WATER GLOBAL PRACTICE

The Water-Energy-Food Nexus in the Middle East and North Africa

Scenarios for a Sustainable Future

Edoardo Borgomeo, Anders Jägerskog, Amal Talbi, Marcus Wijnen,
Mohamad Hejazi, and Fernando Miralles-Wilhelm

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Executive Summary

Challenges and Opportunities in the Water-Energy-Food Nexus

The Middle East and North Africa's water crisis is an early warning signal. Water availability and variability influence all economic activities, and growing water scarcity undermines food and energy security. As water constraints become binding and demands for food and energy increase, the Middle East and North Africa is experiencing the consequences of unmanaged trade-offs between these sectors. Groundwater depletion due to overpumping (fueled by subsidized energy), reliance on cheap energy sources for desalination, and overabstraction of surface waters to sustain irrigation for food self-sufficiency are all examples of these interactions that—if left unmanaged—can strain social, economic, and environmental systems.

Taking action to address the water crisis requires looking beyond the water sector: recognizing the synergies and managing risks that arise from linkages with energy and food policies. Water, energy, and agriculture have been conventionally dealt with separately in investment planning. For each of these sectors, regulatory frameworks, organizations, and infrastructure have been put in place to address sector-specific challenges and demands. As the Middle East and North Africa works toward building a more sustainable future and meeting the Sustainable Development Goals (SDGs), a different approach is needed, one that views the demands and related policies arising from different sectors as interconnected and emerging in response to common social, economic, and environmental trends.

To enable long-term planning and identification of these synergies and risks, this report presents findings from an exploratory modeling analysis of the water-energy-food nexus in the Middle East and North Africa. These findings are meant to help policy makers develop long-term visions for sustainability and security, and to analyze cross-sectoral impacts across a range of possible future scenarios of global social, economic, and environmental change. They are not meant to provide exact predictions of what the region's freshwater resources will amount to 50 years from now.

This report is targeted to policy makers, the academic community and a wider global audience interested in exploring the interactions between water, agriculture, and energy. The report aims to promote debate and broaden understanding of current trends related to the water-energy-food nexus through an exploratory modeling analysis. The focus is a country- and economy-level analysis of some of the water-energy-food nexus challenges, with an emphasis on understanding the impact of changes in freshwater resources availability on food and energy production.

Challenges

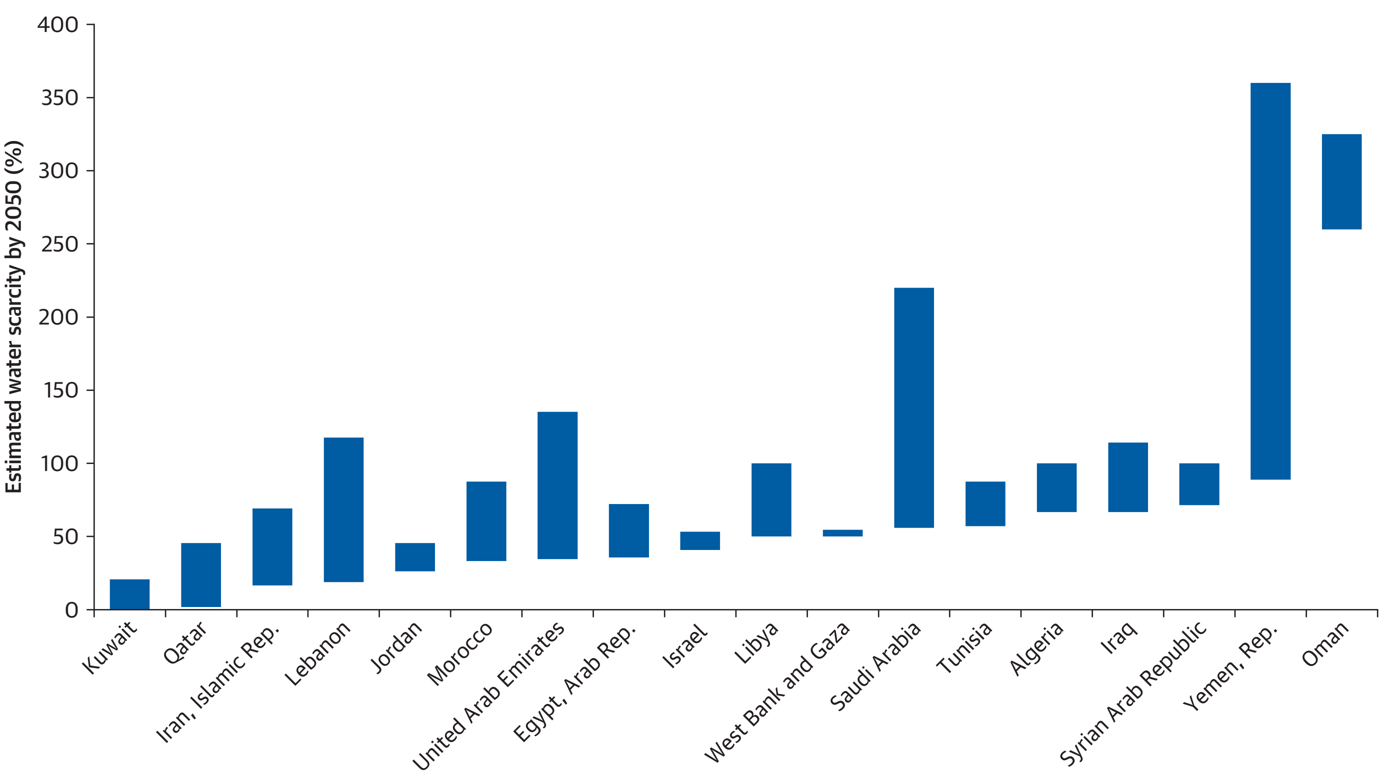
Water Scarcity is Set to Increase and Nonrenewable Groundwater Reserves May Disappear by 2050 Under a "Business as Usual" Scenario

This report focuses on physical water scarcity, what is commonly referred to as "demand-driven scarcity," or use-to-availability ratio. Focusing on demand-driven scarcity means comparing the amount of renewable freshwater withdrawn from rivers and aquifers—based on present-day observations or future projections—with the total renewable freshwater resources available.

Water scarcity increases in all economies over the coming decades. The water scarcity index (water availability to use ratio) estimated for 2015 and 2050 shows an increase across the region. The results are displayed in figure ES.1 as the percentages increase from 2015 levels of freshwater scarcity. The results are shown as a range to account for the uncertainty in freshwater availability and the demand projections used to calculate the 2050 water scarcity values. The uncertainty originates from the possible socioeconomic and climatic evolution of the region and the world by 2050 considered in the exploratory modeling.

Groundwater resources are under pressure, with nonrenewable groundwater reserves set to disappear in most of the region by 2050 under a "business as usual" scenario. Nonrenewable groundwater resources (also referred to as 'fossil' groundwater) consist of water that infiltrated underground millennia ago when climatic conditions where different and that remained stored underground until humans started withdrawing it. It is essentially like an inherited savings account in a bank that gets replenished very little or doesn't get

FIGURE ES.1. **Projected Range of Water Scarcity Increase by Economy in the Middle East and North Africa by 2050**



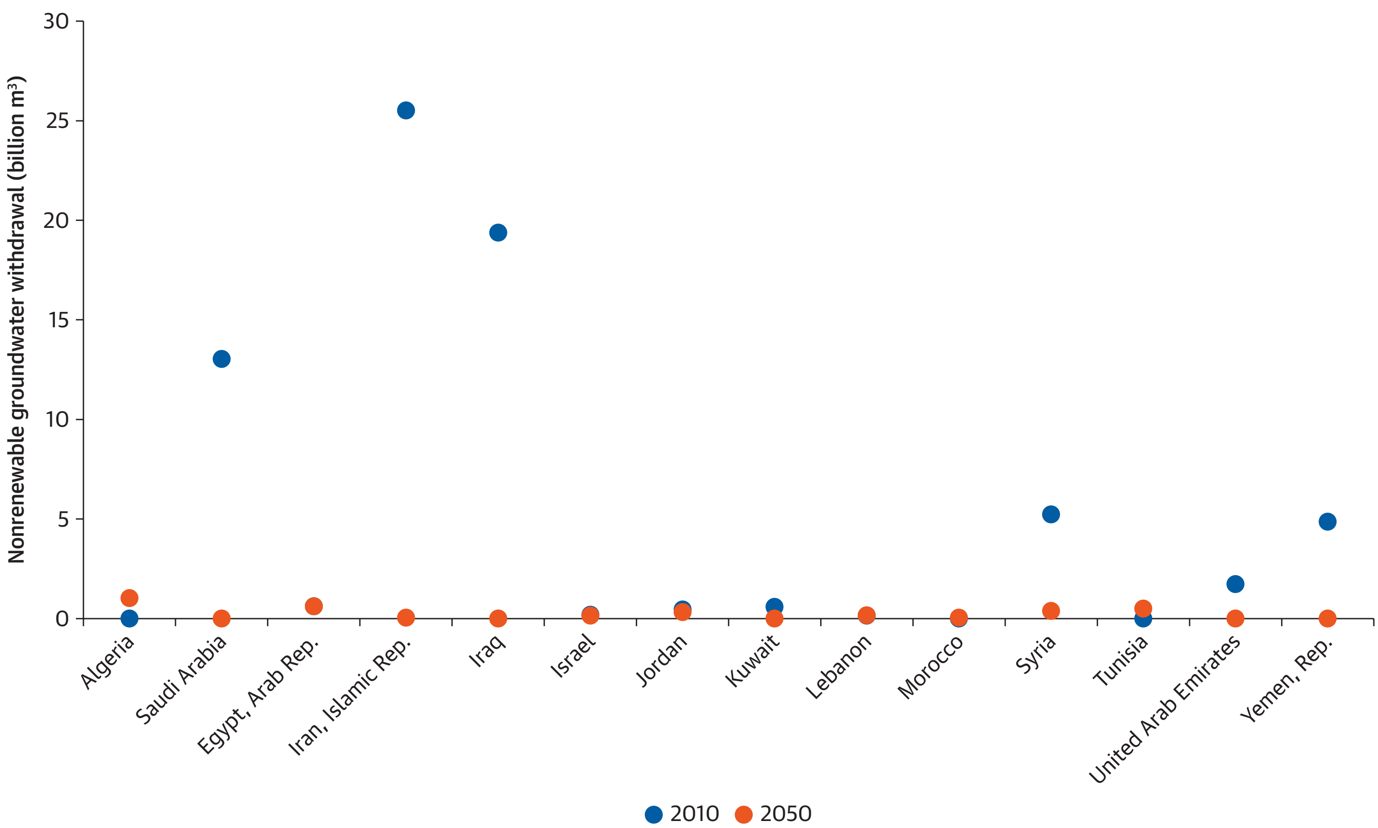
Source: World Bank and University of Maryland calculations.
Note: Figure estimates made using three Global Circulation Models (GCMs) and all the Shared Socioeconomic Pathways (SSPs) using emission scenario Representative Concentration Pathway (RCP) 6 as reference. The lower bound on the range represents the best-projected outcome, and the upper bound represents the worst-projected outcome based on the combination of scenarios considered in this study. Differences between neighboring economies may be due to the different projected levels of future water demands.

replenished at all and hence needs to be managed with care. Most economies for which data could be obtained and model simulations run show depletion of nonrenewable groundwater reserves by 2050 (see figure ES.2).

Nonrenewable groundwater is a strategic resource for resilience in the face of shocks: depleting it eventually undermines livelihoods and economies. Groundwater is a crucial supply source, and it is often used as a buffer against drought. As groundwater becomes depleted, it also decreases in quality and becomes increasingly expensive to abstract. This leads to increased costs of exploitation (and eventually depletion of the resource), making groundwater abstraction uneconomical with significant implications for food security as well as large-scale agricultural systems.

Water scarcity is not going to go away, so it's important to understand its impacts on multiple sectors and develop strategic responses. Increased pressure on water resources as a result of population growth and development, combined with the region's arid and highly variable climate, result in an upward trend in water scarcity. The main drivers behind this upward trend are the region's soaring water demands. If human influences and demands are the

FIGURE ES.2. Annual Nonrenewable Groundwater Withdrawals in the Middle East and North Africa, 2010 and (Projected) 2050



Source: World Bank and University of Maryland calculations.
Note: Figure estimates made under a scenario of moderate economic development and moderate improvements in efficiency (SSP2). Reductions are driven by the progressive reduction of fossil groundwater resources that can be economically abstracted, implying that fossil groundwater resources may become depleted and may need to be substituted with different supply sources. No data for Libya.

main driver behind water scarcity increases, they are also the areas in which interventions aimed at addressing these scarcity challenges would pinch most.

Growing Water Scarcity Will Cost the Region Hundreds of Billions of Dollars in Lost Agricultural Output by 2050 and Require Shifts in Electricity Generation

Due to water scarcity and increasing costs of groundwater exploitation, agricultural production is projected to drop markedly—by as much as 60 percent in some economies. Water supplies will be affected due to increased costs of pumping groundwater from greater depths and availability of surface water. Given water's fundamental role as a factor of production in agriculture, limiting its supplies has significant negative impacts on crop production. Specifically, the production of wheat and other grains is projected to suffer most from water availability constraints.

Reductions in agricultural production will have consequences for food security and self-sufficiency. Food demand is relatively inelastic, so an increase in the price of food within the region due to decreased local production will not cause a similar drop in demand. To respond to this reduction in supply, economies in the region will increasingly have to rely on importing food to meet domestic consumption. This requires strong international trade and safety nets to protect the most vulnerable from international food price fluctuations. Projected reductions in agricultural production are fostering interest in large-scale land acquisitions outside the region, though these practices can have negative impacts on the affected communities if not done in a sensible manner and following principles of responsible investments.

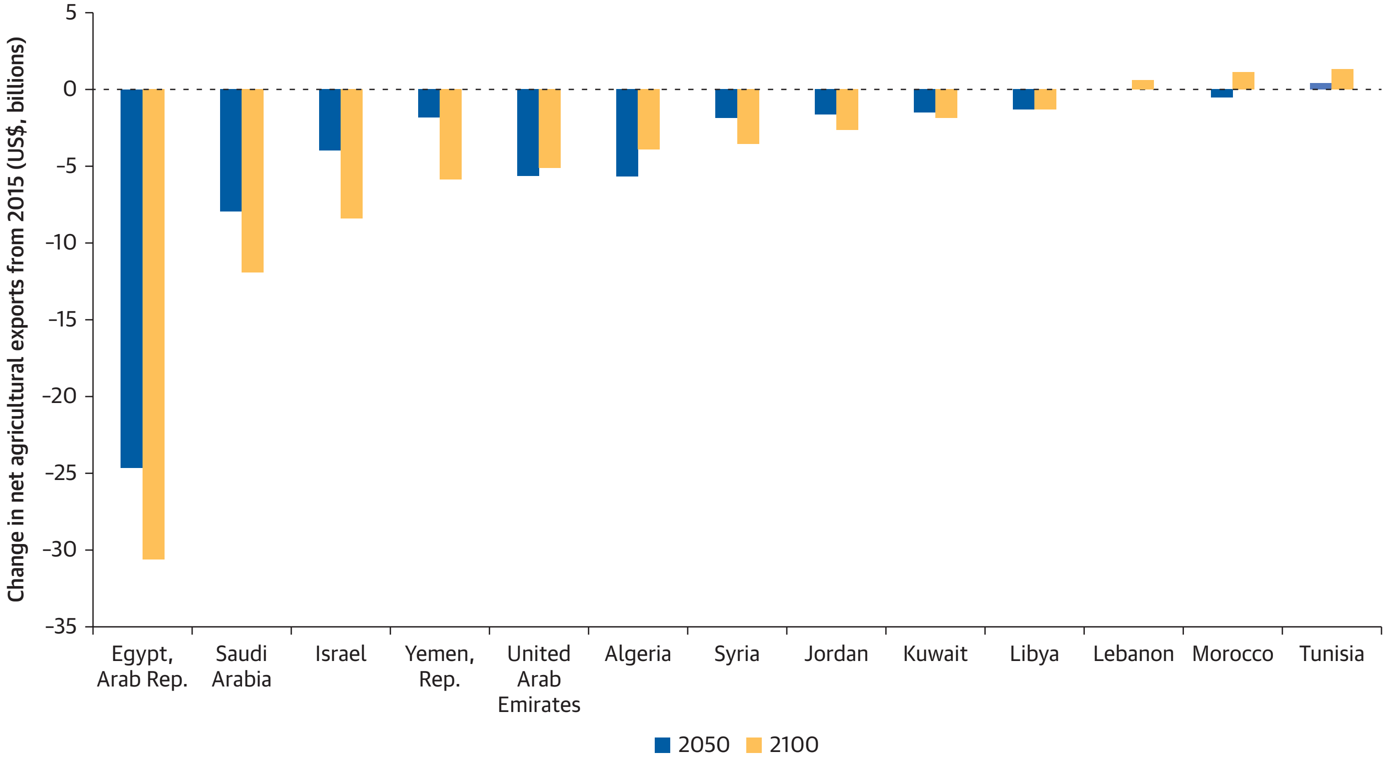
Reductions in agricultural production imply significant revenue losses derived from agricultural commodity exports, costing the region hundreds of billions of dollars by 2050. The reduction in agricultural production has significant economic consequences, leading to a total reduction of about US$50 billion in net agricultural exports by 2050 (see figure ES.3).

Water scarcity impacts electricity generation, with costs to cope with increasing scarcity estimated in the tens of billion dollars. Investments in less water intensive electricity generation technologies, such as solar and wind, are required to cope with groundwater depletion and surface water scarcity. These investments are much lower than what's needed to ensure food security in a water-constrained Middle East and North Africa, mainly because the region already relies extensively on electricity generation cooling technologies with limited withdrawals of freshwater. Nonetheless, the transformation toward less water intensive electricity generation comes at a cost, estimated at US$50 billion by 2050 and US$150 billion by 2100. Economies facing extreme scarcity conditions will have to invest in more expensive energy cooling options, which are also less carbon-intensive, providing a win-win opportunity.

Increasing Water Supply with Desalination May Hinder Progress Toward the Paris Agreement for Greenhouse Gas Emissions Mitigation

The analysis suggests that nonconventional water supplies will need to be significantly augmented to meet projected demands. Supply-side responses include development of a

Figure ES.3. Projected Change in Net Agricultural Exports in the Middle East and North Africa, 2050 and 2100



Source: World Bank and University of Maryland calculations.

Note: Net exports are calculated as the difference between consumption and production multiplied by crop prices estimated by the Global Change Assessment Model (GCAM). No data available for Iraq and the Islamic Republic of Iran. This was estimated using the Goddard Institute for Space Studies (GISS) climate model, one emission scenario (Representative Concentration Pathway [RCP] 6), and the Shared Socioeconomic Pathway 2 (SSP2) scenario for socioeconomic development. Results should be used with caution because different estimates may be obtained depending on the scenarios and model used.

diversified portfolio of solutions, including wastewater recycling and reuse, rainwater and storm water capture, and desalination. The cost of these investments will depend on available technologies, but assuming present-day technologies and production costs, more than US$40 billion will need to be spent in nonconventional water supplies by 2050, with the number going up to US$110 billion by 2100.

There are trade-offs between increasing supplies and decarbonizing the region's economies. Supplying water to farms, industries, and households is already a very energy intensive business. Pumping for irrigation and drainage consumes around 6 percent of total electricity and diesel in the Middle East and North Africa. On average, desalinated water supplied to domestic users requires 23 times more energy than that required to extract and treat surface water, costing four to five times more than treated freshwater. Unless water recycling is integrated into water supply systems and renewable energy desalination becomes mainstream, increasing water supplies with fossil fuels may make it more challenging for economies to reach the greenhouse gas emission reduction targets expressed in the Paris Agreement.

Opportunities

Reducing the Demands and Dependence of the Food and Energy Sectors on Water Helps to Alleviate Water Scarcity

Reducing the dependence and demands of the food and energy sectors on water should be the overarching objective of water-energy-food policies in a water-constrained Middle East and North Africa. As the region becomes drier and subject to higher temperatures, policies that reduce the economy's dependence on water and anticipate climate's effects on the nexus are necessary for development and stability. To reach this overarching objective, multiple strategies can be developed and implemented to increase nonconventional water supplies and transform energy systems.

Agriculture and food production systems play a key role in valuing water and using it more productively. Some of these measures include monitoring use, modernizing irrigation systems, increasing on-farm water productivity, and reducing losses in food-supply chains. Using satellite data to find land areas where water use is not leading to optimal agricultural production is one way to value water (García et al. 2016). This information can then be converted to improving planting decisions or changing irrigation techniques. Modernizing irrigation systems is another important measure, as demonstrated by the low ratio between water required and water withdrawn in many economies in the region and the substantial losses through seepage and evaporation (FAO 2009). Another way to value water is by increasing on-farm water productivity, such as by increasing the skills of the farmers to better manage the timing of irrigation and by investing in such precision delivery technologies as drip or bubbler irrigation (Geerts and Raes 2009).

Phasing out of water intensive cooling technologies for thermal power generation and improving efficiency can reduce water needs for electricity generation. To respond to increasing scarcity, power plants using once-through cooling technologies are likely to be phased out and substituted with less water intensive seawater recirculation technologies or dry cooling.

Transitioning to Renewable Energies can Reduce Water Scarcity

The trend toward adopting renewable energy contributes to a reduction of the energy sector's water use. Although the extent to which different renewable energy technologies have been adopted varies, comprehensive studies from international energy agencies have demonstrated the potential for renewable energy in the region, as well as its ongoing adoption (IRENA 2016a). Electricity generation technologies that use no water may grow tenfold by 2050, largely as a result of the continued expansion of wind and solar photovoltaic technologies.

Climate change mitigation policies will likely accelerate this energy transition depending on the level of commitment in the Middle East and North Africa. The nationally determined contributions describe the mitigation actions that economies plan to undertake to meet the Paris Agreement targets. Several economies in the region have made unconditional commitments (that is, voluntary and implementable without outside support) to reduce greenhouse gas emissions. The Gulf Cooperation Council (GCC) countries and the Arab Republic of Egypt have not formally expressed any unconditional emission reduction targets but have provided some form of mitigation target. This lack of voluntary commitments suggests that greenhouse gas emission reduction may not be a driving force of regional energy policy.

Intraregional Instruments for Collaboration can Support Policies Addressing Water-Energy-Food Nexus Challenges

Increasing intersectoral collaboration is key to address water-energy-food nexus challenges. Cooperation and partnerships around water, agriculture, and energy add value to governance and technological measures needed to address these challenges. Regional partnerships with national, regional, and global actors foster development and trust across the Middle East and North Africa, leveraging resources and knowledge needed to develop innovative and inclusive solutions. Regional initiatives, such as the Arab League's nexus dialogue program, provide platforms to inform the development of policies to address water-food-energy challenges. Similarly, partnerships between bilateral and multilateral development institutions, such as the Arab Coordination Group, can enhance coordination for more effective water-energy-food nexus policies.

Chapter 1 Water-Energy-Food Nexus in the Middle East and North Africa

The linkages between water, energy, and food are growing in importance as demand for each of these vital resources increases. Several regions of the world are already experiencing water, food, and energy security challenges, which hamper progress toward sustainable economic growth. In addition, there is evidence of the effects of climate change on the availability and demand for water, energy, and food.

The water-energy-food nexus is a powerful framework for identifying synergies and for managing risks that arise from these linkages. Water, energy, and agriculture have been conventionally dealt with separately in investment planning. For each of these sectors, regulatory frameworks, organizations, and infrastructures address sector-specific challenges and demands. For instance, most investment planning in water resources takes demands from other sectors as a given when estimating water balances, ignoring the interdependence between these demands and policy choices made in other sectors. The nexus calls for a different approach, which views the demands and related policies arising from different sectors as interconnected and emerging in response to common social, economic, and environmental trends.

To enable long-term planning and identification of these synergies and risks, this report presents findings from an exploratory modeling analysis of the water-energy-food nexus in the Middle East and North Africa. These findings are meant to help policy makers develop long-term visions for sustainability and security, and to analyze cross-sectoral impacts across a range of possible future scenarios of global change. They are not meant to provide exact predictions of what the region's freshwater resources will amount to 50 years from now.

This report introduces one important methodological innovation related to groundwater resources assessment. Most studies to date have assumed that nonrenewable ("fossil") groundwater resources, which account for a significant share of the region's supply sources, are unlimited and can be accessed at zero cost. These are groundwater resources that infiltrated underground millennia ago and have been stored, receiving little or no additional water, since then. This report calculates for the first time the volume of economically accessible nonrenewable groundwater in the Middle East and North Africa. By factoring into the analysis the cost of groundwater production—related to well installation, pumping, and other maintenance costs—the report provides a more realistic assessment of the region's water availability and, subsequently, on its implications for energy and food security.

This report is targeted to policy makers, the academic community, and a wider global audience interested in exploring the interactions between water, agriculture, and energy. The report aims to promote debate and broaden understanding of current trends related to the water-energy-food nexus through an exploratory modeling analysis. The focus of the report is a country- and economy-level analysis of some of the water-energy-food nexus challenges, with particular attention paid to the impact of changes in freshwater resources availability on food and energy production.

Climate Change and the Water-Energy-Food Nexus in the Middle East and North Africa

The nexus between water, energy, and food is key for the region's stability and economic development. Although freshwater resources have been successfully managed for millennia, rapid evolution of the region's economic, social, and environmental context is making the trade-offs between water, energy, and food policies starker. High population growth, increasing consumption, food self-sufficiency policies, and inadequate governance arrangements have led to overexploitation of water resources (Swain and Jägerskog 2016).

Climate change adds challenges to the nexus, first by influencing the availability and variability of water resources. Historical data on rainfall amounts in the region show a negative trend at national and regional scales (Verner 2012). Average annual runoff is expected to decrease due to climate change, and temperatures are expected to increase. High evapotranspiration and soil infiltration rates in the region reduce soil moisture and, consequently, increase irrigation requirements that typically surpass 80 percent of total water withdrawal in most economies (Verner 2012). Increasing temperatures and water requirements will have disproportionate impacts in areas dominated by rainfed agriculture (Waha et al. 2017).

The agricultural sector is very sensitive to the impacts of climate change. Current approaches for food production, which rely on ever-increasing inputs of land, water, and fertilizers, may no longer be suitable under climate change. The allocation of water to agriculture will likely face increased competition from high-value uses in the industrial and urban sectors. Alongside climate change, urbanization will drive water competition between cities and agriculture, requiring major improvements in agricultural water use. The cost of producing crops might rise as groundwater levels drop and costs of pumping deeper water increase. From a nexus perspective, increased exploitation of groundwater for food production will require more energy, potentially resulting in higher greenhouse gas emissions.

On the energy side, the region is heavily reliant on fossil fuels (coal, oil, and gas) to generate electricity and, in some economies, to generate water supplies. The dependence on fossil fuels is frequently complemented with energy imports, which adds uncertainty to the security of energy supplies. To address this issue, some economies have launched renewable energy development programs to diversify their energy sources and to achieve objectives of energy security and environmental sustainability (IRENA 2016b). Economies are also exploring innovations in renewable energy desalination to hedge against the risks associated with volatile energy markets (World Bank 2012). Yet some of these policies may have negative impacts on other sectors if their benefits are not carefully weighed against their costs.

While understanding and adapting to climate change impacts is essential to achieve water and food security, climate change also requires implementing mitigation policies to meet the emission reduction targets expressed in the Paris Agreement. Mitigation policies are typically implemented in the energy sector, in the form of neutral or negative carbon emission technologies, and in the agricultural sector, such as in the form of land management practices that enhance soil carbon storage. The water and land required to implement some of these measures are rarely accounted for, and water policies are rarely framed in terms of mitigation. A focus on the nexus means exploring the trade-offs between mitigation and adaptation objectives and their effects on water resource availability and conservation, energy, and food security. It also means understanding how some solutions for water security, such as desalination, may impair progress toward mitigation targets.

Exploring these interdependencies and trade-offs is challenging. The water, energy, and food sectors often use different units of measurement, planning horizons, and regulatory frameworks. Considering the nexus means bridging some of these differences to explore alternative scenarios, identify areas where more understanding is needed, and inform the choice of water, energy, and food policies in an uncertain future.

Snapshot of the Approach

This report uses a modeling approach integrating environmental and economic variables to explore the impacts of water scarcity on the water-energy-food nexus in the Middle East and North Africa. The issues relating to the impact of water on food and energy go well beyond water scarcity and availability, encompassing issues such as variability, occurrence of extreme events, reliability, and affordability of service delivery. Addressing all of these issues is beyond the scope of this report, which focuses on the effects of physical water scarcity (water use to availability ratio) on agricultural production and electricity generation in the Middle East and North Africa region, quantified using a state-of-the-art model that integrates environmental and economic variables.

Projecting the impacts of water scarcity on agricultural production and electricity generation is a complex task. Future changes in climate and their impact on water scarcity, evolution of economic structures, technological innovations, and political priorities cannot be known. Similarly, consumer preferences and habits, including consumer use of water and food preferences, are hard to project.

Given the insufficient knowledge and unresolvable uncertainties about future trends in water, energy and food systems, this report employs an exploratory modeling approach. This means that while the models' results cannot be interpreted as predictions of what will happen, they reveal how the world would behave if various guesses and inputs to the model were correct (Bankes 1993). Exploratory modeling uses computational experiments to ask "what if" questions, unraveling the implications of different assumptions and hypotheses about future trends on outcomes of interest to societies and policy makers.

To characterize socioeconomic change, this report uses the Shared Socioeconomic Pathways (SSPs) to develop plausible scenarios of future demography, policy, economy, and emissions. These should be interpreted as descriptions of alternative future worlds that emerge out of specific combinations of decisions with respect to economic progress, climate change mitigation, and climate change adaptation (see box 1.1).

These scenarios are implemented in the Global Change Assessment Model (GCAM) to simulate their implications for water scarcity and then one (called "middle of the road") is used

BOX 1.1. Socioeconomic Development Scenarios

Long-term scenarios play an important role in research on global environmental change. The climate change research community has developed new scenarios that integrate future changes in climate and society to investigate climate impacts as well as options for mitigation and adaptation. One component is a set of alternative futures of societal development known as the SSPs. The SSPs describe the future evolution of key aspects of society that would together imply a range of challenges for mitigating and adapting to climate change.

O'Neill et al. (2014) present "SSP narratives": five qualitative descriptions of future changes in demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources. Development of the narratives draws on expert opinion to identify key determinants of these challenges that are essential to incorporate in the narratives and combines these elements in the narratives in a manner consistent with their interrelationships. The narratives are intended as a description of plausible future conditions at the level of large world regions that can serve as a basis for integrated scenarios of emissions and land use, as well as climate impact, adaptation, and vulnerability analyses.

Within the conceptual framework for integrated scenarios, the SSPs are designed to span a relevant range of uncertainty in societal futures. Unlike most global scenario exercises, the relevant uncertainty space that the SSPs are intended to span is defined primarily by the nature of the outcomes, rather than the inputs or elements that lead to these outcomes. Therefore, the SSP outcomes are specific combinations of socioeconomic challenges to mitigation and socioeconomic challenges to adaptation. That is, the SSPs are intended to describe worlds in which societal trends result in making mitigation of, or adaptation to, climate change harder or easier, without explicitly considering climate change itself. The five SSPs and related assumptions are shown in table B1.1.

TABLE B1.1. SSP assumptions as Implemented in GCAM-MENA

		SSP1: Low challenges	SSP2: Intermediate challenges	SSP3: High challenges	SSP4: Adaptation challenges dominate			SSP5: Mitigation challenges dominate
					High income	Medium income	Low income	
Socioeconomics (billions)	Population in 2100	6.9	9	12.7	0.9	2.0	6.4	7.4
	GDP per capita (US$) in 2100	46,306	33,307	12,092	123,244	30,937	7,388	83,496
Fossil resources (technical change/ acceptance)	Coal	Med/Low	Med/Med	High/High	Med/Low	Med/Med	Med/High	High/High
	Conventional gas & oil	Med/Med	Med/Med	Med/Med	High/Low	High/Low	High/Low	High/High
	Unconventional oil	Low/Med	Med/Med	Med/Med	Med/Low	Med/Low	Med/Low	High/High
Electricity (technical cost)	Nuclear	High	Med	High	Low	Low	Low	Med
	Renewables	Low	Med	High	Low	Low	Low	Med
	CCS	High	Med	Med	Low	Low	Low	Low

table continues next page

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BOX 1.1. Continued

TABLE B1.1. Continued

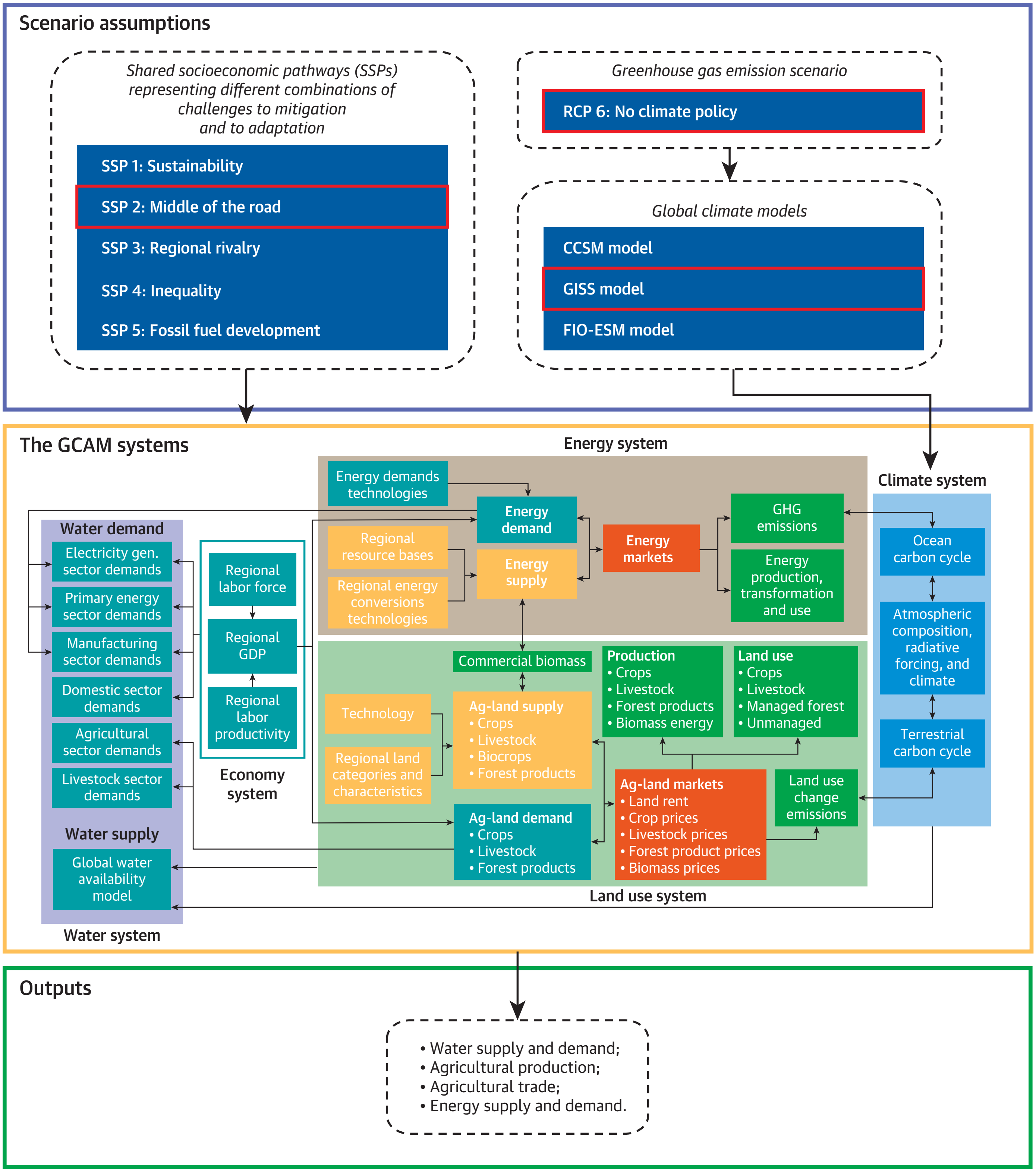
		SSP1: Low challenges	SSP2: Intermediate challenges	SSP3: High challenges	SSP4: Adaptation challenges dominate			SSP5: Mitigation challenges dominate
					High income	Medium income	Low income	
Fuel preference	Renewables	High	Med	Med	High	High	High	Med
	Traditional biomass	Low	Low	High	Low	Low	High	Low
Energy demand (service demands)	Buildings	Low	Med	Low	High	Med	Low	High
	Transportation	Low	Med	Low	High	Med	Low	High
	Industry	Low	Med	Low	High	Med	Low	High
Agriculture & land use	Food demand	High	Med	Low	High	Med	Low	High
	Meat demand	Low	Med	High	Med	Med	Med	High
	Productivity growth	High	Med	Low	High	Med	Low	High
	Trade	Global	Global	Global	Regional	Regional	Local	Global
	Spa policy				Afforestation	Limited afforestation	No land policy	
Pollutant emissions	Emission factors	Low	Med	High	High	High	High	Low

Source: World Bank and University of Maryland.
Note: CCS = carbon capture and storage; GCAM = Global Change Assessment Model; MENA = Middle East and North Africa; SSP = Shared Assessment Pathway.

to explore water-energy-food nexus scenarios (see figure 1.1). This analysis examines what happens to agricultural production and electricity generation under moderate population growth and climate change. More importantly, it examines what happens to agricultural production and electricity generation when water constraints become binding, that is, when the limits to surface freshwater abstraction due to environmental flow requirements and the costs of groundwater exploitation are taken into account. This latter point is particularly important for the Middle East and North Africa where groundwater supplies meet a large part of water demand. Not all available groundwater can be economically withdrawn, so accounting for these limitations allows for an improved understanding of the water-related constraints to economic development in the region.

GCAM employs representations of the economy, energy sector, land use, and water resource allocation linked to climate models to explore what happens to energy and food security under a range of pressures and responses. GCAM is capable of simulating the effects of climate adaptation and mitigation policies including carbon taxes, carbon trading, regulations, and deployment of energy technologies (Edmonds and Reilly 1985; Kim et al. 2006). The model also uses spatial representations of food production, particularly agriculture.

FIGURE 1.1. Approach Used in Exploratory Analysis of Water-Energy-Food Nexus



Note: Scenario assumptions highlighted in red were used to generate the results presented in chapters 3 and 4. CCSM = Community Climate System Model; FIO-ESM = First Institute of Oceanography Earth System Model; GDP = gross domestic product; GHG = greenhouse gas; GISS = Goddard Institute for Space Studies; RCP = Representative Concentration Pathway.

To obtain country- and economy-level data for the Middle East and North Africa, GCAM was broken into economies or subregions[1] to obtain a higher resolution analysis of water-energy-food issues.

This analysis employs the GCAM to shed light on possible impacts of climate change on freshwater availability and on cascading impacts through the water-energy-food nexus. From a number of computational experiments, this approach tries to answer the following questions:

- How will future freshwater availability change?
- What happens to agricultural production and trade under increasing water scarcity?
- What happens to energy production and energy system transitions under increasing water scarcity?
- What type of water-food-energy nexus policies are needed for a sustainable and decarbonized future?

The first question is answered in chapter 2. Findings related to the second and third questions are presented in chapter 3, in which impacts of water scarcity on food and energy systems are described. In chapter 4, strategic directions for a sustainable and decarbonized future are explored to answer the fourth question.

Note

1. The GCAM-MENA model includes the following countries and economies: Morocco, Algeria, Tunisia, Libya, the Arab Republic of Egypt, Israel, Lebanon, the Syrian Arab Republic, Iraq, Jordan, the Islamic Republic of Iran, the United Arab Emirates, the Republic of Yemen, Kuwait, and the Arabian Peninsula (including Oman and Saudi Arabia). Bahrain, Qatar, and the West Bank and Gaza are currently not represented in the model.

Chapter 2 A Future without Water?

Growing Surface Water Scarcity

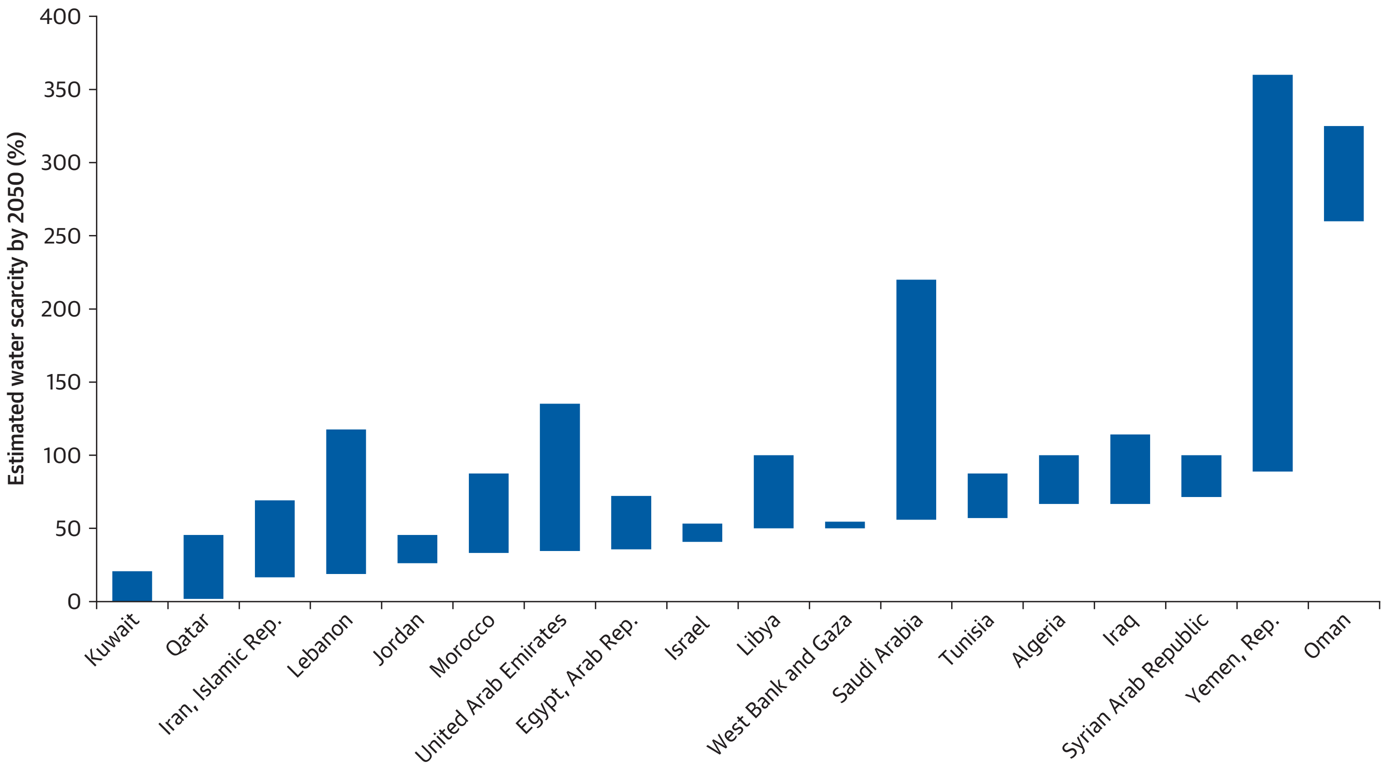
Water scarcity can be defined in multiple ways. Water resources, or physical water scarcity, is typically defined in terms of the water available for use in a given region or per capita. It is mainly a function of the availability of water resources and the distribution and magnitude of water use from different economic sectors. However, water scarcity may also result from economic, social, or political factors that constrain the ability of populations to enjoy access to water and use it for a range of activities, including productive or cultural uses (Kummu et al. 2010).

This report concentrates on assessing physical water scarcity. More specifically, it focuses on what is commonly referred to as "demand-driven" scarcity or use-to-availability ratio (Falkenmark et al. 2007). Focusing on demand-driven scarcity means comparing the amount of water withdrawn from rivers and aquifers—based on present-day observations or future projections—with the total freshwater resources available. This focus is limited in that it does not consider the contribution of nonconventional water supplies (desalination, water recycling) to total water availability, which is significant for the Gulf Cooperation Council (GCC) countries mostly for domestic water uses, nor demands arising from environmental requirements. However, this approach does consider both surface and groundwater resources, which are the main sources of supply underpinning agricultural and energy production in the region.

Results show an increase in water scarcity over the coming decades. The water scarcity index (water availability to use ratio) estimated for 2015 and 2050 shows an increase throughout the region. The results are displayed in figure 2.1 as the percentage increase from 2015 levels of water scarcity. The results are shown as a range to account for the uncertainty in freshwater availability and the demand projections used to calculate the 2050 water scarcity values. The uncertainty originates from the possible socioeconomic and climatic evolution of the region and the world by 2050, as expressed in the scenarios in box 1.1.

Long-ranging measures need to be adopted to deal with this permanent scarcity. The estimates in figure 2.1 were generated using scenario combinations, including those of sustainability and improvements in water use efficiency (SSP1 in figure B1.1). Even under this latter scenario, which determines the lower bound for the bars in figure 2.1, most economies still experience an increase in water scarcity between 25 percent and 50 percent. In at least nine economies, the analysis suggests a minimum expected 50 percent or greater increase in water scarcity by 2050.

FIGURE 2.1. **Projected Range of Water Scarcity Increase in the Middle East and North Africa by 2050**



Source: World Bank and University of Maryland calculations.

Note: Figure estimates made using three Global Circulation Models and all the Shared Socioeconomic Pathways using emission scenario Representative Concentration Pathway (RCP) 6 as reference. The lower bound on the range represents the best-projected outcome, and the upper bound represents the worst-projected outcome based on the combination of scenarios considered in this study. Differences between neighboring countries and economies may be due to the different projected levels of future water demands.

Increases in water scarcity are concentrated in economies affected by fragility and conflict. Water use to availability is set to increase by 50 percent to 100 percent in Iraq, the Syrian Arab Republic, and the Republic of Yemen by 2050. Results for the Republic of Yemen are particularly concerning, because even the lower bound projections (the best projected outcomes) suggest that water scarcity might double by 2050. The projected percentage increase might be as high as 350 percent in the Republic of Yemen by 2050.

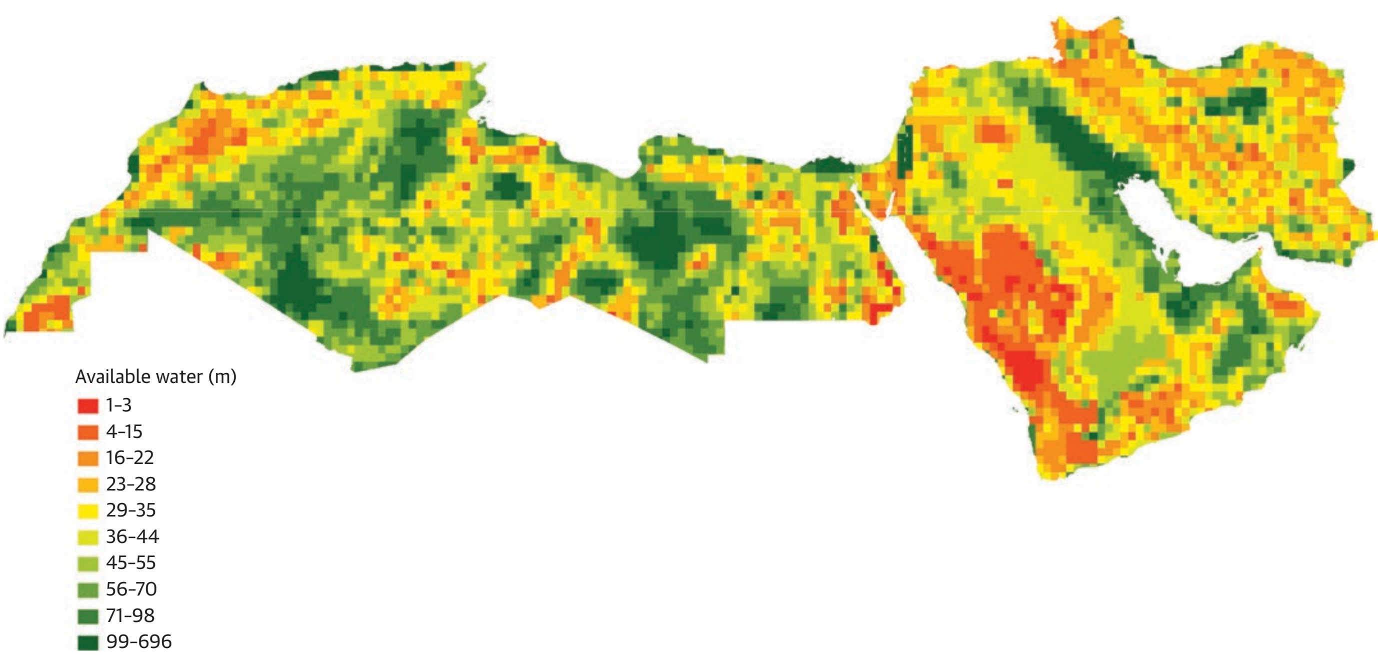
Groundwater Overexploitation and Depletion

Faced with increasing water scarcity, economies in the region have turned to groundwater resources to meet booming demands. In all economies, more water is being used than it is available on a renewable basis; that is, they face a condition of nonsustainable water use in which water withdrawals consistently exceed available water (World Bank 2017a). To respond to this condition and continue meet demands, upper-middle-income economies with large fossil fuel reserves have invested in desalination technologies as alternatives to continued withdrawal of freshwater resources (World Bank 2012). Other economies largely rely on the withdrawal of nonrenewable fossil groundwater resources.

Much of the region's groundwater resources are overexploited and headed toward depletion. Groundwater overexploitation is justified as a strategy to cope with climate variability in the short term (for instance, in response to prolonged drought). However, in the long term, continued overexploitation of groundwater resources is not sustainable because it can reach a critical point where nonrenewable aquifers are depleted and renewable aquifers are drawn down to the point where abstraction is no longer economically feasible (Wada and Bierkens 2014; World Bank 2017a). As aquifers are drawn down, exploitation costs increase because of the increased pumping depth and the additional costs required to treat the low-quality water produced by overexploited aquifers. As shown in map 2.1, groundwater available for abstraction is increasingly limited and comes at increasingly higher costs (see map 2.2).

At the current pace of exploitation, nonrenewable fossil groundwater reserves are set to disappear or become too expensive to abstract by 2050. Figure 2.2 shows the amount of fossil groundwater withdrawals in 2020 and 2050. The GCC countries, Iraq, the Syrian Arab Republic, and the Islamic Republic of Iran are all projected to run out of fossil groundwater reserves by 2050, with some running out as early as 2030.

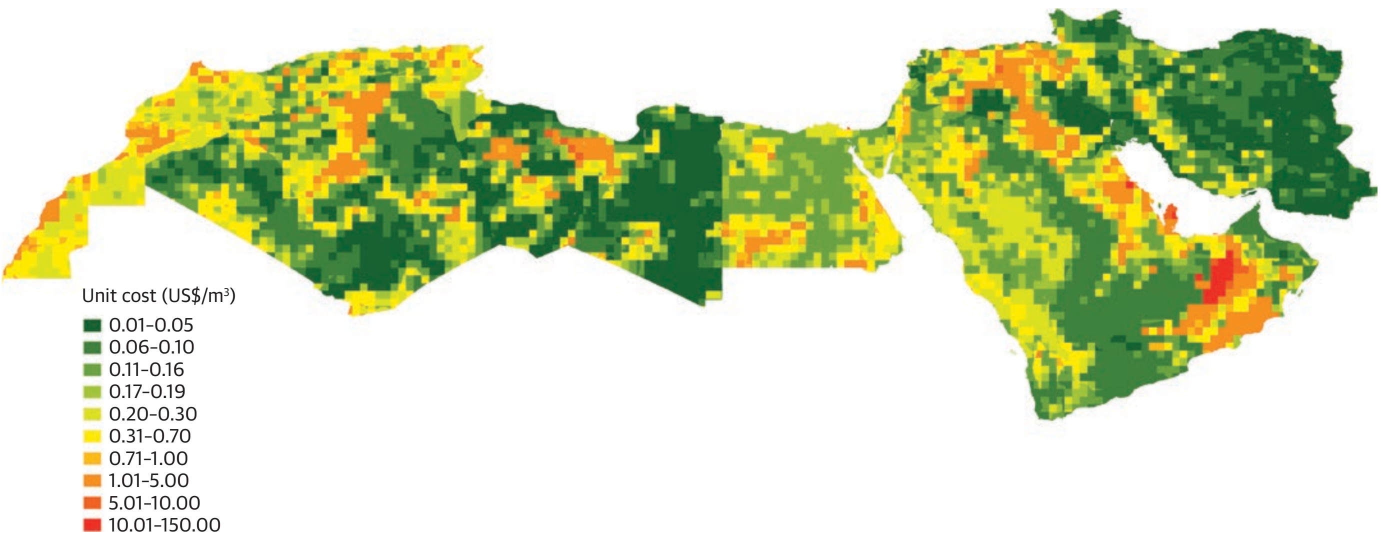
MAP 2.1. Spatial Distribution of Estimated Total Available Groundwater in the Middle East and North Africa



Source: University of Maryland calculations.

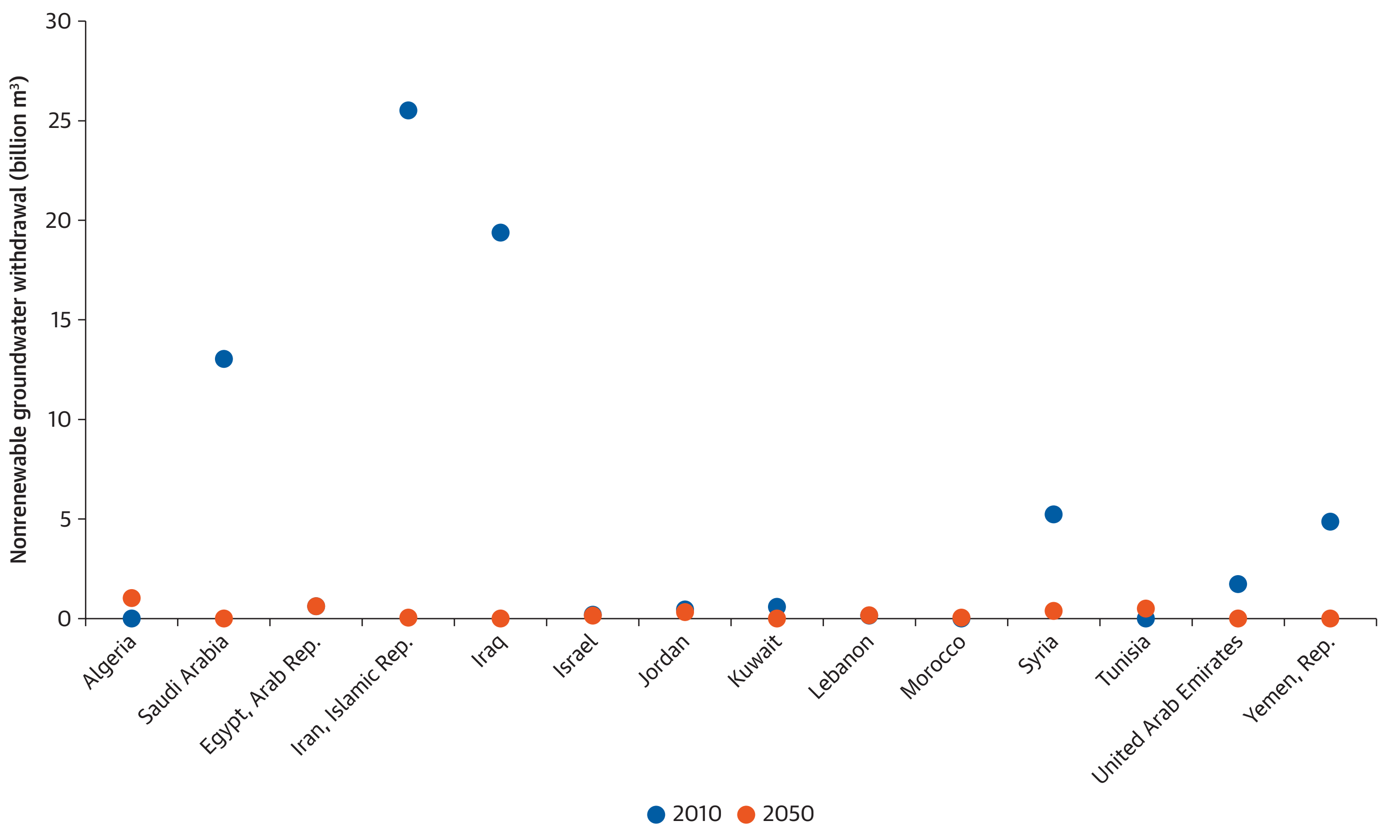
Note: "Available water" is expressed as depth of water column. Values reflect the total available groundwater underground, some of which may not be available for abstraction given limits of water pumps.

MAP 2.2. Estimated Total Groundwater Abstraction Cost in the Middle East and North Africa



Source: University of Maryland calculations.

FIGURE 2.2. Annual Nonrenewable Groundwater Withdrawals in the Middle East and North Africa, 2010 and (Projected) 2050



Source: World Bank and University of Maryland calculations.

Note: Estimated under a scenario of moderate economic development and moderate improvements in efficiency (SSP2). Reductions are driven by the progressive reduction of fossil groundwater resources that can be economically abstracted, implying that fossil groundwater resources may become depleted and may need to be substituted with different supply sources. No data for Libya. SSP = Shared Socioeconomic Pathway.

Less Water for More People: The Role of Increasing Population Demands and Climate Change on Water Scarcity

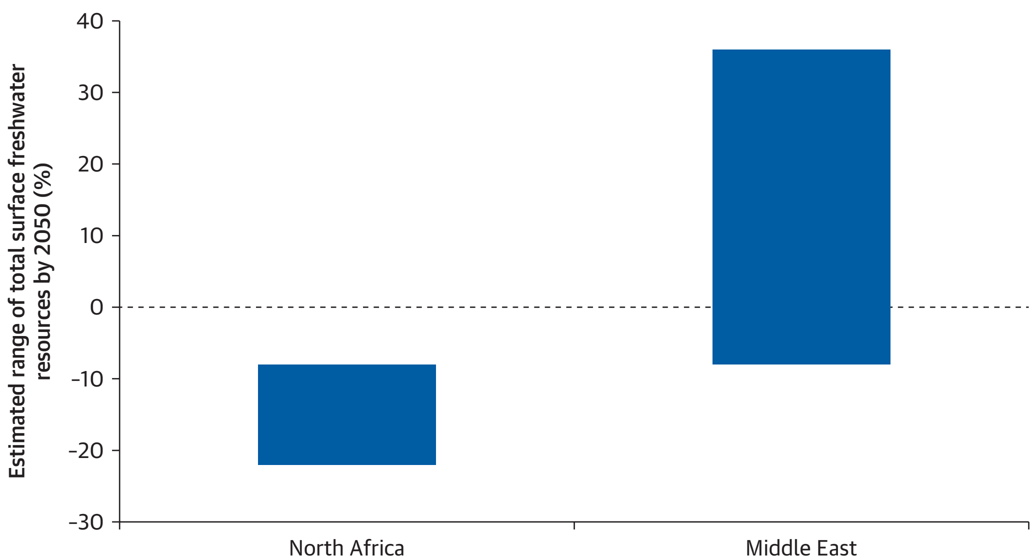
To understand what's driving water scarcity, the evolution of water use and water availability is considered in isolation. Water scarcity is a function of both availability and use, so considering these two factors in isolation helps understand the extent to which they drive changes in water scarcity.

Total available freshwater is set to decrease overall in North Africa, models used in this study suggest. A reduction in the range of 8 percent to 22 percent is projected by the climate models used in this study (see figure 2.3). In the Middle East, climate models reach different conclusions, with some suggesting an 8 percent reduction in total available freshwater by 2050 and some suggesting a 30 percent increase by 2050.

The range of projected freshwater availability is due to the different climate models used. All models are run under the same forcing conditions, that is, the same greenhouse gas emissions and under the same climate mitigation policy assumption. The differences in the projections are due to the different ways in which they represent and parameterize climate processes such as land surface and atmosphere interactions, cloud cover, or sea ice cover (Karl and Trenberth 2003).

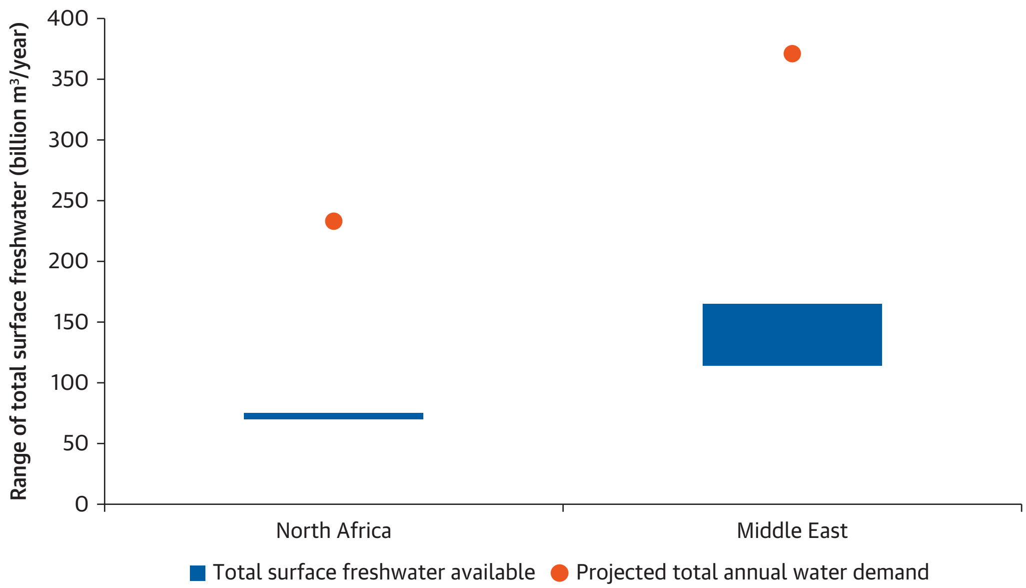
Although freshwater resources available may increase in relative terms in the Middle East, they will still not be enough to meet soaring demands. In figure 2.4, projected

FIGURE 2.3. Projected Change in Total Available Surface Freshwater in North Africa and in the Middle East by 2050



Source: World Bank and University of Maryland calculations.
Note: This figure highlights some of the uncertainties in projected freshwater resources availability in the Middle East, especially in the Levant. This was estimated using three Global Circulation Models (GCMs) and one climate forcing scenario (Representative Concentration Pathway [RCP] 6). The range is due to the different ways in which models parameterize climate processes such as cloud cover, land surface and atmosphere interactions, and sea ice cover.

FIGURE 2.4. Range of Total Surface Freshwater Available and Projected Total Annual Water Demand in the Middle East and North Africa by 2050

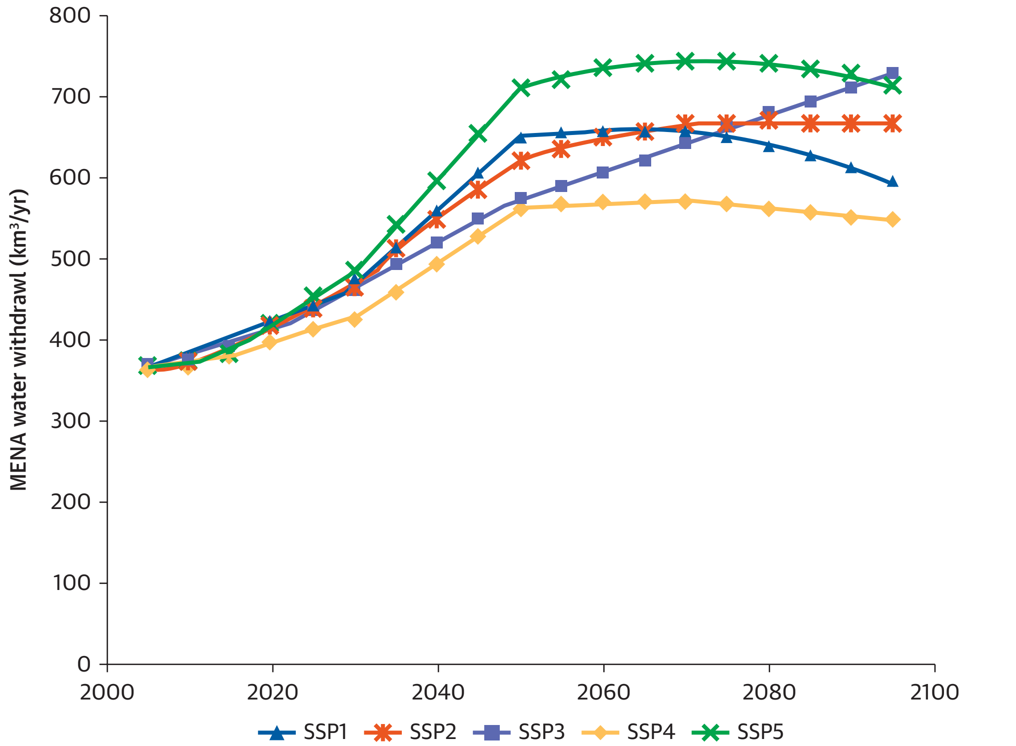


Source: World Bank and University of Maryland calculations.
Note: Lower bound is worst projected outcome, upper bound is best projected outcome based on the scenarios considered in this study and uncertainties in climate model output.

demands under a middle-of-the-road scenario (SSP2, which embodies a world with moderate population growth and moderate efficiency improvements in resource use) are compared to projected surface freshwater available in absolute terms. Based on the projections, demands exceed available freshwater supplies.

Increasing water demands drive water scarcity. Under all scenarios—even a scenario of sustainable resource use embodied in SSP1—water withdrawals are projected to increase by about 40 percent by 2050. These projected increases are two to three times greater than the projected available freshwater resources. By implementing the SSP scenarios in GCAM, the water withdrawals associated with each of the five SSPs can be simulated (figure 2.5). Water withdrawals are lowest in SSP4, the "inequality" scenario (refer to figure B1.1 and table B1.1). This can be explained by considering the projected increases in productivity and sustainability of resource use in upper-middle-income economies that stabilize water withdrawals after 2040. However, under this scenario low-income economies do not seize the opportunities of economic development and become even more vulnerable to the impacts of climate change. SSP1, embodying a world of sustainable resource use, shows the greatest decrease in water withdrawals, which highlights the potential for longer-term sustainability of water use in a world characterized by moderate economic growth and highly productive agricultural systems and low meat demands.

FIGURE 2.5. Projected Water Demand in the Middle East and North Africa, 2000–2100



Source: University of Maryland calculations.
Note: SSP = Shared Socioeconomic Pathway.

Growing populations, changing diets, rising incomes and urbanization are some of the factors behind increasing demands and thus water scarcity in the Middle East and North Africa. Human development and food needs are the core drivers of water scarcity, so efforts to realign incentives for water use and reducing demands need to be significantly scaled up if the region is to thrive in a water-constrained world. Many economies in the Middle East and North Africa are also relatively young in terms of their population age distribution and have high fertility rates, compounding future water scarcity challenges.

Chapter 3 Impacts of Water Scarcity and the Nexus

The challenges of the water-energy-food nexus are intensified in the context of global climate change, rapid population growth, and urbanization. Data availability, spatial scales involved, and difficulty in modeling specific processes restrict the nexus analysis to specific sectors. Nevertheless, an estimate of the range of projected impacts for food and energy production arising from water scarcity can be determined with GCAM and is presented in this chapter.

Water Scarcity and Food Production

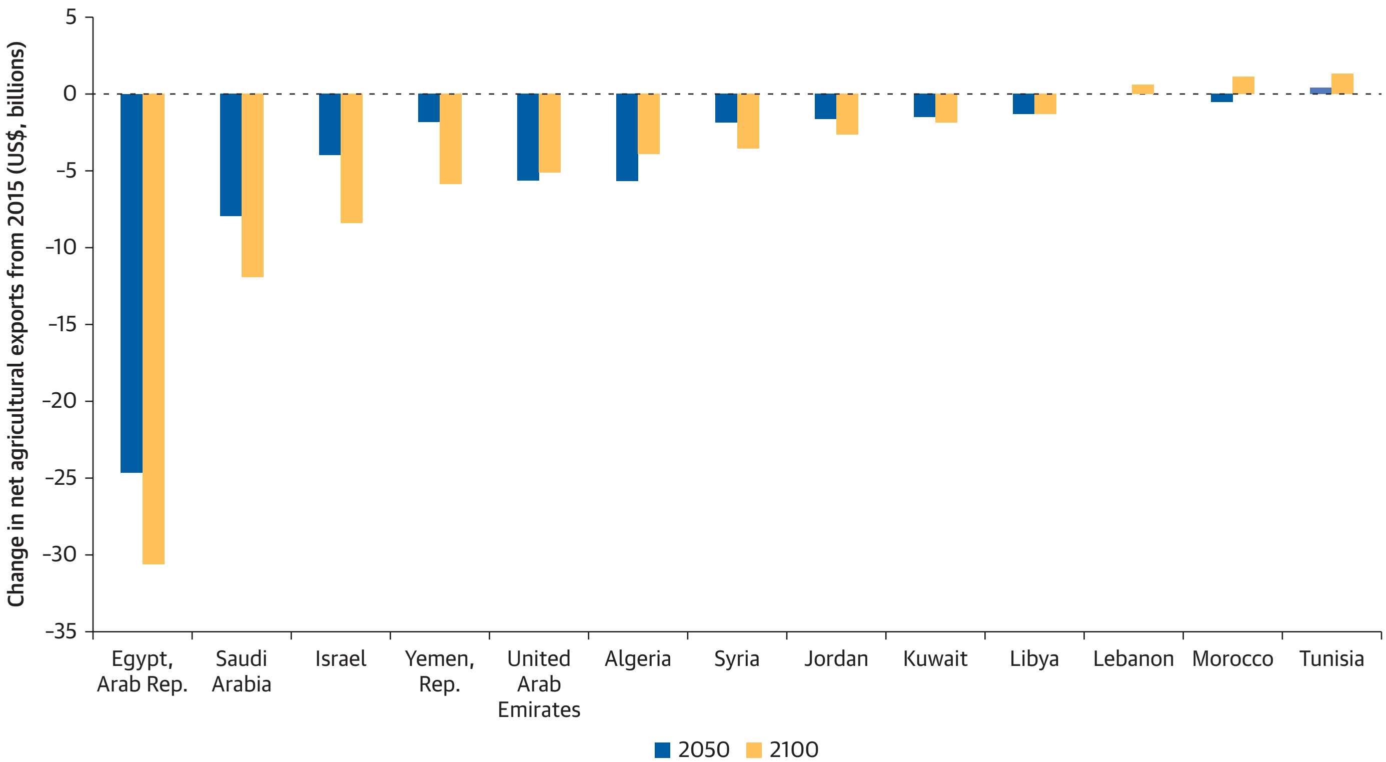
Increasing water scarcity has significant negative impacts on food production. With increasing water scarcity, there will be significant overall reductions in agricultural production and changes in the type of crops produced. The impacts will depend on the economy and on the type of water management policies developed to cope with scarcity. Under the moderate economic development scenario adopted in this study, Saudi Arabia has the largest projected losses in agricultural production by 2050 (about 65 percent reduction from current levels), followed by the Republic of Yemen (with a 35 percent reduction), and the Syrian Arab Republic (projected to lose 13 percent of its agricultural production). The Islamic Republic of Iran and Lebanon each stand to lose about 5 percent of their agricultural production under the scenario considered here. Economies in North Africa are projected to face lower losses.

Limits on water availability will also affect the types of crops grown in the region. Water scarcity constraints may contribute to changes in the crop basket, especially in economies that are already projected to suffer losses in agricultural production. Wheat production is projected to drop markedly in Saudi Arabia. This is line with government plans phasing out wheat cultivation because of the strong concerns over depleting groundwater reserves (FAO 2017). In the Republic of Yemen, production of herbs, most notably qat, is projected to decrease significantly. Rice production in the northern region of the Islamic Republic of Iran is also projected to suffer from increasing water scarcity.

With water constraints limiting opportunities for food production, export revenues from food commodities are projected to drop. Models suggest that in some economies, export revenues from the agricultural sector could drop by tens of billions of dollars. Figure 3.1 shows the change in total net exports by 2050 and 2100. The Arab Republic of Egypt, Saudi Arabia, Israel, and the Republic of Yemen appear to have the highest projected losses in agricultural exports under the scenario considered in this study.

Against this backdrop of decreasing agricultural production due to water constraints, achieving food security in the region is a demanding task. Agricultural systems are faced with maintaining agricultural production at current levels in a more variable climate, under significantly higher temperatures and extremes, and under increased competition for scarce water resources from growing cities. As discussed in the next section, stronger safety nets and increased participation in global markets are some of the approaches to achieve food security in a water-constrained world.

FIGURE 3.1. Projected Change in Net Agricultural Exports in the Middle East and North Africa, 2050 and 2100



Source: World Bank and University of Maryland calculations.
Note: Net exports are calculated as the difference between consumption and production multiplied by crop prices estimated by the Global Change Assessment Model (GCAM). No data available for Iraq and the Islamic Republic of Iran. This was estimated using the Goddard Institute for Space Studies (GISS) climate model, one emission scenario (Representative Concentration Pathway [RCP] 6), and the Shared Socioeconomic Pathway 2 (SSP2) scenario for socioeconomic development. Results should be used with caution because different estimates may be obtained depending on the scenarios and model used.

Increasing water scarcity that results in declining agricultural production may also accelerate migration patterns. Subsistence and small holder farmers, especially in rainfed areas, stand to suffer the most from climate-related water scarcity. Global evidence suggests that water scarcity may amplify and accelerate migration patterns (Wrathall et al. 2018). Rising temperatures, set to affect the Middle East and North Africa as a result of climate change, have also been identified as a potential influence on migration, especially in the most agriculture-dependent economies (Cai et al. 2016).

In light of the decreasing agricultural production related to the depletion of local water reserves, many economies are strengthening food trade networks and encouraging farmers to engage in alternative sustainable production activities. In Saudi Arabia, for instance, farmers have been encouraged to move from cereal cultivars to higher value production activities such as vegetable and fruit production using advanced drip irrigation techniques (FAO 2017).

The modeling results are not intended to provide an exact forecast of agricultural production by 2050. Instead, they are intended to improve understanding of the potential impacts of water scarcity on agricultural production in the context of changing climatic conditions and growing populations in the Middle East and North Africa. They were obtained considering a scenario of moderate improvements in agricultural productivity in a world with sustained population and economic growth (SSP2; see box 1.1). The coarse resolution of the model used means that impacts on supply chains and on minor crops prevalent in some parts of the region and of important nutritional value are not considered.

Water Scarcity and Electricity Generation

Coping with increasing water scarcity and groundwater depletion requires energy, while water is needed to process and deliver energy. Groundwater pumping, desalination, water transfer and wastewater treatment represent some of the most energy intensive activities in the region. In the energy sector, water is used for thermoelectric (such as fossil fuels and nuclear) power plant cooling (see box 3.1), fossil fuel extraction, and processing. Water is also increasingly used for carbon capture and storage (Byers, Hall, and Amezaga 2014).

BOX 3.1. Using Water for Power Plant Cooling

Power plants create electricity with steam turbines. Once steam passes through a turbine, it is typically cooled off with water before it can be reheated and used to produce more electricity. There are three main methods of cooling:

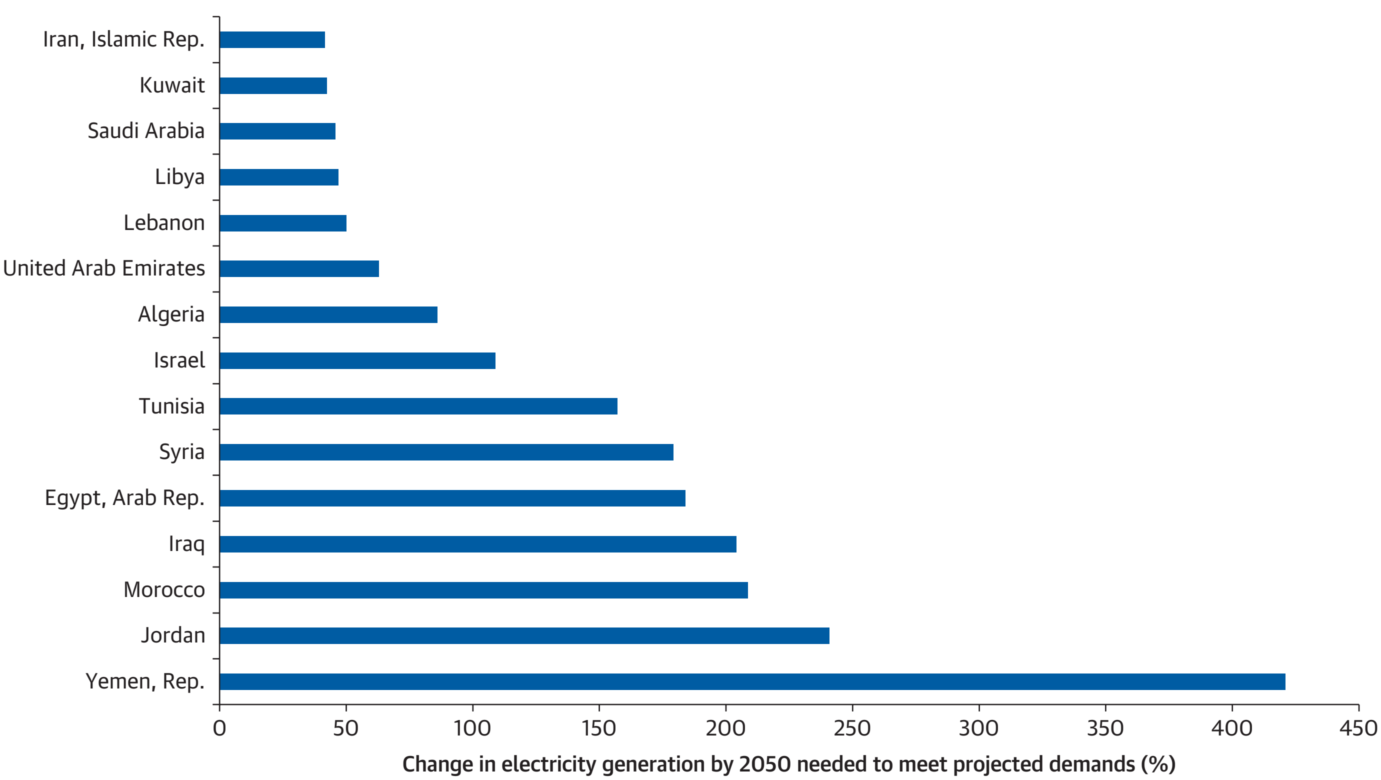
- **Once-through.** This type of cooling withdraws water (either freshwater or seawater—if the plant is along the coast) and circulates it through the system to cool off the steam before discharging it back into the local water source. This technology does not permanently remove water from the environment (it is not a consumptive use), yet it can cause significant disruption to local aquatic ecosystems because the temporary withdrawal can lower river levels and because of the high temperatures of the water discharged. Although most old power plants employ this cooling method, very few new power plants use once-through cooling.
- **Wet recirculating.** These cooling technologies reuse water in a cycle rather than discharging it has circulated through the system. Wet recirculating systems withdraw water only to replace water lost to evaporation in cooling towers. They withdraw far less water than once-through technologies, but have an overall higher water consumption.
- **Dry cooling.** These systems use air instead of water to cool off the steam exiting the turbines. Dry cooling technologies use no water and can decrease total power plant water consumption. However, compared to water-based cooling technologies, dry cooling is less efficient and more expensive (meaning that more fuel, such as gas or nuclear, is needed per unity of electricity generated).

Source: Union of Concerned Scientists 2017.

The water-energy nexus tops the list of critical uncertainties for energy leaders in the region. A recent survey by the World Energy Council revealed that energy leaders rank the water-energy nexus as one of the topmost critical uncertainties affecting energy security, alongside geopolitical risks and commodity prices (World Energy Council 2017). The survey reveals how the water-energy nexus is deemed as a highly critical yet uncertain factor with potentially severe consequences for the region's energy security. These consequences include depleting water levels in dams (due to droughts), subsequently lower hydropower production, competition for water resources from domestic and agricultural users, and changing water availability patterns due to climate change.

The energy sector will face challenges to meet rising demands, adapt to increasing water scarcity, and work toward climate change mitigation objectives. Under the moderate development scenario (SSP2), electricity generation alone is expected to increase by 35 percent by 2020 and by 85 percent by 2050 to meet increasing energy demands. Figure 3.2 shows the increase in electricity generation needed to meet projected demand

FIGURE 3.2. Projected Change in Electricity Generation to Meet Projected Electricity Demands in the Middle East and North Africa, 2015–50



Source: World Bank and University of Maryland calculations.

Note: This was estimated using the Goddard Institute for Space Studies (GISS) climate model, one emission scenario (Representative Concentration Pathway [RCP] 6), and the Shared Socioeconomic Pathway 2 (SSP2) scenario for socioeconomic development. Different estimates may be obtained depending on the scenarios and model used.

growth by economy. These projections are broadly in agreement with energy demands estimated in the literature, in which substantial growth in the energy sector in response to fast-paced population growth and access to domestic resources is expected (Bayomi and Fernandez 2017; IEA 2017). Policy makers and other stakeholders must understand the implications of water scarcity on electricity generation at present and in the future—given growing electricity needs and accounting for the deployment of clean energy technologies.

Country- and economy-specific circumstances lead to different impacts and energy outlooks. Forces driving energy system change depend on contexts and include, but are not limited to, levels of economic development, fossil fuel reserves, energy access, and concern for water and food security. Most high-income oil exporting economies are set to experience moderate increases in energy demands by 2050. Other economies that are low- and middle-income and that are net energy importers stand to face 100 percent to 200 percent increases compared to current levels of energy demands.

Water policies are behind some of these booming energy demands. The dependence of some economies in the region—most notably the Gulf Cooperation Council countries and Israel—on desalination, which accounts for between 10 percent to 30 percent of their energy consumption, is just one of the drivers of energy use in the water sector (IRENA 2016b). Across the whole water supply chain, energy demands are projected to increase as wastewater treatment expands and groundwater pumping continues.

Whilst technological improvements, system integration, and competition have helped reduce the cost of desalination, desalinated water is still the most expensive and energy intensive water supply source. On average, desalination requires 23 times more energy than that required to extract and treat surface water, costing four to five times more than treated freshwater (World Bank 2016b). This means that desalination is still not economically feasible to supply water for lower value added uses (for instance, agricultural production).

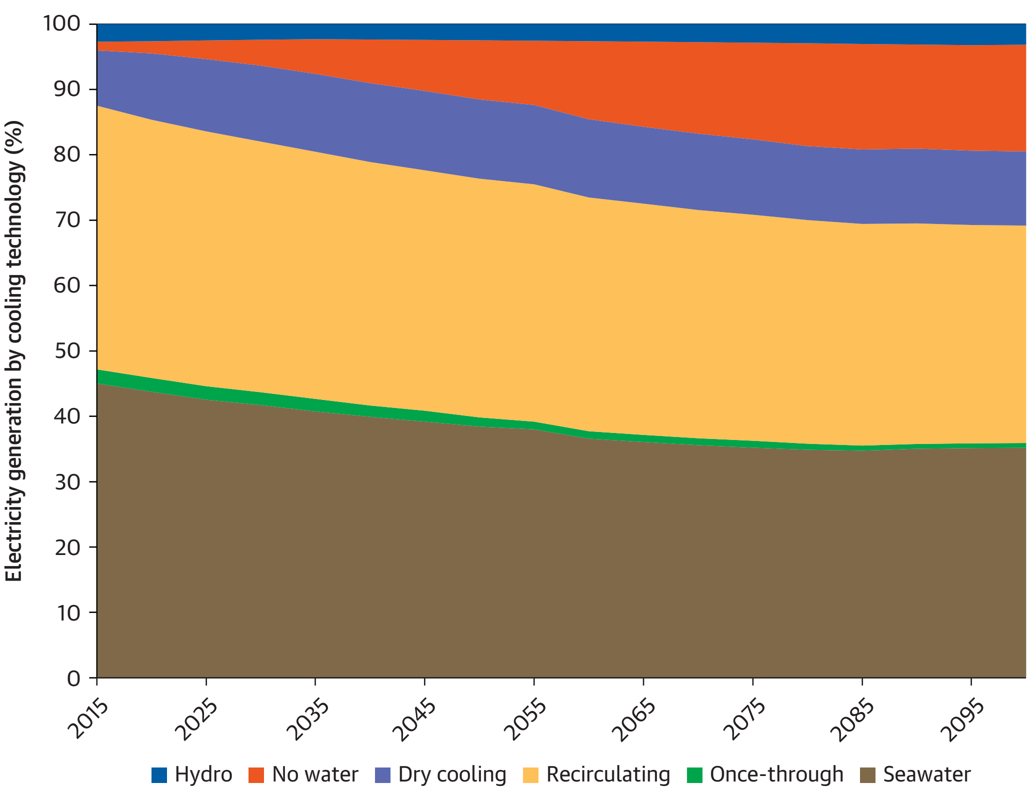
Pumping for irrigation and drainage consumes around 6 percent of total electricity and diesel in MENA (Commander, Nikoloski, and Vagliasindi 2015). Pumping groundwater from deep nonrenewable aquifers for irrigation requires more energy than using gravity-based conveyance of surface water. In economies relying almost exclusively on groundwater pumping for irrigation, such as the Republic of Yemen, energy use in agriculture accounts for more than 20 percent of total energy consumption. In principle, pumping efficiency improvements could lead to significant energy savings, possibly as much as 10,000 gigawatt hours of electrical power per annum (Commander, Nikoloski, and Vagliasindi 2015). Energy requirements vary depending on the total discharge, the hydraulic head, and the efficiency of the pumping system.

Water-related constraints may drive a shift in energy systems, leading to the phasing out of water intensive cooling technologies for thermal power generation and pushing for greater water use efficiency. To respond to increasing scarcity, power plants using once-through cooling technologies are likely to be phased out and substituted with less water intensive seawater recirculation technologies or dry cooling. Once-through cooling technologies already account for a low share of cooling technologies in the region (Siddiqi and Diaz Anadon 2011), so this shift toward less water intensive cooling options does not involve a major change in the overall picture of water use in the energy sector nor major adaptation costs.

The clear trend across the whole Middle East and North Africa toward adoption of renewable energy contributes to a reduction of the energy sector's water use. Although the extent to which different renewable energy technologies have been adopted varies, comprehensive studies from international energy agencies have demonstrated the potential for renewable energy in the region, as well as its ongoing adoption (IRENA 2015). As shown in figure 3.3 (for definitions, see box 3.1), electricity generation technologies that use no water will grow tenfold by 2050, largely as a result of the continued expansion of wind and photovoltaic technologies.

Climate change mitigation policies will likely reinforce some of these trade-offs and synergies, depending on the level of commitment in the Middle East and North Africa.

FIGURE 3.3. Electricity Generation Cooling Technologies in the Middle East and North Africa, 2015–2100



Source: University of Maryland.

Note: Data include renewables. See box 3.1 for definitions of cooling techniques.

The nationally determined contributions describe the mitigation actions that economies plan to undertake to meet the Paris Agreement targets. Several economies in the region have made unconditional commitments (that is, voluntary and implementable without outside support) to reduce greenhouse gas emissions. The Gulf Cooperation Council (GCC) countries and Egypt have not formally expressed any unconditional emission reduction targets but have provided mitigation targets. This lack of voluntary commitments suggests that greenhouse gas emission reduction may not be a driving force of regional energy policy (Griffiths 2017).

Chapter 4 Future Sustainability for the Water-Food-Energy Nexus in the Middle East and North Africa

The water-food-energy nexus is a promising approach to steward water resources sustainably for food and energy security. Its deployment in policy is, however, challenging and requires changing organizational practices and structures, economic incentives, and perceptions in all three sectors. The strategic responses described in this chapter demonstrate how considering the nexus interdependencies helps to address the region's sustainability and growth challenges. This chapter provides strategic recommendations instead of specific policy prescriptions, because the exploratory analysis carried out as part of the study does not warrant the identification of country- and economy-level priorities for policy making.

Reducing the dependence and demands of the food and energy sectors on water should be the overarching objective of water-energy-food policies in a water-constrained Middle East and North Africa. As the region becomes drier and subject to higher temperatures, policies that reduce the economy's dependence on water and anticipate climate's effects on the nexus are necessary for development and stability. To reach this overarching objective, multiple strategies can be developed and implemented. This chapter discusses some of the potential outcomes and nexus implications of strategies aimed at valuing water, increasing nonconventional water supplies, and transforming energy systems.

Valuing Water

Addressing the water-energy-food nexus interdependencies of the 21st century requires valuing water. Valuing water is difficult due to water's physical, economic, social, and cultural characteristics, yet it is a necessary step toward improved management of the resource and better water-related outcomes (Garrick et al. 2017). Governments must communicate water scarcity conditions using instruments such as transparent allocation, pricing, or the assignment of water rights (FAO 2017).

Although there is widespread recognition that water is scarce in the Middle East and North Africa, its productive value is rarely recognized. Many economies have some of the lowest water productivities in the world (World Bank 2017a). Low productivity happens when water is not reliably delivered to where it can be most productively used. Preparing the region for some of the inevitable consequences of water scarcity means recognizing water's productive value.

Efforts to value water can take many forms. These range from economic instruments to administrative tools. At the level of domestic users, they mainly take the form of water tariffs. Throughout the Middle East and North Africa, domestic users pay only a fraction of the costs of service provision, though this situation is reversing now with many economies gradually removing subsidies to water utilities (World Bank 2017a). Increasing municipal water tariffs needs to be done carefully to ensure that the poorest and most vulnerable populations retain access to water.

At the level of agricultural use, there are multiple ways to value water and use it more productively. Some of these measures include monitoring use, modernizing irrigation systems, increasing on-farm water productivity, and reducing losses in food-supply chains. For instance, satellite data can be used to find areas where water use is not leading to optimal agricultural production (García et al. 2016). This information can then be converted to improved planting decisions or changes in irrigation techniques. Modernizing irrigation systems is another important measure, as demonstrated by the low ratio between water required and water withdrawn in many economies and the substantial losses through seepage and evaporation (FAO 2009). Another way is by increasing on-farm water productivity, such as by increasing farmers' skills to better manage irrigation timing and by investing in precision delivery technologies (for instance, drip or bubbler irrigation) (Geerts and Raes 2009).

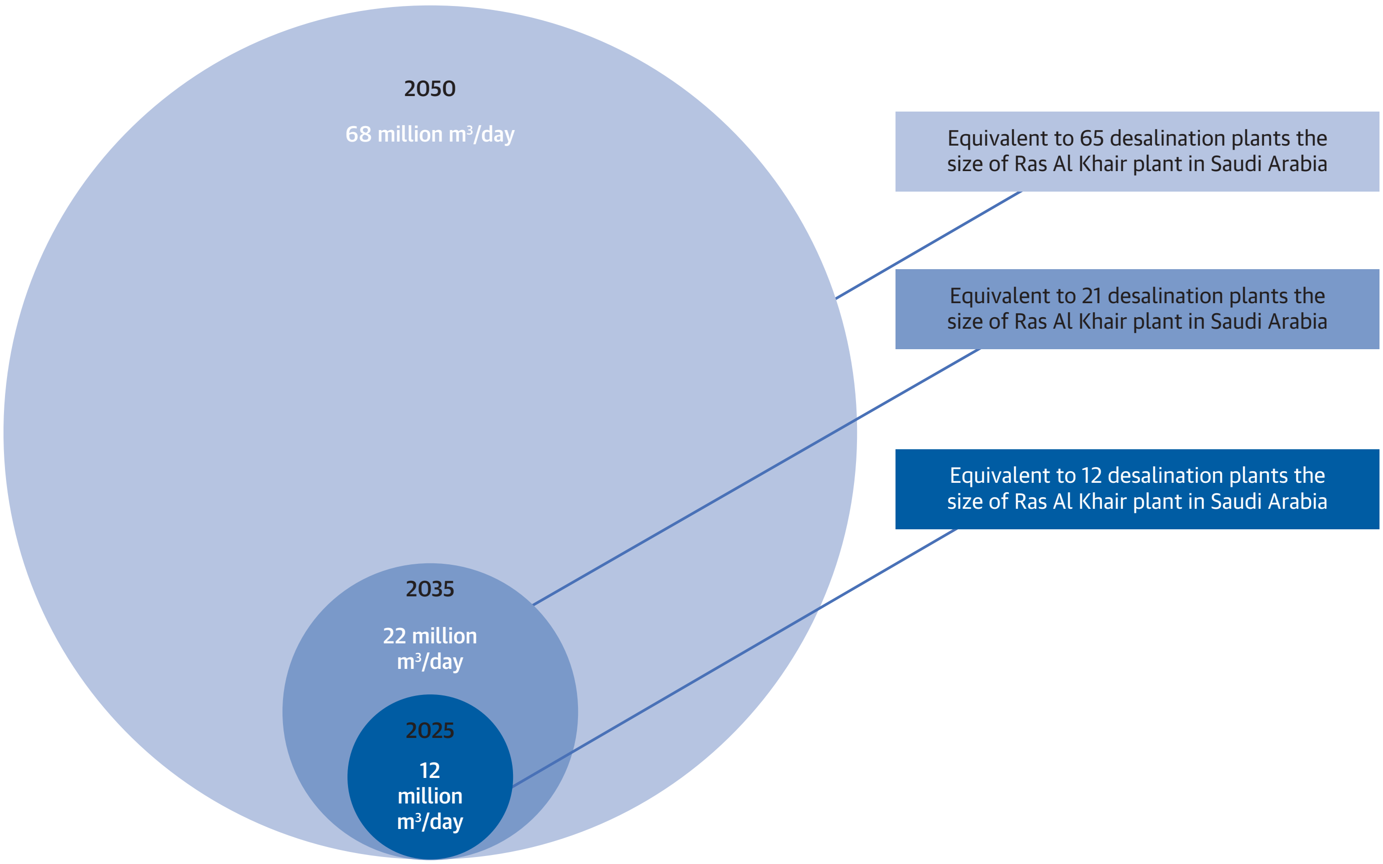
Improving the way water is valued and managed requires strengthening legal frameworks. When it comes to water, most economies in the Middle East and North Africa have less comprehensive legal frameworks than the global average. This represents both a challenge and an opportunity because legislation offers a fundamental tool for sustainable water resources management. Government legislation to support sustainable water management may include prescribing maximum allowed abstractions to preserve water quantities (especially of groundwater), creating impact assessments of proposed abstractions, and implementing water resource plans (Burchi 2012). In the pursuit of improved allocation of water to maximize its productive value, strong legal frameworks will be essential to ensure equitable resource allocation while providing the opportunity for efficiency gains.

Increasing Nonconventional Supplies

Nonconventional water supplies, including desalination and water recycling, offer opportunities to mitigate water scarcity, especially for high value added water uses. The Middle East and North Africa already account for about half of the world's desalination capacity, a number set to increase in the coming years (World Bank 2017a). Most of this capacity is concentrated in the high-income Gulf Cooperation Council countries, where large fossil fuel reserves make desalination economically feasible.

Under moderate improvements in agricultural productivity and land use practices ("middle of the road" scenario), the region would still need to increase supplies by 35 percent by 2030 and by 60 percent by 2050 from current levels. In water volumes, this means that the region is projected to reach additional supplies of about 12 million cubic meters per day by 2025 and of 68 million cubic meters per day by 2050 from the present day 34 million cubic meters per day (figure 4.1). Advancing technologies for wastewater recycling and desalination are viable alternatives to augment supplies, especially for growing urban centers and contiguous irrigation districts. In this scenario, only moderate demand-side efficiency

FIGURE 4.1. **Projected Increase in Water Supply Capacity Needed in the Middle East and North Africa by 2050**



Source: World Bank and University of Maryland calculations.
Note: Figure reflects amounts needed to meet soaring demands and confront depletion of renewable and nonrenewable freshwater resources under a scenario of moderate economic development and moderate improvements in efficiency (SSP2). This was estimated using the Goddard Institute for Space Studies (GISS) climate model, one emission scenario (Representative Concentration Pathway [RCP] 6), and the Shared Socioeconomic Pathway 2 (SSP2) scenario for socioeconomic development. Different estimates may be obtained depending on the scenarios and model used. The Ras Al-Khair plant located in Saudi Arabia is taken here for illustration purposes only and data on its capacity were taken GWI (2016).

measures are implemented. Under a higher efficiency scenario, projected levels of supply would be somewhat lower given the far-reaching implications of demand management measures and water reallocation.

Integrating water recycling into the water supply portfolio will be key to meet growing demands and achieving water security. About 80 percent of the region's wastewater is being discharged into the environment without being reused (World Bank 2017a). At present, some of the treated wastewater is recycled in agricultural systems or is injected in coastal aquifers, especially to prevent saltwater intrusion. Positive experiences in the region, for instance in Jordan and Tunisia, show that wastewater can be safely recycled for use in irrigation and managed aquifer recharge. Where wastewater is already treated to high standards or where investments in wastewater treatment are being planned, recycling should be considered as part of integrated water management strategies to meet known demand (Kfouri, Mantovani, and Jeuland 2009).

Water recycling also offers opportunities at the water-energy nexus. Water recycling can be achieved at zero-net energy use by capturing and reusing for energy generation wastewater treatment by-products, such as biogas and sludge. This contributes to mitigate emissions from the water sector and reduces overall energy demands. Similarly, water recycling in the energy sector provides a more economically attractive alternative to expensive desalination or freshwater overexploitation, especially when the full costs of the depletion are taken into account (Kajenthira, Siddiqi, and Anadon 2012).

Desalination offers the potential of highly reliable water supplies, yet it is not a panacea to solve water scarcity. Recent advances in membrane technology are making desalination an increasingly viable alternative to traditional freshwater resources, yet the environmental impacts of brine disposal on marine ecosystems are increasingly constraining the expansion of desalination, especially in the Gulf. When seawater is desalinated, brine waste products are generated and typically disposed of in surrounding marine waters. In closed and shallow seas such as the Gulf, these impacts can be significant and can go beyond negatively impacting marine ecosystems to impair desalination processes as well (Dawoud and Al Mulla 2012). Higher salinity concentrations make desalination more expensive: in the long term, desalination plants need more energy to desalinate the same volume of water because of higher salinity concentrations.

Adopting nonconventional water supply sources is challenging, especially if they have to substitute for depleting groundwater resources. The depletion of groundwater resources means that the demands previously met with groundwater will have to be met by alternative supply sources. Groundwater is a widely abundant resource found in many parts of the Middle East and North Africa, and it is a crucial supply source in rural areas. Replacing it with alternative supplies is challenging, especially because nonconventional supplies, such as desalination and wastewater reuse, require large-scale capital investments to treat and convey the water. Thus, as groundwater becomes depleted and nonconventional supplies are gradually scaled-up, economies will face challenges relating to costs of these more centralized water supply options.

Promoting water recycling requires recognizing the real costs of freshwater resources depletion. If the real costs of freshwater resources depletion were taken into account, integrating water recycling into supply systems would make economic sense. The economic costs of freshwater resources depletion—and its related impacts on livelihoods and ecosystems—are traditionally not factored into food and energy policies. This makes the economic case for water recycling somewhat less compelling and incentivizes overexploitation.

Moving Toward Renewable and Less Water Intensive Electricity Generation

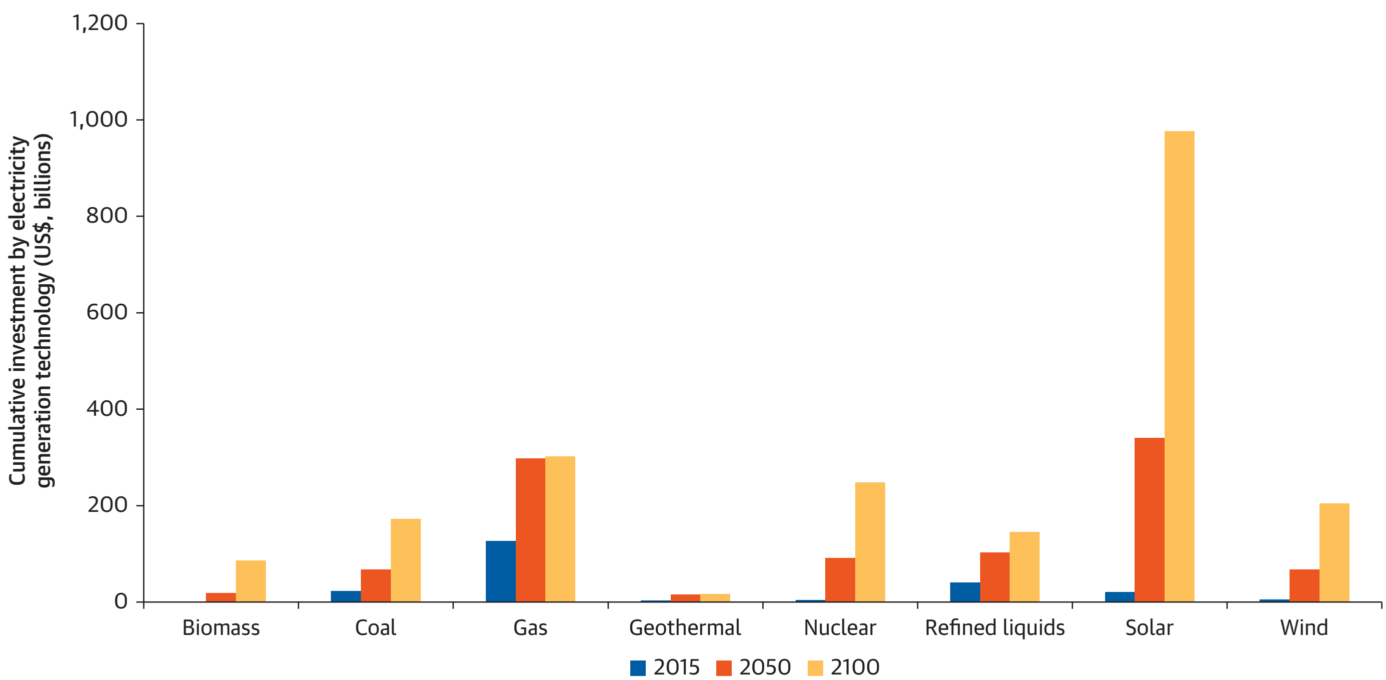
Restructuring energy systems toward renewable energy sources contributes to water sustainability. Shifting toward less water intensive power plant cooling technologies and investing in low water intensity renewable technologies (in particular, solar photovoltaic technologies and wind) comes at a cost, estimated to total approximately a thousand billion dollars by 2050.

Gas, biomass, and solar photovoltaics all have an important role in adapting the electricity generation system to increased scarcity and competition for water resources. In a water-constrained world, shifting toward renewable energy sources also means lowering the demand for water resources for electricity generation. The expected costs by technology to 2050 and 2100 to adapt the electricity generation system to a water scarce world are shown in figure 4.2.

Moving toward a less water intensive energy sector also rests upon changing incentives. Raising the effective price for groundwater pumping can reduce the incentives for wasteful irrigation practices. In some instances, this can go as far as influencing national food policies, pushing economies to move away from food self-sufficiency policies toward increased reliance on global markets (Commander, Nikoloski, and Vagliasindi 2015). Importing food products can contribute toward reduced energy and water consumption in the agricultural sector, as long as farmers are provided alternative livelihood and income opportunities.

The potential for greater energy efficiency is untapped, providing an additional benefit that needs to be integrated into water-energy-food planning. The potential for energy

FIGURE 4.2. Cumulative Investments by Electricity Generation Technology to Meet Projected Demand in the Middle East and North Africa, 2015, 2050, and 2100



Source: World Bank and University of Maryland calculations.
Note: Refined liquids refer to hydrocarbon fuels (including diesel, gasoline, and kerosene) used for electricity generation.

savings from efficiency programs in the region by 2025 is estimated at 21 percent (World Bank 2016a). Many economies are already developing energy efficiency programs, including moving away from the more energy intensive desalination technologies (for instance, multistage flash distillation). These efforts need to be expanded and integrated into national strategies for carbon emission reduction and resource sustainability.

Even if the transition to less water intensive energy systems comes at a cost, renewables still make economic sense. This is because when regional water availability and infrastructure costs are considered, that is, when water scarcity is priced, low water intensity energy technologies start to make economic sense. The importance of accounting for water scarcity and related opportunity costs in energy planning has been recognized in other parts of the world, such as South Africa (World Bank 2017b).

A transition toward low water intensity renewables makes sense from a climate mitigation perspective. Economies would have to invest in low water intensity technologies such as solar and wind power if they are to meet greenhouse gas reduction targets following the Paris Agreement. Therefore, there are synergies in the efforts to reduce the water intensity of electricity generation and efforts to reduce greenhouse gas emissions.

Energy system transitions are not just a function of technical and economic factors. The results here do not consider political and human factors, which are crucial for electricity projects to succeed. Therefore, they should be considered as an indication of what the future energy system of the Middle East and North Africa could look like in a water scarce world.

Chapter 5 Conclusions

In the rapidly evolving contexts of the Middle East and North Africa, water scarcity will intersect other pressures such as migration, land use change from rapid urbanization, and increasing temperatures from climate change, which will strain agricultural production. Achieving water security under these conditions will be increasingly challenging and will require new policy and technology instruments, including conservation and permanent or temporary reallocation of water to higher value added uses. Failure to act will have significant economic implications, some of which are estimated in this study, and could have repercussions on social and political systems. Evidence from the western United States shows that profits from continued agricultural production can be maintained under increased competition for scarce water resources if water allocation mechanisms are flexible and if all users, especially in growing urban centers, conserve water (Dozier et al. 2017).

Water scarcity will impact electricity generation, requiring a shift toward less water intensive renewable energy sources. Investments in less water intensive electricity generation technologies need to occur if the region is to meet the greenhouse gas emission mitigation targets specified in Paris Agreement. This suggests that decarbonizing electricity generation in the region provides a win-win option from a climate mitigation and water security perspective.

In implementing the governance and technological measures needed to address these challenges, cooperation and partnerships around water, agriculture, and energy will be essential. Regional partnerships with national, regional, and global actors foster development and trust across the Middle East and North Africa, leveraging resources and knowledge needed to develop innovative and inclusive solutions. Regional initiatives, such as the Arab League's Nexus Dialogue Programme, provide platforms to inform the development of policies to address water-food-energy challenges. Similarly, partnerships between bilateral and multilateral development institutions, such as the Arab Coordination Group, can enhance coordination for more effective water-energy-food nexus policies.

This study contributes to advancing knowledge on the linkages between water, energy, and food in the region. These three sectors are linked across different scales. In this study, interdependence at the national and regional levels was examined. However, links between water, food, and energy also materialize at the household, community, and local levels. Thus, the findings from the analytical framework employed here should be complemented with information on local impacts to build a more comprehensive picture of the water-energy-food nexus in the region.

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