The Water-Energy-Food Nexus in Arid Regions: The Politics of Problemsheds

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Abstract and Keywords

Systems of producing, consuming, and distributing water, energy, and food involve trade-offs that are rarely explicitly considered by firms and policymakers. The idea of the water-energy-food "nexus" represents an attempt to formalize these trade-offs into decision-making processes. Multinational food and beverage firms operating in arid regions were early promoters of nexus approaches, followed by aid donors, consultancies, and international institutions seeking a new paradigm for resource management and development planning. The first generation of nexus research focused on quantitative input-output modeling to empirically demonstrate interdependencies and options for optimizing resource management. This chapter employs a different approach, analyzing institutional "problemsheds" that shape the implementation of nexus initiatives in arid regions of the United States, the Persian/Arabian Gulf, and China. Our analysis reveals how nexus approaches are conditioned by property rights regimes, economic growth strategies based on resource extraction, and the ability to externalize environmental costs to other regions and states.

Keywords: Water-energy-food nexus, resource management, development, arid regions, China, United States, Persian/Arabian Gulf

Introduction

The water-energy-food nexus has emerged as a widely discussed concept in development policy circles in recent years. The core of the nexus concept is that the production, consumption, and distribution of water, energy, and food are inextricably linked, and that decisions in one sector typically impact other sectors, often adversely (Hoff 2011). From its inception, however, the notion of the water-energy-food nexus carried normative implications about how to manage resources more efficiently. Advocates argued that thinking in terms of interdependencies and trade-offs between water, energy, and food would produce more awareness of interactive effects and foster coordination among the water, energy, and food sectors. Thus, the water-food-nexus was from the outset also a political and normative undertaking rather than simply a technical framework for resource management.

This chapter thus analyzes the evolution and implementation of the nexus concept, focusing particularly on arid regions where water security drove firms and policymakers to consider nexus effects. We explore how different actors have understood, promoted, and made use of the nexus concept. As we show, the water-energy-food nexus was initially promoted by a small number of multinational firms in the food and beverage sector, where water is a primary input and thus water scarcity thus an issue of supply chain security (Waughray 2011). Nexus initiatives thus emerged particularly in semi-arid and arid regions where water scarcity had begun to pose constraints on the production of food, fiber, and energy. Disseminated by consultancies and Western donors, much of the development community subsequently adopted the water-energy-food nexus as a new paradigm for resource management and development planning (Boccaletti 2009; Hoff 2011; 6th World Water Forum 2012; Waughray 2011). However, efforts to promote cross-sectoral coordination across water, energy, and food present a number of difficult political and institutional challenges—as was also the case with earlier attempts to integrate water resource management across different sectors.

While donors and consultancies have sought to create generic conceptual templates of the linkages between food, water, and energy security, an array of public, private, and civic actors have adopted the nexus for different reasons and to achieve different ends. Drawing on empirical cases of institutional “problemsheds” in selected arid regions of the United States, the Middle East, and China, we analyze the politics of the water-energy-food nexus, focusing on how key actors promote or hinder nexus approaches to resource management. We identify obstacles to sectoral coordination for improved resource management and suggest opportunities for new coalitions and political pathways forward.

What Is the Water-Energy-Food Nexus?

Nexus approaches call for a better understanding of the linkages and trade-offs associated with the operation of water, energy, and agricultural systems of production, distribution, and consumption. Water, energy, and food are connected in multidirectional and complex ways, through several sub-nexuses. The water-energy subnexus has received the most attention in scholarly and development circles. The production of energy is associated with both consumptive and non-consumptive uses of water (Weinthal et al., this volume). The extraction of fossil fuels such as gas, oil, and coal require water for exploration, drilling, and pumping; nuclear power and concentrated solar power require water for cooling of power plants; hydropower leads to evaporation from reservoirs built to enable the generation of electric power; and geothermal energy requires water for drilling (Williams and Simmons 2013). All of these uses may also degrade water quality, sometimes significantly. In the United States, the largest share of energy-related water withdrawals (as opposed to water consumption) is used for power-plant cooling (Waughray 2011: 59). In arid regions, when water is scarce, fossil fuel and nuclear plants have been closed for lack of cooling water. Evaluating the water-consumption profiles of different energy sources thus provides one useful metric for decision-makers.

Water systems similarly require energy. Water pumping, irrigation, treatment, and desalination require substantial amounts of energy to produce, distribute, and treat water (IEA 2012). Water systems thus have different energy footprints. Calculations of energy intensity for different water sources used in southern California showed that using local and reused wastewater sources costs less than 500 kilowatt hours for every acre-foot (326,000 gallons) of water, whereas desalinated water cost more than 4,000 kilowatt hours per acre-foot (Waughray 2011: 60). The design and construction of large-scale water systems constructed during the hydraulic mission of the twentieth century has often failed to account adequately for differential energy requirements.

The second dimension of the nexus highlights the connection between water and food. Approximately 70 percent of global freshwater is withdrawn for agriculture. Apart from percolation and reflow into aquifers and rivers, much of this withdrawal is consumed by plants via evapotranspiration. It cannot be used twice in a given hydrological cycle—unlike, for example, the cooling water of a power plant that still can be used for other purposes downstream. Hence, if consumptive use of water is taken into account, the share of agriculture is even higher, at 92 percent (Hoogeveen et al. 2015). Agriculture is thus the largest global consumer of water. A vast quantity of the water embedded in agricultural products is traded through globalized grain and food supply chains, providing consumers with fresh and processed food. Meat and dairy production are especially water-intensive, as livestock production requires substantial inputs of water-intensive fodder crops. The concept of “virtual water,” conceived by Tony Allan and quantified by Arjen Y. Hoekstra, illustrates the amount of “virtual” water hidden in agricultural produce. For example, to produce a ton of wheat requires 1,300 cubic meters of water, while a ton of beef requires approximately 16,000 cubic meters depending on the age of the animal and whether the livestock has been raised on pasture or in a feed lot (Allan 2011).

The third dimension of the nexus concept pertains to the sub-nexus of energy and food production. The energy system provides direct inputs to the food system for cropping, livestock, and fisheries, as well as in food processing, distribution, retail, preparation, and cooking (FAO 2013a). Globally, agriculture has become heavily dependent on fossil fuels over the twentieth century. The invention of the Haber-Bosch process in 1908−10 made the industrial production of nitrogen fertilizers possible, while fossil fuels have been applied on a large scale to drill wells and to fuel tractors and combine-harvesters (Smil 2001).

In recent decades, the energy-food nexus has become even more prominent, with government subsidies to convert food crops such as corn and sugar into biofuels. In Europe, the production of biodiesel from rapeseed prevails, whereas in the United States ethanol is produced from corn and in Brazil, from sugar. A controversial debate has ensued about the energy balance of such production processes, with some arguing that it is negative (Pimentel 2003; Pimentel and Patzek 2005, 2008). Methodological controversies center on the role of coproduct utilization, chosen databases, technology, and plant location. Most studies see a slightly positive energy balance of about 1.3:1 for ethanol production from corn and a more favorable ratio for sugar, which produces about seven to eight times more energy than the fossil energy consumed in its conversion process to ethanol (National Geographic 2015; US Department of Agriculture 2010; US Department of Energy 2007; Wang et al. 2008). Greenhouse gas emissions from biofuels are in any case considerable when the effect of land-use change from expanded cultivation is taken into account (Searchinger et al. 2008).

More problematic for biofuels, however, are the tradeoffs in consuming water for energy production rather than for growing food. This issue links the energy-food sub-nexus with the one for water and food. The energy market, if measured in calories, is twenty times larger than the market for food. Even minor replacements of fossil fuels with biofuels constitute a huge drain on the scarce water resources needed for food production (Waughray 2011: 61).

The expansion of bioenergy production pursued by the European Union, the United States, and some large developing country economies also means competition between producing food for consumption and food for energy. Biofuels thus highlight not only linkages and trade-offs between water and energy but also between food and energy production (Bizikova et al. 2013). An OPEC-funded study estimated that if governments achieve the targets they have set for biofuels production, the result might be an increase in the price of grain by 30 percent in the 2010s (Fischer et al. 2009). Although biofuels suggest significant negative impacts when viewed from a nexus perspective that incorporates energy and water consumption, the United States and the European Union continue to provide extensive subsidies for biofuels.

Consumers, their food choices, and how they waste food are also significant issues in understanding the water-energy-food nexus. Growing populations require more food, water, and energy. At the same time, global economic change has increased the number of affluent consumers, particularly in Asia. As a result, further pressures on water, energy, and food systems are increasingly evident. Some analysts suggest that if business-as-usual strategies of resource management—in which the energy and agricultural sectors do not include water considerations—continue to be the norm, global water demand will outstrip conventional water resources by 40 percent by 2030 (Chartres and Varma 2010). Such estimates may even be conservative, as in the United States alone the growing demand for water for electricity production and shale oil and gas extraction has not been included in such calculations. At the same time, many organizations involved in the agricultural sector continue to employ old production systems that do not attribute value to water as a crucial input, comparable to labor, energy, or transport costs (Allan 2013). Doubling food production to meet growing demand, as the Food and Agriculture Organization of the United Nations (FAO) has suggested, overlooks the need to rework the ways in which farmers and agribusiness firms operate water-soil-food systems.

This chapter examines how nexus analyses are decisively political and politicized processes rather than technocratic exercises. Much of the first generation of nexus research focused on quantitative input-output modeling of energy and water in particular to demonstrate empirically interdependencies and options for optimizing resource management and policy choices (see, e.g., Bazilian et al. 2011; for the Middle East, Siddiqi and Anadon 2011; for China, Kahrl and Roland-Holst 2007). This chapter instead builds upon another strand of analysis, which emphasizes the importance of governance issues and institutional constraints in devising and adopting nexus approaches (e.g., Lele et al. 2013; Scott et al. 2011).

While water analysts often invoke the natural boundaries of “watersheds” as the appropriate unit of analysis and policy intervention for water issues, environmental economists have long recognized the importance of different scales of governance and institutions for environmental decision-making. In 1968, the economist Allen Kneese coined the term “problemshed” to highlight that administrative agencies for environmental regulation must be constructed at different spatial scales to respond to different types of environmental problems (Kneese 1968). We have adapted the term “problemshed” to highlight the multi-scalar institutional contexts needed to grasp adequately the dimensions of any specific water-energy-food nexus. Rather than applying nexus approaches in a technocratic, positivist manner, we emphasize how the underlying politics behind natural resources management shape and limit the ability of decision-makers to respond to problems of resource scarcity and degradation. In this respect, the problemshed for a given water-energy-food nexus may include formal regulatory institutions, comparative political systems, informal norms and practices of resource access and management, corporate supply chains, consumer behavior, and the impacts of financial and commodity markets. Our analysis of nexus problemsheds in arid regions of the United States, China, and the Persian/Arabia Gulf reveals the importance of legal and administrative histories of property rights, the institutional “stickiness” of economic growth strategies based on resource extraction, and the ability to externalize environmental costs to other regions and states as key factors in understanding the policy space for nexus initiatives.

Origins of the Water-Energy-Food Nexus

The idea of analyzing the linkage and trade-offs in water, energy, and food “systems” draws on natural and social sciences approaches emphasizing interdisciplinary inquiry and systems theory. Systems theory approaches were spearheaded by the biologist Karl Ludwig von Bertalanffy, and Ross Ashby, a pioneer in the field of cybernetics, the study of complex systems, in the 1940s and 1950s (Von Bertalanffy 1950). In heuristic terms, a system means a configuration of parts connected and joined together by a web of relationships (Bánáthy 1996). Scholars working with systems theories sought to draw on insights and methods from a variety of fields, including ontology, political science, physics, computer science, philosophy of science, biology, engineering, sociology, geography, psychotherapy, and economics. In studies of ecology, “systems theory” was also advocated by Howard Thomas Odum, who asserted that humans are the masters of Earth processes, since they shape the biosphere for their own ends (Odum 1994).

Several scholars in the 1970s argued that the interdependences of the energy and food systems constitute a crucial developmental challenge, although they did not refer explicitly to a nexus and did not focus on water as a principal resource of concern (Pimentel et al. 1976). Several studies in the 1980s and 1990s further emphasized the interdependence of energy and food in analyzing the dynamics of rural economies (Batliwala 1982; Sachs 1984; Sachs and Silk 1990). Hydrology only entered systems approaches to natural resource management in the 1990s, under the rubric of Integrated Water Resources Management (IWRM).

Conceived in the early 1990s, IWRM emerged as a policy framework emphasizing inter-sectoral and multi-scalar approaches to water management. An early formulation of IWRM was articulated by a meeting of water experts in 1992, known as the Dublin Statement. The Dublin principles identified water as (a) a finite, vulnerable resource of basic necessity and (b) an economic good with scarcity value, while also noting the importance of (c) women's roles and (d) participatory management. Some of these four principles were in tension with each other. While the statement called for participatory processes for decision-making at various levels of governance, it also argued that water should be viewed as an economic good, which could conflict with water as a basic right and an entitlement for survival (GWP 2006).

IWRM soon featured prominently in international development debates, yet the approach largely omitted the highly political nature of decision-making in water management and the mitigating role of the trade in virtual water (Allan 2003; Conca 2006). Its amorphous definition and lack of applicability in the real world have not gone unnoticed (Biswas 2008). IWRM was also criticized for elevating water ministries and water planning over other agencies and sectors, mainly food and energy, which are integrally tied to water usage. As Allan (2003) and Giordano and Shah (2014) argued, water experts overestimated their political clout in assuming that complex political questions of power and resource allocation could be significantly impacted by adopting the IWRM paradigm. IWRM planning approaches also generally failed to include stakeholders other than those from the water sector. As a result, IWRM remained the province of water experts despite the best attempts of European development agencies to broaden its application. As Giordano and Shah (2014) stress, successful interventions in water management have often strayed from the core principles of IWRM.

Alongside the turn to IWRM, water scientists also began to focus on identifying various "types" of water. These water types help illuminate the intimate connections between the water and food sub-nexus. To illustrate the different types of water used in agriculture, the Swedish scientist Malin Falkenmark introduced a chromatic framework that includes green, blue, and grey water (Falkenmark and Rockström 2006). In the hydrological cycle, the "ultimate source of water" on Earth is rainfall (Mulligan 2013). Precipitation waters plants, creating biomass. The precipitated water that infiltrates the soil profile and is held there is referred to as green water. The runoff of precipitation recharges groundwater and surface water reservoirs. This water is defined as blue water (Ringersma et al. 2003). It can be used for irrigation and accounts for about 40 percent of the world's food production by augmenting green water.

Green water held in soil supplies an estimated 60 to 70 percent of global food production (Ringersma et al. 2003; Allan et al. 2015). Despite its importance in global food production, green water is remarkably under-studied compared to blue water use. Several initiatives have recently begun to address green water systems, such as NASA's Soil Moisture Active Passive program to measure global soil moisture (SMAP 2015).

The era of surface and groundwater abundance has come to an inevitable end (Zetland 2011), particularly in the agricultural sector as the largest global consumer. Rainfall regimes associated with anthropogenic change impact both blue and green water supplies (for the Middle East and North Africa, see Sowers et al. 2011). While green water is used to produce the majority of food, blue water is a key input that enables farmers to attempt to mitigate the uncertainties of weather in agricultural production. Particularly in arid regions, irrigation with blue water can mitigate the impacts of drought in the short run. As irrigators over-extract available water supplies, however, irrigation must be very carefully managed to achieve long-term sustainability.

During the 2000s, discussions about water scarcity and security moved from networks of water experts into broader discussions fostered by UN agencies and multinational firms. One such forum was the United Nations Global Compact, a broad initiative launched by the United Nations to work with private firms to promote standards regrading human rights, labor, anticorruption measures, and environmental issues. The Global Compact marked the first engagement of one of the world's biggest food corporations, Nestlé, with international development initiatives. Food and beverage companies such as Nestlé, Unilever, SABMiller, and others, had several reasons to be concerned with water scarcity and poor water quality. Water was a primary input for products in their supply chains. In addition, as multinational firms attempted significant expansion in developing countries, they became controversial players in broader social and political conflicts around foreign investment and the assertion of local and national water rights. Such conflicts around water directly affected firms' assessment of business risk and future profitability.

The engagement of food corporations with nexus issues highlighted the importance of supply chains and the need to go beyond the agricultural upstream sector when assessing the relevant impacts of the water and food nexus. Since agriculture accounts for 92 percent of the global consumptive water use, farmers are crucial actors in attempts to improve stewardship around water. Yet they have limited voice in a global food system that is highly concentrated on the procurement and distribution sides. Food and agribusiness companies, on the other hand, have considerable leverage in the global food system. Agrobusiness firms largely communicate with the agricultural upstream sector via contracts that ignore or misprice water and its economic externalities. Only recently have firms started to communicate with the farming sector and the broader public about their approaches to reforming unsustainable agricultural practices (Allan et al. 2015).

The Global Compact initiative led to the creation of the CEO Water Mandate, launched in 2007 by UN Secretary-General Ban Ki-moon, which focused specifically on the importance of private firms in assessing water risks and promoting water stewardship.[1] Several private-sector companies from the food and beverages, mining, agribusiness, financial sector, engineering and construction, and information technology industries agreed to fund further water-focused initiatives through the Geneva-based, businessfriendly World Economic Forum (WEF).[2] Notably, this initiative did not involve energy utilities in the discussion, as the main nexus of interest was water and food.

The World Economic Forum initiative promoted water security as the new paradigm for water management. Advised by a prominent group of international scientists, the International Finance Corporation, donor agencies such as the Swiss Development Agency and USAID, and the World Wide Fund for Nature (WWF), the approach shifted emphasis from the democratic, participatory, socially inclusive, and values-based IWRM principles to framing water security in terms of risks to businesses and governments. The message of the WEF gatherings was that water is a highly strategic asset and should be treated as an economic good with potentially very serious implications for national security and business security. The concerns and commercial interests of multinationals such as Nestlé, PepsiCo, and Unilever prompted the WEF to host several meetings on water security from 2005 onward.[3]

Private-sector interest in water security was highlighted in 2009 during the annual WEF-organized Davos event, under the title “The Bubble is Close to Bursting: Water Security” (Waughray 2011). The private-sector-funded report “Charting Our Water Future” by the 2030 Water Resources Group and the global consulting firm McKinsey brought water security to the attention of a wider group of corporate decision-makers (Boccaletti 2009).[4] Nestlé chairman Brabeck-Letmathe highlighted his firm’s concern with water quality and scarcity by noting that “I am convinced the world will run out of water before running out of fuel” (Waughray 2011).

In 2011 and 2012, the World Economic Forum presented further research on the interlinkages among water, energy, and food systems, based on global meetings held with business leaders, international organizations, nongovernmental organizations (NGOs), academics, journalists, trade experts, and religious leaders. The majority of these stakeholder dialogues took place in Asia, Africa, and Latin America. As Herbert Oberhaensli of Nestlé stressed, private-sector firms were fully aware that discussions of the nexus were inherently political discussions, taking place not only in boardrooms but also in electoral platforms, civic associations, and government offices.[5] Despite the conviction of the private sector that stronger governmental water policies were required, corporations avoided putting forward policy positions that could be interpreted as “lobbying for a specific cause.”[6] Instead, these firms supported the advisory work carried out by the 2030 Water Resources Group. This group was based at the International Finance Corporation (IFC), in Washington, DC, and focused on identifying water risks for corporate strategy and investment in particular supply chains.[7]

The water-energy-food nexus moved from corporate to public-sector support when the German government convened several high-profile meetings to promote the notion of the water-energy-food nexus in 2011 and 2013. A 2011 conference on "The Water, Energy and Food Security Nexus—Solutions for the Green Economy" was advertised as a specific German contribution to influence the UN Conference on Sustainable Development in Rio de Janeiro in 2012. While these initiatives did not produce significant changes in public-sector financing or corporate practices, the nexus concept continues to be taken up by donors and stakeholders, including the US federal government, state governments, environmental NGOs, and international aid agencies (FAO 2013b; DoE 2015).

While the nexus discourse remains an important area of discussion for water experts, development agencies, and multinational corporations interested in water security, it was not taken up more broadly by corporations as initially envisioned by those involved in the World Economic Forum initiatives.[8] Food trading firms and energy companies that consume vast quantities of water and are much more politically influential have yet to employ the nexus perspectives to address resource trade-offs.[9]

In light of the evolution of the nexus concept, the next sections analyze three case studies of arid regions, drawn from the United States, the Persian Gulf, and China. We show which actors and considerations have driven nexus approaches and why nexus approaches have typically failed to be adequately implemented. We argue that meaningful nexus approaches must address the relevant problemsheds, including regulatory institutions, property rights, and local political economies.

The Nexus in the United States: Drought and Problemsheds

Recent episodes of intense and prolonged drought in the United States, combined with the growth of water-intensive production of non-conventional fossil fuels, particularly shale gas, have made the water-energy-food nexus a topic of increasing interest to policymakers, environmental organizations, and firms. As with climate policy, states and municipalities have proved more important arenas for social contestation and policy engagement than the federal government (on climate policymaking, see Rabe 2004; Selin and VanDeveer 2009). This bottom-up policymaking stems not only from the United States' federal system but also from the distinctive supply chains involved in the water, energy, and food systems. We argue that these institutional arrangements constitute problemsheds that are not coterminous with natural watersheds and catchments, sectoral business interests, or conventional jurisdictions of government.

Drought has been a significant catalyst in highlighting the interdependencies of water, energy, and food in the United States, as well as driving rising concern with the effects of global climate change. The United States Drought Monitor, jointly produced by the National Drought Mitigation Center at the University of Nebraska–Lincoln, the US Department of Agriculture (USDA), and the National Oceanic and Atmospheric Administration, shows that in August 2014, 48 percent of the continental United States landmass was classified as under some form of water stress, with 33.56 percent in some form of drought conditions and 14.56 percent abnormally dry. The summer before was even worse: in August 2013, 58.91 percent of the U.S. was water stressed, with 42.65 percent classified as in drought.[10]

The Midwest, Southwest, Southeast, and West have long been prone to periods of drought, and as elsewhere, farmers, cities, and industry increasingly rely on groundwater. Yet groundwater resources generally continue to be depleted faster than they are recharged. For example, the Ogallala Aquifer, the largest known aquifer that provides irrigation water to one of the most significant global breadbaskets,[11] has been extensively mined, causing a 3–30 meter (or 20–30 percent) decrease in depth. Given the impervious geological formation of the Ogalalla and decreasing precipitation patterns, the recharge rate of the aquifer is minimal. Thirty percent of the aquifer has been depleted and an additional 39 percent will be pumped in the next fifty years if current demand continues. Only 15 percent of current depletion rates is recharged. More worryingly, it would take on average 500–1300 years to recharge the whole aquifer (Steward et al. 2013). Thus, depletion of groundwater has been the water-supply solution to drought. The political and institutional response to drought-induced uncertainty for agriculture in the U.S. has long been transfer and compensatory payments for farmers, administered by the USDA and the Internal Revenue Service through disaster relief and agricultural subsidy programs.

More recently, however, water scarcity has begun to engage officials and firms involved in energy planning and development. As noted by Allan (2011), state-owned companies and private multinationals in the energy supply chain have long been isolated from municipal, provincial, and public-private entities involved in water policy. Moreover, while agribusiness and farming communities have long mobilized and lobbied to safeguard water rights, energy firms rarely found their water requirements open to social contestation or regulation. The combination of new water-intensive, polluting technologies for fossil fuel extraction and processing (“fracking”), combined with intense periods of drought in arid parts of the United States, have begun to call the water complacency of energy firms into question, bringing increased scrutiny to conventional uses of water in energy production as well. To highlight the scope of the water-energy nexus, for instance, water withdrawals for once-through cooling in thermoelectric power plants accounted for 41percent of all freshwater withdrawals in the United States in 2005 (Kenny et al. 2009). Water consumption is also not trivial.

Arid regions of the U.S., particularly states such as Texas, Arizona, Nevada, and California, have been at the forefront of water scarcity issues throughout the twentieth century (Reisner 1993). Rapid economic development led to rapid population growth, in-migration from other regions, and significant expansion in suburban and urban areas, which in turn took its toll on water resources. While some states have begun to adopt nexus approaches looking at the various interdependencies between water, food, and energy, others have lagged behind in doing so.

Nevada, for instance, despite mounting water scarcity, has yet to apply food-water-energy nexus approaches to challenges of economic development. The state, with a population of 2.8 million in 2014, grew by 400,000 people over the past ten years amidst continuous drought. Immigration was driven largely by the economic incentives provided to the Las Vegas tourist industry (Allen 2014). Nevada ranks as the leading US state for gambling and entertainment, with 52.6 million visitors between February 2013 and February 2014 alone (Nevada Commission on Tourism 2015). In addition to tourism, the main consumers of water are the agricultural sector and the energy industry. The average farm size in Nevada is 3,500 acres, which places the state’s farms as the third largest farm units in the United States. Most of these industrial-size farmers are devoted to livestock and water-intensive fodder production such as alfalfa (Nevada Department of Agriculture 2015).

Tensions between economic growth strategies predicated on agriculture and tourism and the available water resources are already visible. Lake Mead, the main water source of the “world’s entertainment capital,” Las Vegas, is characterized by white “bathtub rings” that reveal the over-exploitation of water resources (figure 1). The state agricultural industry is increasingly in competition over water for drinking and sanitation and energy. Nevada is thus emblematic of a much larger group of states, in which growth strategies in the US Southwest and West have largely overlooked trade-offs and interconnections between water, energy, and food.

Click to view larger

Figure 1 Lake Mead viewed from the Hoover Dam, August 2014

Photo credit: Martin Keulertz

In Texas, water issues are increasingly important in light of the recent expansion in non-conventional oil and gas extraction. Hydraulic fracturing, or “fracking,” combined with new drilling technologies, have enabled extraction of oil and gas from previously inaccessible sources, including shale formations, “tight” sand formations, and coalbeds (EPA 2015: ES-2). Hydraulic fracturing “involves injecting water blended with sand and chemicals under high pressure into a bedrock formation via the well” (USGS 2014). The process requires substantial withdrawals of fresh water, with different types of wells consuming between 1.5 and 4 million gallons per oil and gas well (ES-9). Over half of the hydraulic fracturing wells declared to the US Environmental Protection Agency (EPA) were contained in Texas, out of fracking wells reported by twenty states (ES-5). The EPA reports that southern and western Texas are particular areas where water availability is likely to be adversely impacted by the effects of drought, over-extracted groundwater supplies, and hydraulic fracturing (ES-9).

Water quality issues around hydraulic fracking operations, particularly in drinking water, are also of significant concern in Texas and other arid regions of the United States. Water quality impacts can stem from leaks from drilling wells, underground migration of fracking fluids into water supplies, and inadequate collection and treatment systems. The EPA reported the public water sources for 8.6 million people were located within 1 mile of a hydraulically fractured well in 2013 (EPA 2015: ES-6) Thus, the new bonanza for oil is associated with environmental risks and costs for water resources that impact the energy-food-water nexus more broadly.

In response to the water risks associated with hydraulic fracturing, environmental and business organizations have begun to adopt nexus approaches into their analysis and advocacy efforts. For example, the Coalition for Environmentally Responsible Economies worked with the World Resources Institute to analyze water demand from hydraulic fracturing for natural gas in arid regions of the United States. Their report found that over 55 percent of hydraulically fractured gas wells built since 2011 were located in areas of high or extreme water stress, and 36 percent were located in areas experiencing groundwater depletion. Energy producers generally have inadequate disclosure standards regarding water consumption and impacts, which add to institutional problems on how to address water emergencies (Freyman 2014: 6).

In Texas, state jurisdiction over both water and energy development is limited. Texas water law is highly complex, stemming from a combination of Spanish law (which emphasizes codified law) and English common law (which emphasizes case law). Most oil and gas well developments are concentrated in a handful of counties, many of which lack the capacity, expertise, and funding to adequately assess or regulate water use by energy firms or water suppliers. Water rights depend on the source: surface water belongs to the state, groundwater to the property owner. Due to climatic conditions, approximately 60 percent of available water in the state is groundwater. The proprietor may capture groundwater as private property without any legal ramifications in case of overuse. Moreover, water rights are in some cases (under Spanish law) unconnected to the land and can be sold or mortgaged like any other property. Texas courts have refused to adopt the federal doctrine inspired by common law, of “reasonable use,” and hence legislators have almost no influence over water use (Kaiser 2002).

In theory, Texas could acquire water rights from landowners. Yet, at a time of increasing scarcity, the costs of such policies would be very high. Water service providers are highly concentrated, with the firms of Halliburton, Schlumberger, and Baker Hughes supplying over half of all water used (Kaiser 2002: 11). The problemshed thus includes counties and water supply firms as well as energy firms, in a legal climate that favors private ownership of water resources. It remains unclear whether Texas courts or the legislature may at some point overhaul existing water law. At present, the legal question of property rights to water presents severe problems for governing the political problemshed in Texas. Moreover, Texan farmers are potentially affected, as their water use may face increased competition from energy companies using hydraulic fracturing techniques.

In contrast to the halting movement toward nexus approaches in Texas and the lack of initiatives in Nevada, the politics of nexus problemsheds are evolving quickly in California. With years of protracted drought, hydropower output diminished, gas-fired utilities requiring water for cooling were threatened by water curtailments, and wildfires downed power lines. Utilities began to lobby water authorities to secure water allotments in response. In July 2014, for instance, the California Energy Commission, the California Public Utilities Commission, and the California Independent System Operator Corporation warned that water cuts that limit electricity generation would pose threats to public health and safety, in a letter sent to the State Water Resources Board (Doan 2014). Energy generation is important to the safety and security of water supplies as well. In

California, an estimated 20 percent of energy use goes to water use and supply, according to the California Energy Commission (Waughray 2011: 60).

Groundwater supplies have been tapped at an unprecedented rate by farmers and urban consumers in response to the drought, but supplies are dwindling and becoming more polluted. In April 2015, Governor Brown issued a statewide emergency water-use reduction for cities and towns requiring urban residents to cut their water use by 25 percent (*USA Today* 2015). On the agricultural side, the California legislature has been more hesitant to take action as of 2015. Although 80 percent of California's water is used by the agricultural sector, the Sacramento legislature only moved to require groundwater planning for all of the state's aquifers in August 2014, a belated measure to cope with effects of drought and increased withdrawals that had brought most of the state's groundwater basins to historical lows (Doan 2014). The institutional framework is based on creating new management agencies for each groundwater basin, requiring extensive decentralized coordination and cooperation between counties, municipalities, utilities, and farmers. As with decentralization of irrigation, local-level agencies often devolve to represent privileged players with access to money, resources, and time.

In California's Central Valley, farmers were the first to feel the drought. Most of the water available to Californians in the central and southern part of the state comes from the Sacramento-San Joaquin River Delta. Engineering interventions, in the form of the State Water Project and Central Valley Project, altered the natural flows of the delta continuously since the 1920s. These projects negatively affected fish populations in the delta, leaving the ecosystem at risk. Legally, the delta is protected through the Bay Delta Conservation Plan (BDCP), which draws upon the Endangered Species Act (ESA) of 1973. Federal and state regulators hope to ensure ecosystem health of the delta through a fifty-year habitat conservation plan. Federal regulators have thus limited water deliveries from the delta to the Central Valley, in which most of the crops in California are cultivated.

The fourteen-year drought as of 2015 in California has worsened competition for water between farmers, ecosystem uses, and cities. Farmers deprived of water from the delta have protested, blaming federal and state politicians for the water crisis (figure 2). Farmrs have left fields close to the transport arteries of Interstate 5 and State Route 99, which connect the north and south of the state, dry and uncultivated to send a message to passing motorists. Instead of acknowledging the drought and increased farming activity in the Central Valley, farming groups such as Families Protecting the Valley blame "big government" in Washington for the water crisis.[12]

Click to view larger

Figure 2 Farmer protest signs in California's Central Valley, July 2014

Photo credit: Martin Keulertz

Thus, evolving water politics in California presents an urban–rural divide. Concerns of decision-makers to ensure high water quality for urban areas such as the San Francisco Bay Area illustrate the power relations over water. As one Washington-based consultant stressed, "in the end, the city wins."[13] This may also prove true for the energy sector over the needs of agriculture. At the same time, federal and state authorities remain reluctant to propose regulatory policy frameworks to limit water use in agriculture. While policies to ensure adequate water quality are within the mandate of EPA, it has no power over policies that manage water quantity. Water management remains largely the domain of state legislators, who are wary of farmers as influential political constituents. Representatives from the organization that represents the political voice of farmers, the American Farm Bureau, have emphasized the opposition of farmers to any form of water regulation.[14]

It therefore comes as no surprise that federal government representatives, such as the Chief Economist of the USDA, Joseph Glauber, suggest that the "main driver of change must come from the market itself."[15] In other words, the most potent regulators of water use in political problemsheds are large-scale agribusiness companies. Funded by leading figures in the US agribusiness and food industry, initiatives such as the Field to Market® alliance provide farmers with monitoring tools to help them compare efficiencies of different management decisions at the farm level (Field to Market 2015). Farmers are paid a premium if they use the tool to disclose their natural resource consumption. Some agribusiness representatives note that these and similar corporate voluntary initiatives are also promoted to forestall more rigorous state regulation.[16]

In sum, in the United States, subnational policies, institutions, and strategies of economic development at the state level have thus far been more important in nexus politics than the federal level. Variations across US states in terms of nexus approaches are clearly apparent, reflecting the different pressures of various economic interests and varying state capacities. In Nevada, neither local nor state governments have yet adopted nexus approaches for the tourism or the agricultural-livestock center despite mounting evidence of water scarcity. In California, long-standing conflicts between allocating water for cities, water for food and agriculture, and water for ecosystem services in areas such as the Sacramento-San Joaquin river delta have been exacerbated by drought, prompting state and municipal governments to adopt water rationing. However, local governments have found it more political expedient to impose rationing on cities than on agriculture or energy producers, both of which consume far more water than municipalities. California's agricultural lobby has avoided significant rationing in favor of corporately sponsored voluntary initiatives. However, California's state government will likely pursue more integrated nexus planning as water constraints tighten. In Texas, regulation of water resources is even more challenging, given that most groundwater resources are legally private property and that a handful of large multinational conglomerates control water supply systems.

The Water-Energy-Food Nexus in the Arab Gulf Monarchies

The oil-rich monarchies in the Arabian Peninsula provide another interesting case study of nexus politics. The region has an arid climate similar to parts of the southwest and west of the United States, but with significantly different political systems. The emergence of nation-states under dynastic rule across the Arabian Peninsula was integrally tied to the success of ruling families in monopolizing and redistributing natural resources such as water and oil (Jones 2010). In a hyper-arid ecology, the Gulf institutional problemshed has thus been characterized by the internal politics of family dynasties and their requirements for legitimacy. The problemshed of family rule has been augmented by the nationalization of the energy and water sector into state-owned firms that are in turn reliant on international expertise, inputs, and technologies from abroad. Thus, despite differences in political regime and business organization between the Arab monarchies and the U.S., similarities emerge in approaches to the food-water-energy nexus, particularly when we consider how agricultural lobbies often hinder robust implementation of nexus approaches.

As Sowers (2013) showed for Egypt, policymaking in the Middle East around water, food, and energy policies has long been the domain of "expert" networks comprised of local scientists, foreign, and domestic consultants, and Western donors and firms. In the smaller, less bureaucratically organized Gulf monarchies, the impacts of expert networks and the importance of external sources of expertise are even greater than in North Africa. Weak domestic capacities and the politics of family rule result in a bureaucratic landscape characterized by overlapping responsibilities, competitive organizational fragmentation, and reliance on external consultancies. State organizations are segmented from each other and orient themselves instead toward the respective central rulers (Hertog 2010).

During the consolidation of Arab Gulf monarchies, the oil-driven motor pump and the importation of irrigation schemes from similar climatic regions in the southwest of the United States fundamentally transformed water usage in the region, superseding methods of traditional agriculture and pastoralism adapted to arid and semi-arid climates (Woertz 2013). Imported technologies and approaches to water management were combined with extensive state subsidies for water, energy, and food. Subsidies constituted a key part of the social contract of these authoritarian states, which tried to compensate their publics for the lack of political participation with transfer payments.

These factors laid the groundwork for large subsidized programs of wheat cultivation in the desert and other agricultural support schemes that took off in the 1970s and 1980s. Costly and questionable proposals by expert networks to alleviate water scarcity, such as cloud seeding, diversion of river waters from Turkey, or the towing of icebergs, were contemplated even earlier, first in the 1950s and then the 1970s.

The interlinkages between energy and water became apparent as the agricultural support schemes, launched in the 1970s and expanded during the 1980s and 1990s, predictably led to the exhaustion of fossil groundwater aquifers (Elhadj 2004). Faced with significant depletion, Gulf governments announced that some subsidized agricultural programs would end; Saudi Arabia, for example, announced plans to phase out its wheat program by 2016. However, entrenched farm lobbies that benefited from these schemes delayed reform measures by commissioning new studies, influencing royals, and drawing on connections to the country’s consultative body, the Majlis al-Shura. Change does not come easily, especially as well-known royal family members and leading business families are also frequently agro-entrepreneurs.

In this political context, estimates of groundwater depletion are controversial and shrouded in strategic secrecy and interest politics. Farm lobbies try to marshal countervailing studies to those of outside experts to pressure for continued groundwater abstractions. Estimates concerning groundwater reserves in Saudi Arabia vary widely: the Scientific Research Institute’s Water Resources Division at Dahran in Saudi Arabia’s Eastern oil region puts the number of economically recoverable water reserves at more than double the figure of the Ministry of Planning and more than triple the figure of the

Water Atlas of Saudi Arabia (FAO 2008). Estimates of probable and possible reserves differ even more among these sources. In 2011, opponents of the 2016 wheat phase-out enlisted the support of the influential Minister of Interior and then-Crown Prince Nayef. Prince Nayef ordered a renewed study of the issue in order to reach more “balanced results” than earlier studies of the groundwater situation (Woertz 2013: 87).

As fossil water aquifers have been depleted, natural scarcity has begun to impose constraints. Just drilling deeper for groundwater is no longer enough. Saudi Arabia uses almost ten times more than its annual renewable water reserves (FAO 2008). The Abu Dhabi Water Resources Master Plan of 2009 estimates that with current withdrawal rates for agriculture and forestry, all of the emirate’s resources of fresh and moderately brackish water will be depleted within twenty to forty years (Government of Abu Dhabi 2009). Unsustainable farming practices must be weighed against industrial and residential water needs, which invariably represent a greater contribution to GDP and are a basic necessity for residents. In this regard, Saudi Arabia, California, and Nevada face some of the same difficult choices.

As in California, investment in supply-side solutions and energy-intensive technological fixes remain compelling for rulers in the Middle East and North Africa (Sowers et al. 2011). Desalination has emerged as the supply-side technology of choice to address water scarcity in the Gulf. Desalinated water now constitutes the majority of residential water supplies in the Gulf region. The Gulf accounts for 57 percent of global desalination capacity, with other MENA countries including Iran, Algeria, and Israel contributing another 3 percent (Alterman and Dziuban 2010; Saif 2012). While the more energy-efficient reverse osmosis process prevails in the United States, Spain, China, Japan, and Australia, the Gulf countries mainly use the thermal multi-stage flash process in combined-cycle power plants. With the exception of Qatar, all Gulf Cooperation Council (GCC) countries now face a natural gas shortage and must resort to burning diesel, fuel oil, and even crude oil in power generation and desalination plants.

Energy is thus an increasingly important constraint on water production via desalination. Electricity and water production account for 65 percent of Saudi Arabia’s domestic oil consumption. Because of desalination’s growing importance for water provision and its connection to power generation, Saudi Arabia moved the water portfolio from the Ministry of Agriculture in 2001 into a newly established Ministry of Water and Electricity in 2004. The connection between water and energy was clearly exemplified in this reshuffle, just as the linkages between water and food were revealed by the Saudi decision to phase out wheat production by 2016. As it tries to develop unconventional shale gas resources, Saudi Arabia faces another trade-off: it lacks the water necessary to extract these resources.

Although the small state of Qatar does not face a shortage of natural gas, the country faces serious water scarcity that limits domestic food production. Current agricultural practices rely largely on highly inefficient technologies and flood irrigation. Qatar imports 90 percent of its food from international markets. However, the 2007–2008 global food commodity price spikes and concerns over readily available food imports prompted the Qatari leadership in 2009 to establish the Qatar National Food Security Program (QNFSP) to increase domestic food production and reduce reliance on global markets. With this decision Qatar increased its expected water deman for food production dramatically, alongside the existing water needs of energy production. To address water scarcity constraints, the General Secretariat for Development Planning developed the Qatar Vision 2030 (Qatar Secretariat for General Development Planning, 2008), which called for applying integrated decision-making for water, energy, and food. The Secretarat proposed techniques based on dryland farming to reduce groundwater irrigation, with supplemental irrigation sourced from desalination plants as needed to avoid further depletion of groundwater. To minimize greenhouse gas emissions from increased desalination, technical solutions based on solar energy were also envisaged. While this integrated approach aimed at improving existing practices technically, aggregate water consumption was expected to increase despite water efficiency gains, because of the expected growth in agricultural production.

Qatari planners also pursued another initiative in the context of seeking to ensure food security with the creation of Hassad Food, a subsidiary of the Qatar Investment Authority (QIA), the country’s sovereign wealth fund established to manage oil revenues and invest in the long-term diversification of the country’s economy. Hassad Food was tasked with directly investing in food production abroad in countries such as Australia and Sudan.

Domestic food production was initially predicted to increase Qatari food self-sufficiency to 70 percent by 2023 (Keulertz 2013). These ambitious goals were later downsized to 40–60 percent self-sufficiency. Even these reduced targets, however, are likely unrealistic. After inter-agency rivalries ensued, responsibilities to implement the National Food Security Plan were moved from QNFSP to an inter-ministerial implementation committee in 2014. The replacement of QNFSP and its technocratically minded leadership under Fahad al-Attiyah weakened the advocates of expanding dryland agriculture within Qatar. Domestic agriculture in Qatar imposes goth economic and ecological costs; it would require large subsidies, and the environmental impact of brine disposal from using desalinated water in agriculture would be significant even if desalination were powered by solar energy as planned (Baker 2012). With its plan to establish a Global Dry Land Alliance, the QNFSP also ran into opposition from foreign policy circles in Qatar, which saw the initiative as an infringement on their portfolio.

Fusing nexus consideration to imperative of domestic food production limited the appeal of nexus approaches. At this stage it is unclear whether the limited nexus approaches to food, water, and energy as initially proposed by QNFSP will be implemented. Nexus technocrats concentrated around the QNFSP have less influence than the decision-makers charged with foreign investment overseas and food trade, such as Hassad Food. As a subsidiary of QIA, Hassad Food is more embedded in the broader economic development strategy. It is, for example, supposed to trade commodities for one of Qatar's most significant infrastructure projects, a new port to increase Qatar's role in global trade.

The institutional problemshed for the water-energy-food nexus in the Gulf States thus comprises decision-makers within the royal families, the upper echelons of state ministries oriented toward these courts, well-connected business interests, and networks of consultants and technocrats. Successive outside consultancies for the same problem are often solicited to weigh different options, as was done in Qatar with the food security plan and in Saudi Arabia with the reduction of agricultural subsidies. Sometimes the motivation is to restart momentum to tackle difficult problems; in other cases, the demand for consultancies is to stall reform initiatives, as with Prince Nayef's request for new groundwater depletion studies.

The nexus problemshed in the Gulf monarchies is further complicated by fear of the continued spillover from the uprisings across the region that began in 2011. The Gulf countries have sought to placate social unrest and political opposition with subsidy extensions and pay raises in the public sector. These measures work against proposed reforms to enhance demand-side management and engage insubsidy reform for water and energy. Subside expansion, however, came under strain with the late 2014 fall in world oil prices. Unlike some oil-producing countries, Gulf monarchies have significant cushions of foreign reserves and access to international capital markets in order to deal with revenue shortfalls. However, they will need to adjust their water-food-energy policies should low oil prices prevail over a prolonged time period.

The Water-Energy-Food Nexus: China

The interlinkages and dependencies among water, energy, and food systems have emerged clearly in arid parts of China. As in the United States, conflicts over access, affordability, and ownership rights of water, land, and energy are highly politicized, at different levels of governance. Problemsheds associated with the nexus rarely map easily onto formal governmental jurisdictions or natural watersheds, whereas corporate supply chains and competing regulatory jurisdictions are of primary importance. Moreover, attempts to avoid domestic water constraints are well under way, as Chinese state-owned entities take significant stakes in global food production and trading companies such as Noble, Smithfield, and Nidera (Keulertz and Woertz 2015).

In the world's most populous country, environmental impacts pose the most urgent risks to future economic growth. China has therefore been described as a global choke point with respect to water, energy, and food (Shifflett et al. 2015). China's share of world population ranks at 19 percent, but it has access only to 6 percent of global freshwater (blue water). As a result, China's per capita water share is around 2,200 m^3/year, about one-third of the global average (Wong 2010). Water resources are also distributed unevenly in China. While the southern region hosts 55 percent of the Chinese population and 84 percent of the water resources, it has about 40 percent of the cropland. In contrast, 45 percent of the remaining population lives in the northern region, where 60 percent of the overall cropland is located, but only 16 percent of China's water resources. The multi-decade South-North Water Transfer megaproject seeks to convey 44.8 billion cm^3 per annum from the Yangtze River to the water-scarce northern provinces. This artificial river would contain the equivalent of more than half of the River Nile flow, making it one of the most expensive engineering projects in human history (Chang 2014). Only parts of the project are currently constructed, however, and there are grave concerns that project would further pollute water resources due to the new river's proximity to industrial operations (International Rivers 2015).

China is already the largest energy consumer in the world. While energy consumption per unit of GDP has begun to decline with efficiency gains, China's high economic growth rates and role as "workbench" of the world are closely linked with energy use. If present trends continue, China will account for nearly one-fourth of global energy demand by 2030, consuming 60 percent more energy than the United States and twice as much as the European Union (Michael et al. 2013).

To meet projected energy demand, Beijing has pursued several energy policy options. The present energy mix is heavily dependent on coal mining in the water-stressed north of the country. Coal demand grew rapidly during the early 2000s, and the country became a net importer of coal in 2007 (Kahrl and Roland-Holst 2007). Coal transportation to the rest of the country absorbs about half of all railway capacity. Coal will continue to remain the biggest source of energy with a projected additional 363 plants by 2020. In addition, nuclear power reactors will be expanded from 21 to 49 by 2020 (Michael et al. 2013).

At the same time, China has begun to invest in renewable energy. Described as a "revolution" by some analysts (Cooke 2015), this fundamental shift in energy policy costs China approximately $90 billion annually (EIA 2015). In November 2014, the United

States and China reached a climate and clean energy agreement in which China promised to double renewable energy sources such as hydropower, solar, and wind energy from the current 10 percent of total supply to 20 percent by 2030 (IAEA 2013; Michael et al. 2013; White House 2014; WRI 2014). China is already the largest wind producer in the world (Shukman 2014). In addition, hydroelectric power is set to provide 15 percent of China's overall energy needs (EIA 2015). Hydropower development is therefore the most crucial source of clean, renewable energy, yet it brings adverse political and environmental impacts for the greater South-East Asian region. Riparians of transboundary river basins such as the Mekong are already detrimentally affected by China's use of the headwaters.

Almost all energy options will require additional water resources or greater control of shared water resources. In particular, the construction of next-generation coal-fired plants aimed at decreasing air pollution in urban areas is projected to withdraw and pollute ten billion cm of water annually starting in 2015. As of 2012, half of the proposed new coal projects are located in areas with extreme or high water risk in the northern provinces (WRI 2014). This in turn detrimentally affects farmers in the north, who produce the majority of China's food.

The Chinese leadership has begun to address the nexus between water and energy through policy reforms aimed at investment in renewable energy and restructuring of water management systems. As a result, China is perceived to be on track in terms of providing sufficient energy resources. In addition, water consumption has leveled off in China, in part through investments in agricultural water efficiency and water productivity (including sustained investment in rural infrastructure and irrigation), and in part through sustained economic transformation from agriculture to services and industry (Lele et al. 2013: 50–52). Specific water-sector measures have included dam rehabilitation, canal lining, adoption of drip irrigation, and demand management incentives to local and provincial authorities.

With respect to food, however, China seeks to externalize its environmental costs by "going global." While it tries to maintain a high rate of self-sufficiency in grains for human consumption out of strategic concerns, China has developed into a large importer of animal feedstock, especially soybeans, and industrial inputs such as rubber and timber. In April 2014, the largest state-owned food company, COFCO, announced a joint venture with Noble Group, leading to an effective takeover of one of the largest cereal trading companies in the world (Koons and Venkat 2014). Noble has contract farming operations around the world in regions with water readily available for food production. COFCO also purchased US pork producer Smithfield for $7 billion in 2013 to import pork meat and supply chain expertise from North America (Haas and Humber 2014). More recently, COFCO purchased the Dutch grain trader Nidera B.V., which is seen as a further step by decision-makers to establish a grain trader akin to the four large agricultural trading firms that dominate agribusiness, namely Archers Daniels Midlands, Bunge, Cargill, and Louis Dreyfus. These four firms currently control 70–80 percent of the global grain trade (Blas 2015; Keulertz and Woertz 2015).

China's policies around water, energy, and food include both natural resource quantity and quality. However, Beijing does not pursue a nexus approach as such, that seeks to jointly manage linkages and tradeoffs between these water, food, and energy systems. Instead, China's economic policy remains conceived by the central government in Beijing through five-year plans. While the food footprint is gradually externalized through strategic investments outside its border, the energy sector is addressed through measures focusing on energy self-sufficiency. This is very similar to the growth path of Western economies since 1945 (*The Economist* 2012). The externalization of food to other world regions such as Latin America, North America, or potentially Africa provides short-term solutions to feed China. Whether an integrated nexus approach will be applied in the future will depend on China's economic growth path and investment in its global supply-chain activities.

The Water-Energy-Food Nexus: Paths Forward

This chapter traced the evolution of the water-energy-food nexus and examined some of the regions where nexus approaches have been proposed, catalyzed by water scarcity, food security concerns, and drought. International aid agencies, multinational corporations concerned with water security in their supply chains, and natural resource managers have increasingly promoted nexus approaches as a means to manage water, energy, and food systems through more integrated and explicit assessments. Despite initial support from these diverse actors, however, food-water-energy nexus approaches have yet to be effectively implemented.

This chapter has argued that devising integrated policies for the water-food-energy nexus is first and foremost a problem of navigating distinctive political problemsheds. Water scarcity—including the water intensity of various forms of energy production and the water embedded in the agricultural systems—has served as a common exogenous driver for actors in arid regions of the United States, the Persian Gulf, and China. In each case, however, the political economy of different levels of governance explains the extent to which nexus approaches were adopted. In particular, the cases in this chapter call attention to the ways in which entrenched farming and energy interests—with political and property connections at the local, state, and national levels—shaped considerations of the water-energy-food nexus.

Looking forward, several trends are emerging in how the water-energy-food nexus is conceptualized. Increasingly, technocratic modeling approaches to the water-energy-food nexus in semi-arid regions focus on issues of managing green water and of providing adequate energy supplies to small and medium farmers. Such a reconsideration of approaches to drylands agriculture is particularly needed as water shortages and droughts intensify in light of anthropogenic climate change across arid regions. Various climate models generally converge on the assessment that changing precipitation regimes associated with anthropogenic climate change will generally make arid regions drier, combined with more intensive but infrequent episodes of precipitation and flooding.

Efforts in integrating water, energy, and food policies thus focus in part on better understanding and accounting for the green water embedded in soil. As noted earlier, green water exceeds blue water resources in many drylands of the world (Braudeau and Mohtar 2014). With the expansion of agricultural mechanization and irrigation technologies, particularly through importing production systems and practices not suitable for dryland agriculture, blue water has been over-extracted while green water has been underutilized. While green water has been defined as soil water, soil scientists have yet to agree what specifically constitutes this water. In the future, improved national or even regional green physical water accounting could identify trade-offs. Such modeling, which is still in its infancy, could examine the natural soil organization and changes to this natural organization as a result of using non-conventional water sources.[17]

Dryland agricultural research institutes such as the International Center for Agricultural Research in the Drylands, with its various research stations in North Africa, the Middle East, Central Asia, South Asia, and China, have long highlighted the need for farm systems to value water and soil productivity and sustainability. However, the prevailing agricultural production systems in drylands still largely devalue green water and soil productivity, emphasizes maximizing yields even as desertification is a critical issue for drylands farming. Accurate accounting and mapping of green water resources, combined with reassessing such elements in the production system as appropriate seed and crop varieties, farm practices, and adaptive supplemental irrigation, could allow land once considered unsuitable for food production to once again be sustainably productive (Oweis and Hachum 2004).

Improving water, energy, and food policies in drylands agriculture, however, calls attention to the marginalized role that medium and small farmers typically play in policy formation and implementation. As the cases in this chapter showed, large agribusiness, trading, and energy interests are generally well represented in political systems as varied as those found in California, Texas, Saudi Arabia, China, and Qatar. Adequate policy supports for small and medium farmers in drylands, however, are generally lacking. More adequate integration of food, water, and energy resources thus depends in large part upon devising policy interventions and support programs for small and medium agricultural users to more sustainably manage water and energy.

Including small and medium farmers explicitly into nexus participation and planning becomes even more critical given increasing sectoral conflict among different water users. China has begun to consider the trade-offs and linkages between water, energy, and food in its five-year planning approach, informing domestic and international investment strategies. When water scarcity intensifies, as it did in the Persian Gulf and in the United States during the 2000s, even large-scale agricultural interests find themselves losing out on water when faced with the more inelastic demand from cities and industry. In California, Texas, and the Persian Gulf, municipal consumption, industrial uses, and tourism interests increasingly claim water that conflicts with water needs in agriculture. Since these sectors often outperform agriculture in terms of conventional investment returns, agricultural producers are often at a disadvantage. In states like Nevada, tourism may even claim priority. Since sectoral competition between users typically has been over "blue" surface and groundwater supplies, agricultural producers in arid regions may have to rely increasingly on green (soil) water as well as unconventional water sources, including reused water, waste water, brackish water, water used in the oil and gas industry, and harvested rainwater. However, these options raise concerns about water quality and food safety, requiring adequate regulatory and legal frameworks currently lacking in many countries.

Future research on political problemsheds for the water-energy-food nexus will also have to grapple with globalized financial and energy sectors as well as globalized supply chains for water and food. This chapter highlighted how multinational firms in the food and beverage sector helped to create the initial momentum for nexus approaches, as part of their interest in securing water supplies for their global operations. Other multinational firms, particularly in the energy sector, have thus far been less willing to adopt nexus approaches. While this calculation may change in arid regions as unconventional oil and gas extraction competes with other water users, there is little indication that the energy or biofuels sectors have yet seriously incorporated trade-offs between water, energy, and food systems into their decision-making.

Providing adequate energy supplies to small and medium farmers is another area where integrated water-energy-food policies may emerge in arid regions facing water stress. While energy for food production may not be an issue for large-scale farming, it can be a limiting factor for small-scale production enterprises. Off-the-grid technology deployment for moving water from its sources (surface and groundwater) to cultivated areas requires energy as do various farming practices, processing, and post-harvest handling and storage processes. Ensuring access to energy will not only improve and ensure adequate yields, but also prevent detrimental post-harvest losses, which account for an estimated 1.6 gigatons per year lost out of 6.0 gigatons of annual total food production (FAO 2013a).

While the development and research community has largely focused on the role of technology and policy innovation, this chapter has argued that a clear and coherent grasp of political problemsheds at different scales is needed to more adequately implement nexus approaches in arid regions. While multinational firms and international institutions initially highlighted nexus challenges of global importance, an emerging arena for nexus applications is at more local and subnational scales, in problemsheds where rural livelihoods are directly impacted by changing water, energy, and food systems. Devising appropriate trade-offs and synergies for the water, energy, and food nexus in arid regions means support for adaptation of local agricultural livelihoods as well as changes in multinational supply chains.

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Notes:

([1]) http://ceowatermandate.org/.

([2]) These companies were: CH2M HILL, Cisco Systems Inc., Coca Cola, Dow Chemical Company, Halcrow Group Ltd., Hindustan Construction Company Ltd., McKinsey & Company, Nestle SA, PepsiCo Inc., Rio Tinto Group, SABMiller plc, Standard Chartered Bank, Syngenta AG, and Unilever.

([3]) Keulertz, Woertz, and Sowers interview with Dominic Waughray, Senior Director and Head of Environmental Initiatives, World Economic Forum, 26 June 2014.

([4]) During the 2010 London Water Research workshop, Israeli scientist Eran Feitelson criticized the data and interpretations in this report. For example, the macro abatement cost curve approach for water only incorporated high assumptions on population growth, leaving room for wide deviation of results in case of lower population growth.

([5]) Keulertz interview with Herbert Oberhaensli, Vice-President Economics and International Relations, Nestlé Corporation, 21 July 2014.

([6]) Keulertz, Woertz, and Sowers interview with Dominic Waughray, Senior Director and Head of Environmental Initiatives, World Economic Forum, 26 June 2014.

([7]) Keulertz and Sowers interview with Andy Wales, Senior Vice President Sustainable Development for SABMiller, 16 July 2014.

([8]) Keulertz, Woertz, and Sowers interview with Dominic Waughray, 26 June 2014.

([9]) Keulertz and Sowers interview with Stuart Orr, Head of Water Stewardship at The World Wildlife Fund, 14 July 2014.

([10]) http://droughtmonitor.unl.edu/Home/TabularStatistics.aspx.

([11]) The aquifer extends beneath the High Plains including the states South Dakota, Nebraska, Colorado, Texas, Oklahoma, New Mexico, Kansas, and Wyoming. Those “breadbasket” states mainly crop wheat and corn, which are highly strategic crops for global food security.

([12]) Keulertz interview with Denis Prosperi, Chairman of Families Protecting the Valley, 29 July 2014.

([13]) Keulertz interview with Gary Blumenthal, president of the agricultural consulting firm World Perspectives, 22 July 2014.

([14]) Keulertz interview with Veronica Nigh, environmental economist at the American Farm Bureau, Washington, DC, 21 October 2014.

([15]) Keulertz interview with Joseph Glauber, Chief Economist of USDA, 23 July 2014.

([16]) Keulertz interview with Carl Hausmann, former vice-president of Bunge Limited, 26 July 2014.

([17]) For instance, new models that address the swelling-shrinkage processes of the soil—specifically the thermodynamics of the soil and its changes and evolution—are needed to assess the water retention curve and soil shrinkage curve (Assi et al. 2014; Bellier and Braudeau 2013; Braudeau and Mohtar 2014).

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