from the activities at sea ("sea-based activities"), as well as the state of the environment ("biodiversity"). These segments are interconnected: attaining the goal under the biodiversity segment also relies on the successful implementation of the actions included under the other three segments.

In addition, the section on horizontal topics addresses cross-cutting issues such as climate change, monitoring, maritime spatial planning, economic and social analysis, knowledge exchange and awareness raising, hot spots, and financing. Furthermore, measures within all segments are designed to strengthen the overall resilience of the Baltic Sea, consequently improving its ability to respond to the effects of climate change.

Note

1. Relevant experiences are available from China and South Africa, where extensive analytical work has been carried out to inform public policy and guide sustainable resource allocation.

Chapter 7
Policy Pathways Going Forward

This report, written about and for the GCC, focuses on the water-energy nexus. Previous chapters identified the most salient challenges, risks, and opportunities, based on supportive background reports, analyses, and regional examples. These assessments limited the scope of ambition and refrained from prescribing any strict directives. This brief, concluding chapter draws on the report's highlights to recommend broad policy pathways.

7.1 Key Recommendations

Use climate change as an opportunity to build resilience through the water-energy nexus. Climate risks are real and worsening. Rising heat, falling precipitation, high evaporation, increased demand, and protracted drought all threaten to further stress water resources. GCC members already possess the knowledge, resources, skills, and technology to adapt to water scarcity. Climate change provides a catalyst for the political will to accelerate and coordinate innovations.

Approach the nexus in ways that both mitigate and adapt to climate change. Desalination requires so much fossil fuel energy that more efficient use simultaneously saves water for future needs and lowers greenhouse gas emissions. Dual gains through the nexus also arise from trade in virtual water, transition to renewables, wastewater reuse, lowering demand, and reducing water loss.

Increase resource supplies by lowering demand. In the long term, the GCC can increase production. But the fastest, simplest, cleanest, and most affordable way to double water or energy capacity is to decrease consumption. This is technically feasible and politically sound. Significant water and energy savings are possible from increased metering, pricing, and reallocating groundwater on farms.

Restructure tariffs to match equity with incentives. Despite the scarcity of water, GCC countries charge among the lowest rates for water supply and energy services, resulting in among the highest per capita water and energy use in the world. Subsidies that try to ensure "lifeline" resource access to the truly needy are instead captured by affluent families. Oman's model shows how to ensure fair yet efficient consumption. It combines targeted subsidies for low-income households with tiered rates that raise prices per unit of demand.

Optimize existing infrastructure by integrating new technology. Smart meters, sensors, appliances, and web-based tools help water and energy end users decrease waste. Pressure management coupled with leak detection/fixing can reduce network losses by 20 percent or more. The United Arab Emirates has shown how strategic recharge of depleted aquifers saves water, money, time, and energy.

Convert wastewater from a liability to an asset. The failure to treat wastewater pollutes land and marine ecosystems. Recycling it, however, offers an indispensable and affordable, green way to augment and diversify water and energy supplies. Other regional experiences suggest the GCC region could recapture up to 90 percent of wastewater for agricultural, industrial, and domestic use.

Decouple water production from fossil fuel consumption. To transition toward a low-carbon economy, GCC countries can speed the adoption of renewables and nuclear energy. Saudi Arabia exemplifies this goal, embarking on the world's largest solar desalination plant. Doing so reserves hydrocarbon fuels for export, eases price risks, meets targets, and cuts greenhouse gas emissions.

Leverage trade to ensure national security. It takes up to 1,500 cubic meters to irrigate 1 ton of grain. By buying grain—and importing its embedded virtual water—GCC nations relieve pressure on domestic aquifers, reallocate groundwater to higher-value uses, and reduce opportunity costs.

Align national resource priorities under one roof. From the Mediterranean to the Baltic, to the Gulf, diverse countries confront escalating threats to shared water resources. By collaborating under a proven common framework, the GCC can streamline codes, standardize rules, share data, compare experiences, and find common solutions to emissions and pollution.

7.2 Areas and Inquiries for Potential Further Analytical Work

This report draws on a comprehensive body of diverse sources. It integrates expertise from within the GCC countries, combined with global experience from the Middle East and North Africa region and other continents. Yet nexus research can never be definitive or complete. Perhaps unsurprisingly, this research highlights areas where more work could be both needed and beneficial. Key questions include the following:

What is the impact of rising sea level on coastal cities, aquifers, and infrastructure? With a few exceptions, like Riyadh, much of the GCC's population—as well as key water and energy plants—have become concentrated along the coast. Researchers have investigated changing water quality. But what happens as the Gulf expands and sea level rises, moving inland?

How intricately does the water-energy nexus incorporate or relate to agriculture? Agriculture is the main consumer of water in the region. This report is focused on the water-energy nexus while more work is needed to better understand the water-energy-food nexus. This includes, for example, looking more deeply at groundwater allocations for farms versus cities. In addition, further analysis could consider the electricity required for pumping wells.

Which strategies optimize and inform trade policies to benefit water and energy? Virtual water began as a concept to understand gains from imported grain. It has since grown far more complex and precise, covering the water footprint of hundreds of goods and services. Trade decisions can weigh the merits of job creation, comparative advantage, or water-energy inputs. How could the Gulf countries benefit from including these considerations in their trade policies?

Where, how, and why do public outreach campaigns work best? Past water and energy supply decisions were dominated by engineers. An improved understanding of how to involve the public and reach people to generate a new water and energy consciousness would be integral to a comprehensive strategy for improved resource management.

What is the relationship between water demand and economic productivity? This report focused on the inverse relationship between energy demand and performance. Given scarce and dwindling water supplies, a similar analysis of a water to GDP ratio could better inform decisions on investments, policy, allocations, knowledge generation, or skills development.

Could water rights and markets make sense in the Gulf? Australia, Chile, and the American West have allowed limited trade in water savings, whether between urban and rural areas, between sectors, between farmers, or even between urban users. Are transparent, incentives-driven mechanisms useful, or inappropriate, for ensuring efficient use in the GCC?

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