



CARBOHYDRATES, H₂O, AND HYDROCARBONS: GRAIN SUPPLY SECURITY AND THE FOOD-WATER- ENERGY NEXUS IN THE ARABIAN GULF REGION

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“Carbohydrates, H₂O, and Hydrocarbons: Grain Supply Security and the Food-Water-Energy Nexus in the Arabian Gulf Region”

“If I were to pick a single indicator—economic, political, social—that I think will tell us more than any other, it would be the price of grain.”

—Lester Brown, president, Earth Policy Institute.¹

Executive Summary

- In the Arabian Gulf region, energy resources generate export revenues, a meaningful portion of which are then used to subsidize food, water, and energy prices paid by local consumers. Such policies deeply embed energy in the food-water-energy relationship. Pressure on one strand of the nexus generally affects both of the other two. In addition, food, water, and energy (here, oil and gas) are three of the world’s most politicized commodity groups, which further complicates policymaking.
- Each tonne of wheat grown in an arid climate like that found in much of the Gulf Cooperation Council region can consume approximately 2,634 cubic meters of water—roughly the same amount needed to fill an Olympic-size swimming pool.
- Pumping this volume of water from 1,000-meter-deep wells would require the use of roughly 10,000 kWh of electrical energy, equivalent to an estimated 7 barrels of crude oil, 3.8 barrels of diesel fuel, 1.1 barrels of fuel oil, and nearly 33,000 cubic feet of natural gas, once efficiency and transmission loss factors are included.²
- Such energy-intensive water extraction means that in the GCC region, the opportunity cost ratio of using exportable hydrocarbons to support domestic grain cultivation can exceed 3:1. In other words, each tonne of wheat grown domestically with deep groundwater can effectively cost three or more times what it would cost to procure that same tonne from the global market.
- Using desalinated water would yield an even more extreme energy requirement of as much 47,000 kWh of energy per tonne of wheat produced: roughly 26 barrels of crude oil per tonne of wheat grown.
- In a nutshell, grain cultivation in a severely arid climate like the Arabian Gulf requires at least two orders of magnitude more energy per tonne of grain produced than would be the case in a temperate climate like Canada, Russia, Ukraine, or the United States where rainfed farming dominates. In the hypothetical case of using desalinated seawater to produce grain, there would be an increase of energy intensity of nearly three orders of magnitude between the temperate countries and the Arabian Gulf (i.e., roughly 5 kWh/tonne versus nearly 50,000 kWh/tonne).

¹ Quoted in Joshua Keating, “A Revolution Marches on Its Stomach,” *Slate*, April 8, 2014, http://www.slate.com/articles/health_and_science/feed_the_world/2014/04/food_riots_and_revolution_grain_prices_predict_political_instability.html.

² Our model results assume a power generation fuel slate similar to that used in Saudi Arabia. The energy intensity figures we derive closely track the findings for specific groundwater pumping energy use found by A.K. Plappally and J.H. Lienhard V, “Energy requirements for water production, treatment, end use, reclamation, and disposal,” *Renewable and Sustainable Energy Reviews* 16, 7 (September 2012): 4818–4848. <http://dx.doi.org/10.1016/j.rser.2012.05.022>.

- To bolster its food supply security, Qatar would be best off foregoing significant domestic grain cultivation and instead expanding strategic grain supplies, becoming a financial investor and/or physical participant in farming operations abroad, and expanding its domestic grain milling capacity.
- With proper inputs, agricultural land is effectively a renewable resource that yields rents on an annual basis over time, unlike hydrocarbons, which can only be extracted and sold once. Such renewability could allow Qatar to leverage its financial resources to acquire larger farmland stakes abroad and develop an independent source of national income to help diversify and reduce the country's dependence on oil and gas revenues.
- Investing capital to create more productive and efficient farming assets would also help bolster Qatar's own food supply security as well as increase global grain supplies. Doing so could advance Qatari diplomacy by demonstrating the country's intent and capacity to serve as a positive geo-economic influencer on the world stage.
- The renewable rents from investment stakes in professional farmland managers can also be substantial. For instance, the enterprise-wide earnings before interest, tax, depreciation, and amortization (EBITDA) margin of South America-focused farmland developer and farming company Adecoagro consistently exceeded that of Rosneft between 2012 and 2015, and in some years, surpassed Google's EBIDTA margin. The Qatar Investment Authority held a 12.7% stake in Adecoagro as of January 2017, according to company filings.³

I. Introduction

Food security attracts intense attention in the Arabian Gulf, for the region's harsh climate makes industrial-scale grain cultivation difficult and the long arc of world history makes governments keenly aware that food insecurity can help catalyze serious social unrest.⁴ In turn, leaders' fears of being forced out of office often helps drive policies that prize an autarkic vision of food at the expense of economic, hydrological, and climatic rationality.

The Gulf region also offers an excellent case study precisely because its extreme dryness, generally prolific energy supplies, relative wealth, and rapid population growth clearly illustrate the contours of trade-offs political leaders make when they emphasize one leg of the nexus over another. The resultant lessons are globally important, for the food-water-energy relationship is the "three legged stool" that modern civilization stands on. In that respect, the experiences of Gulf countries can inform policymaking in numerous arid zones worldwide, including the Western United States, North China, India and Pakistan, southern Europe, Central Asia, Mexico, and much of sub-Saharan Africa.

³ "Institutional Presentation," Adecoagro, January 2017, <http://ir.adecoagro.com/>.

⁴ C. Kelley, S. Mohtadi, M. Cane, R. Seager, and Y. Kushnir, "Climate Change in the Fertile Crescent and Implications of the Recent Syrian Drought," *Proceedings of the National Academy of Sciences* 112 (2015): 3241–6; See also Gabe Collins and Andrew Erickson, "Keeping the Mandate of Heaven: Why China's Leaders Focus Heavily on Grain Prices and Security," *China SignPost™ (洞察中国)* 22 (February 17, 2011), http://www.chinasignpost.com/wp-content/uploads/2011/02/China-SignPost_22_Keeping-the-Mandate-of-Heaven_Grain-supply-problems-a-major-political-risk_20110217.pdf.

Balancing trade-offs between food, water, and energy in ways that fail to comport with climate realities often bring dire—and sometime permanent—consequences. For instance, between 1980 and 1999 alone, Saudi Arabian farms consumed more than 300 billion cubic meters of water—most of which came from deep aquifers that do not recharge—and spent tens of billions of dollars in a failed attempt to cultivate wheat on an industrial scale in its harsh desert climate.⁵ This was enough water to fill more than 60% of Lake Erie, one of the world’s largest bodies of fresh water, or put differently, enough to submerge the entire territory of Qatar under 26 meters of water.⁶

This paper’s key objective is to situate the food security concerns of Arabian Gulf countries against the broad nexus between food, the water needed to grow food, and the energy used to obtain and move the water. In the case of the Gulf Cooperation Council (GCC) and Iran, energy resources are exported to generate revenues, a not inconsequential portion of which are then used to subsidize food, water, and energy prices paid by local consumers. Such policies unintentionally, but surely, further embed energy in the food-water-energy relationship. Each strand of the nexus merits attention because moves in one generally affect both of the other two, and because food, water, and energy (here, oil and gas) are three of the world’s most politicized commodities, which complicates policymaking.

Lessons learned in the Gulf region will, in many cases, be broadly applicable in other arid parts of the world, including northern India, North China, Pakistan, the Sahel, Latin America, Australia, and the western United States.

II. Conceptual Framework

Food security shares many traits with the standard rubric of energy security. At a fundamental level, both center on ensuring sufficient availability of the resource at an affordable price. The definitions provided by relevant international agencies reflect this, with the United Nations defining “food security” as “the condition in which all people, at all times, have physical, social, and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” and the International Energy Agency (IEA) defining “energy security” as “the uninterrupted availability of energy sources at an affordable price.”⁷

Unlike food and energy, water security is defined in less strongly economic terms, despite the real economic costs of obtaining and using water. To that point, the UN has defined “water security” as “the capacity of a population to safeguard sustainable access to adequate

⁵ Elie Elhadj, “Camels Don’t Fly, Deserts Don’t Bloom: An Assessment of Saudi Arabia’s Experiment in Desert Agriculture,” Occasional Paper No. 48, Water Issues Study Group, School of Oriental and African Studies, King’s College London, May 2004.

⁶ “Saudi Arabia’s Great Thirst,” *National Geographic*, accessed October 6, 2016, <http://environment.nationalgeographic.com/environment/freshwater/saudi-arabia-water-use/>; Qatar’s estimated depth calculated as follows: Qatar’s territory covers 11,570 km², which given that a km² contains 1 million m², yields an area of 11.57 billion m³. Dividing 300 billion m³ of water used by 11.57 billion m² reveals that this volume would cover the surface area under nearly 26 meters of water.

⁷ See <http://www.ifpri.org/topic/food-security>; See also “What is energy security?” International Energy Agency, accessed October 3, 2016, <https://www.iea.org/topics/energysecurity/subtopics/whatisenergysecurity/>.

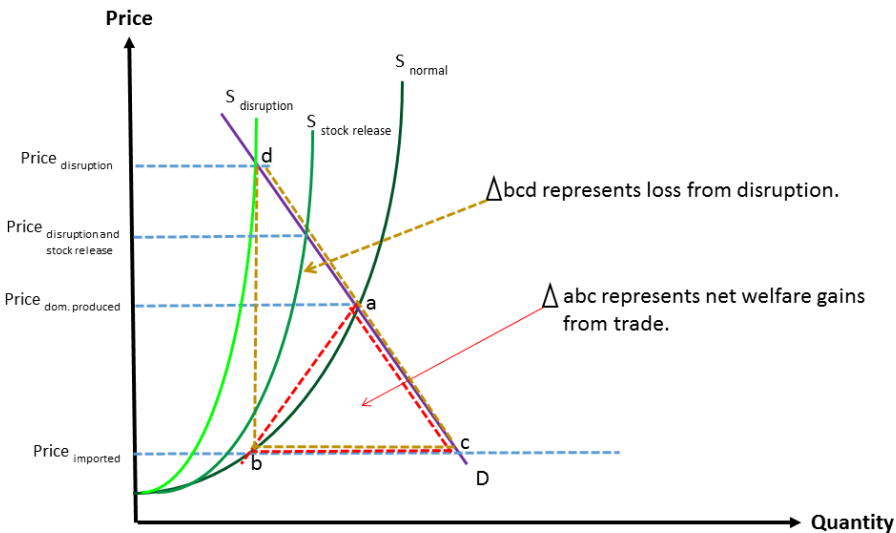
quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development; for ensuring protection against water-borne pollution and water-related disasters; and for preserving ecosystems in a climate of peace and political stability.”⁸

Achieving security in food, energy, and/or water supply often requires policies that are subjective and not easily quantifiable. But each contains clear economic dimensions, as embodied by references to “economic access” for food and “an affordable price” for energy sources. To analyze food and energy security issues through an economic lens, the common supply-demand framework offers robust initial explanatory power, but also suffers from some commodity-specific flaws on both the food and water vectors, which this analysis will explore in more depth. At the core of the framework is the notion that trade—or reliance on imports—carries risk. That said, such risks are acceptable if the expected welfare gains from trade are large enough.

The simplified schematic below demonstrates why—in theory—it makes sense for a higher cost producer to trade for a commodity (Figure 1). In essence, the lower price of importing the good in question creates substantial welfare gains for both sides of the transaction, denoted by Δabc . More to the point for this analysis, it is useful to consider the price effects and welfare losses induced by a significant supply disruption, denoted by Δbcd . Here, the welfare loss caused by the supply disruption clearly exceeds the gains from trade. However, the potential loss that a supply disruption could cause must be probability weighted (probability= p). Ultimately, if $(1-p) \Delta abc > \Delta bcd$, then it still makes sense to import the good.

⁸ “Water Security,” UN Water, accessed October 3, 2016, <http://www.unwater.org/topics/water-security/en/>.

Figure 1. Resource Economics Trade and Disruption Schematic



Source: Baker Institute Center for Energy Studies.

III. Sketching the Nexus: How Food, Water, and Energy Interact with Each Other in the Arabian Gulf Region

In its simplest form, the food-energy-water nexus in the Arabian Gulf takes shape along three fundamental vectors (Figure 2). The first vector is rooted in physics and biochemistry: water-thirsty staple food grains must be irrigated in the region’s arid climate, and water requires energy for movement and extraction. For industrial-scale food cultivation in the arid region, farmers must (1) tap groundwater reserves, which are often deep and energy intensive to exploit, or (2) desalinate seawater, which is even more energy intensive.⁹ At the extreme end of the spectrum, supplying sufficient desalinated seawater to produce one tonne of wheat in climate conditions typical of central/eastern Saudi Arabia or Qatar could require from 9,400 kWh for water treated by reverse osmosis to upward of 45,000 kWh of energy (equivalent to roughly 26 barrels of crude) for water desalinated via

⁹ At present, groundwater pumping in the Arabian Gulf region depends on fossil fuel energy inputs. Using solar-powered pumps where possible could begin to weaken the energy-water linkage for some parts of the economy, although the fundamental environmental problems caused by tapping non-recharging aquifers would remain.

multi-stage flash distillation.¹⁰ Here is another way to visualize the trade-offs of growing grain in a region where ensuring human water supplies is an existential challenge for many governments: the amount of water required to grow one tonne of grain in a climate like Qatar's could supply four Qatari nationals (some of the world's most prodigious water users) or nearly 30 expats for a year.¹¹

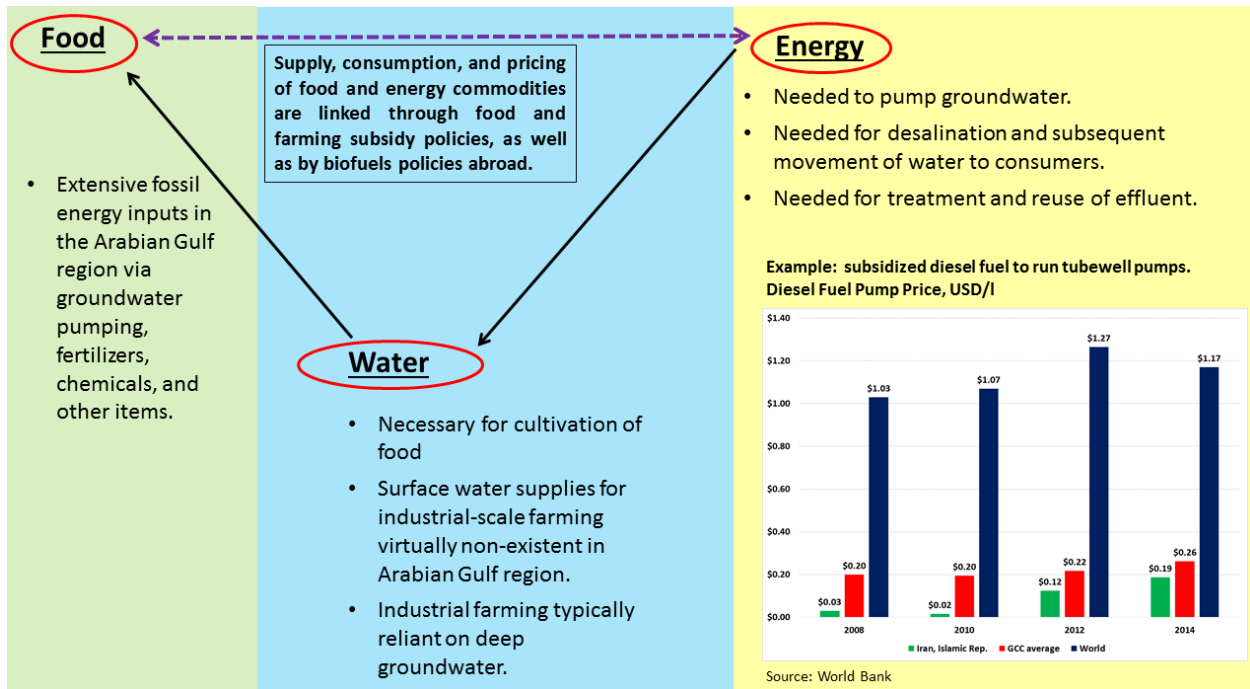
The second set of vectors are overtly political. Domestic political factors often pressure governments to keep energy input prices lower than would be the case in a freely traded market fully linked to global prices (see, for instance the diesel fuel retail prices shown in Figure 2. Artificially low domestic energy prices in the Arabian Gulf region promote inefficient use of energy—and, by extension, water. Such dynamics help make energy a focal point of competition between domestic constituencies seeking low-cost inputs and the economic reality that the national pecuniary interest is typically maximized by prioritizing sales of energy commodities into higher value export markets. Recent subsidy reforms prompted by low oil and gas prices are partially bridging the gap, but the disparity between world commodity prices and subsidized prices for those same goods in the domestic markets remains large and costly to governments in the region.¹²

¹⁰ Arani Kajenthira, Afreen Siddiqi, and Laura Diaz Anadon, "A new case for promoting wastewater reuse in Saudi Arabia: Bringing energy into the water equation," *Journal of Environmental Management* 102 (2012): 184–192, <http://dx.doi.org/10.1016/j.jenvman.2011.09.023>; M.M. Mekonnen and A.Y. Hoekstra, "The green, blue and grey water footprint of farm animals," Value of Water Research Report Series Number 48, http://waterfootprint.org/media/downloads/Report-48-WaterFootprint-AnimalProducts-Vol2_1.pdf; M.A. Darwish and Rabi Mohtar, "Qatar water challenges, Desalination and Water Treatment" (paper presented at the International Conference on Desalination for the Environment, Clean Water and Energy, European Desalination Society, Barcelona, Spain April 23–26, 2012), http://wefnexus.tamu.edu/files/2015/01/Qatar_water_challenge_Journal_paper.pdf; Omar Saif, "The Future Outlook of Desalination in the Gulf: Challenges & opportunities faced by Qatar & the UAE" (master's thesis, McMaster University, 2012), <http://inweh.unu.edu/wp-content/uploads/2013/11/The-Future-Outlook-of-Desalination-in-the-Gulf.pdf>; Bloomberg,, World Bank (transmission losses), <http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS>. The crude oil energy conversion assumes an average energy content of 5.8 million BTU per barrel (Iowa State University Extension Office, <https://www.extension.iastate.edu/agdm/wholefarm/pdf/c6-87.pdf>) and 3,412 BTU per kWh (US Energy Information Administration, <https://www.eia.gov/totalenergy/data/monthly/pdf/sec13.pdf>).

¹¹ Rohan Somam, "Qatar water consumption among the highest in the world," *BQ Magazine*, April 2016, <http://www.bq-magazine.com/industries/2016/04/qatar-water-consumption>.

¹² See, for instance, Jim Krane and Shih Yu (Elsie) Hung, "Energy Subsidy Reform in the Persian Gulf: The End of the Big Oil Giveaway," Issue Brief No. 04.28.16., Rice University's Baker Institute for Public Policy, <http://www.bakerinstitute.org/research/persian-gulf-energy-subsidy-reform/>.

Figure 2. The Food-Water-Energy Nexus in the Arabian Gulf Region



Source: Author’s analysis; World Bank.

Oil substitution policies in major consuming countries—particularly the United States—create a less appreciated but equally important political dynamic that can help motivate irrational agricultural policies in energy exporting countries. Biofuel advocates in the United States often use the perception of insecurity in the Gulf Region to advance their agenda of increasing the use of corn (and to some extent, soybeans) to produce bioethanol and biodiesel that they claim “reduces” US reliance on imported oil.¹³

The impact on US crude oil imports is moderate: US ethanol still produced an average of 966 kbd of ethanol in 2015, according to the US Energy Information Administration (EIA), the energy equivalent of approximately 650 kbd of crude oil. But the impact on the global grain markets is disproportionately large, as more than one-sixth of the global corn crop is used to produce ethanol. Corn’s evolution into a “fuel crop” ripples through the market for a range of substitute grains such as wheat and barley, which are important food sources for livestock and humans alike, and enhances grain market volatility by tying grain and oil prices more closely together. In turn, higher levels of price volatility give rise to feelings of food insecurity elsewhere in the world, including the Arabian Gulf region.

¹³ See, for instance: “Oil Dependence: A National Threat,” Renewable Fuels Association, September 2015, http://ethanolrfa.org/wp-content/uploads/2015/09/99805e3d3d287bdf33_uqm6bw403.pdf.

IV. Price Inelasticity of Food and Human Risk Aversion Amplify Stress Points in the Food-Water-Energy Nexus

The classical resource economics framework, which tends to favor trade, faces robust challenges when applied to food security and food-water-energy nexus situations. Two factors play an especially important role here: price elasticity and human risk aversion.

A. How the Price Inelasticity of Staple Grains Influences Policymakers

Price elasticity represents the proportionate change in demand to a given change in price.¹⁴ Generally speaking, goods with a price elasticity of less than 1.0 are said to be “inelastic” because the percentage drop in demand is smaller than the percentage drop in price. Conversely, goods with a high price elasticity are very price sensitive: if the price for such as good rises by 1%, demand will decline by more than 1%. Luxury goods—such as a restaurant meal—tend to be highly price elastic because there are many practical substitutes and purchases can be postponed.¹⁵

In contrast, staple foods tend to be relatively price inelastic because they are essential to life and there are few, if any, substitutes for many such items. Notably, for many of the core food groups, consumers in low-income countries have higher price elasticities of demand than do consumers in middle- and high-income countries. This illustrates a key factor with deep socio-political implications: richer consumers are less price sensitive because they have space in their budgets to trim spending on non-food items as needed when food prices rise.

For example, a recent study that compiled data from 136 studies and reported 3,495 food price elasticities from 162 different countries showed that in low-income countries, for every 1% increase in staple grain prices, demand only declined by 0.61%.¹⁶ Indeed, the study authors note that “low-income countries tend to have higher price elasticities for all foods than high-income countries, because food represents a large share of total income in these countries, hence price changes have a larger impact on budget allocation.”¹⁷

¹⁴ See Amy Gallo, “A Refresher on Price Elasticity,” *Harvard Business Review*, August 21, 2015, <https://hbr.org/2015/08/a-refresher-on-price-elasticity>.

¹⁵ See Patrick L. Anderson, Richard D. McLellan, Joseph P. Overton, and Gary L. Wolfram, “Price Elasticity of Demand,” November 1997, http://scholar.harvard.edu/files/alada/files/price_elasticity_of_demand_handout.pdf.

¹⁶ Rosemary Green, Laura Cornelsen, Alan D. Dangour, Rachel Turner, Bhavani Shankar, Mario Mazzocchi, and Richard D. Smith, “The effect of rising food prices on food consumption: systematic review with meta-regression,” *The BMJ* (2013): 346, <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3685509/>.

¹⁷ Ibid.

Figure 3. Food Price Elasticities for Various Food Groups, by Income Level

	Low Income			Middle Income			High Income		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Fruit and vegetables	-0.77	-0.72	-0.66	-0.71	-0.65	-0.59	-0.59	-0.53	-0.48
Meat	-0.83	-0.78	-0.73	-0.78	-0.72	-0.66	-0.66	-0.60	-0.54
Fish	-0.85	-0.80	-0.74	-0.79	-0.73	-0.67	-0.67	-0.61	-0.55
Dairy	-0.84	-0.79	-0.73	-0.78	-0.72	-0.66	-0.66	-0.60	-0.54
Eggs	-0.67	-0.55	-0.42	-0.61	-0.48	-0.35	-0.49	-0.36	-0.23
Cereals	-0.66	-0.61	-0.56	-0.61	-0.55	-0.49	-0.48	-0.43	-0.36
Fats and oils	-0.65	-0.60	-0.54	-0.6	-0.54	-0.47	-0.48	-0.42	-0.35
Sweets, confectionery, and sweetened beverages	-0.82	-0.74	-0.65	-0.77	-0.68	-0.59	-0.65	-0.56	-0.48
Other	-1.01	-0.95	-0.9	-0.95	-0.89	-0.83	-0.83	-0.77	-0.71
All food groups combined	-0.79	-0.74	-0.69	-0.73	-0.68	-0.62	-0.61	-0.56	-0.5

Elasticity higher in wealthier countries, but reducing consumption in response to price increases is a very different proposition in a society where consumers spend over \$15,000 per year than it is in one where they spend only a fraction of that.

Source: Green et al., “The effect of rising food prices on food consumption: systematic review with meta-regression.”

Poorer people can only trim spending so much before they enter a daily calorie deficit because food has become economically inaccessible to them. And at that point, the risk of political violence catalyzed by hunger rises significantly. Experts in the food security field support this view, noting that “food insecurity, especially when caused by higher food prices, heightens the risk of democratic breakdown, civil conflict, protest, rioting, and communal conflict.”¹⁸

If grain supplies to a country are sufficiently constrained to the extent that consumers struggle to—or cannot—attain minimum daily necessary calorie intake levels, grain prices then become extremely inelastic. At that point, the government must either spend whatever is necessary to procure emergency supplies or risk significant social unrest by a hungry and angry population.

B. Policymakers’ Risk Aversion Can Amplify Food Price Crises

As grain availability dwindles, political risk increases substantially and, often, in a non-linear fashion, since multiple factors influence events and make it almost impossible to predict the precise tipping point from hunger into unrest. Against such a backdrop of uncertainty, decision-makers often become risk averse.

During a time of rising grain prices and/or physical grain supply scarcity, governments will go to great lengths to preempt problems and avoid the tipping point “danger zone.” One direct effect of this risk aversion is that food price volatility can produce what C. Peter

¹⁸ Henk-Jan Brinkman and Cullen S. Hendrix, “Food Insecurity and Violent Conflict: Causes, Consequences, and Addressing the Challenges,” World Food Programme, July 2011, http://documents.wfp.org/stellent/groups/public/documents/newsroom/wfp238358.pdf?_ga=1.197756396.270783254.1475609478.

Timmer, a Harvard University emeritus scholar, calls “a visceral, hostile response among producers and consumers alike to the very functioning of markets.”¹⁹

Psychological studies demonstrate the power of loss aversion over human decision-making, with research suggesting a loss coefficient of about two.²⁰ In other words, losing \$1 generates a disutility at least as great as the utility of gaining \$2, meaning that human beings tend to substantially “overprice” risk in many situations.

Risk overpricing is especially relevant in the GCC. Consumers in these countries tend to have substantial disposable incomes that would enable them to weather even a severe food price spike in a way that inhabitants of more populous and poorer countries such as Egypt typically could not. Yet despite ample financial capacity to ensure food security, governments may nonetheless face pressures to employ food security policies that are irrational from financial and energy-use perspectives.

Such psychological pressures are amplified by the fact that food is an essential survival item, both in the immediate physical sense for individuals and in a concrete sense for governments as well, since keeping a population well-supplied with food can be a crucial source of legitimacy. There is often a feedback loop in which governments concerned about food supply security restrict trade, which can then trigger panic buying amidst less available supply, catalyzing price spikes that reinforce government and consumer fears and cause additional speculative activity that fuels further volatility. To that point, data from the Food and Agriculture Organization of the United Nations (FAO) show that during the 2007–08 global grain price spike, at least 25 countries restricted or banned exports of key grains.²¹

C. Policymakers’ Risk Aversion Can Also Perpetuate Autarkic Food Policies That Strain Local and Regional Water Supplies

In practice, the behavioral economics dynamics outlined above create a high risk that policymakers will overweight the probability of loss and create a situation in which they believe that during a time of unstable prices, the potential losses will almost certainly outweigh the gains that could be reaped through trade.²² That dynamic helps explain why although the model outlined in the classical framework makes eminent sense from an external perspective—especially with the global market flush with feed grains—an autarkic streak has nonetheless pervaded Arabian Gulf region food security policies for more than 35 years. Trading oil for water to make the desert bloom when there are abundant grain supplies available through highly liquid world markets is essentially irrational from

¹⁹ C. Peter Timmer, “Behavioral dimensions of food security,” *Proceedings of the National Academy of Sciences* 109 (2012): 12315–12320, published ahead of print, September 20, 2010, [doi:10.1073/pnas.0913213107](https://doi.org/10.1073/pnas.0913213107).

²⁰ Patricia Tovar, “The effects of loss aversion on trade policy: Theory and evidence,” *Journal of International Economics* 78, 1 (June 200): 154–167, <http://dx.doi.org/10.1016/j.jinteco.2009.01.012>.

²¹ “Country responses to the food security crisis: Nature and preliminary implications of the policies pursued,” Initiative on Soaring Food Prices, Food and Agriculture Organization of the United Nations, http://www.fao.org/fileadmin/user_upload/ISFP/pdf_for_site/Country_Response_to_the_Food_Security.pdf.

²² C. Peter Timmer, “Behavioral dimensions of food security.”

economic and hydrological perspectives. Yet the Arabian Gulf region's food security history—particularly deep fears of food embargoes—deserves analysis.

The 1970s marked a critical period in the formation of food security policies, the consequences of which reverberate to the present day in both the GCC countries and Iran. After Saudi Arabia led an OPEC oil embargo against countries seen as having supported Israel in the Yom Kippur War, top political leaders in the United States appeared to have seriously considered a retaliatory cutoff of grain supplies to the kingdom. Indeed, as Eckart Woertz details in *Oil For Food: The Global Food Crisis and the Middle East*, the Ford administration “commissioned a classified study about the vulnerability of oil exporters to food embargoes and Congress debated a food boycott as one of several counter-measures to the Arab oil embargo.”²³

Saudi Arabia very likely took the US threats seriously, given that slightly more than three months prior to the Arab oil embargo, the United States restricted soybean exports to try and tamp down rapidly rising domestic prices for soybean meal used in livestock feed. While the soybean export halt did not substantially disrupt the physical availability of soybeans in markets abroad, it reduced the confidence of buyers in Japan and other nations reliant on US soybeans.²⁴

In 1974 and 1975, US authorities imposed moratoria on grain sales to the USSR and Poland due to poor harvests in the United States (1974) and the USSR (1975), where market volatility was exacerbated by unpredictable Soviet and Eastern Bloc grain procurement policies.²⁵ The moratoria were subsequently lifted after the United States signed five-year grain supply agreements with the Soviet Union and Poland, which helped increase transparency and reduce market instability triggered by the prior Soviet pattern of making sudden and often unpredictable large grain purchases on the global market.²⁶

Prior to 1980, US grain export moratoria were driven by domestic factors, as opposed to a desire to use grain exports as an instrument of foreign policy leverage. This changed on January 4, 1980, when President Jimmy Carter prohibited the sale of any US grain to the USSR beyond the 8 million short tons per year guaranteed under the 1975 term agreement.²⁷ The embargo aimed to punish the Soviet Union for invading Afghanistan. Ultimately, the embargo failed due to (1) opposition from US farmers, (2) the existence of alternative suppliers who stepped into the breach and sold grain to the USSR, and (3) improvements in the Soviet grain harvest in 1980 and the USSR's ability to tap its grain reserves to help cover initial supply shortfalls.²⁸

²³ Eckart Woertz, *Oil for Food: The Global Food Crisis and the Middle East* (Oxford: Oxford University Press), 114-116.

²⁴ See, for instance: Kazuhisa Oki, “U.S. Food Export Controls Policy: Three Cases From 1973 to 1981,” Program on U.S.-Japan Relations, USJP Occasional Paper 08-13, Harvard University, 2008.

²⁵ “Embargoes, Surplus Disposal, and U.S. Agriculture: A Summary,” Agriculture Information Bulletin No. 503, US Department of Agriculture Economic Research Service, November 1986, <https://naldc.nal.usda.gov/download/CAT87872440/PDF>, 12-14.

²⁶ *Ibid.*, 13.

²⁷ Robert Paarlberg, “Lessons of the Grain Embargo,” *Foreign Affairs*, Fall 1980, <https://www.foreignaffairs.com/articles/united-states/1980-09-01/lessons-grain-embargo>, 144.

²⁸ Paarlberg, “Lessons of the Grain Embargo,” 146, 149-153, 157.

While the US grain embargo against the USSR proved a strategic failure, it almost certainly led grain importers to question the reliability of US supplies during times of political conflict. Because the Soviet Union's own internal stocks and grain production capacity helped it weather the embargo with relatively minimal disruption to consumers, it is very likely that other import-dependent nations, including those in the Arabian Gulf region, took note and redoubled efforts to bolster their own domestic grain growing capacity.

In the intervening 36 years since the last politically motivated US grain embargo, the deep-seated view that “strong nations produce their own food” has not significantly changed in the Arabian Gulf region. Indeed, contemporary events illustrate the continued salience of trade sanctions that could conceivably be extended to food goods. To that end, a 2013 Chatham House analysis notes that “the international community’s use of trade sanctions against regional neighbors such as Syria, Libya, and Iran provides a constant reminder to GCC populations of the extent to which their food security could be undermined by geopolitical agendas.”²⁹

As such, national food security policies have evolved into a complex *mélange* of semi-autarky, trade-based engagement with the global market, and efforts to develop less water-intensive areas of agriculture to help underpin food availability. The GCC countries in the region are heavily import dependent for their cereal supply, importing nearly 94% of their cereals in 2012, according to data from Alpen Capital and the Arab Agricultural Statistics Yearbook.³⁰

Meat comes next, with a 68% import dependency ratio, followed by dairy products at roughly 57%, fruits at 48%, and vegetables at 46%. For its part, Iran essentially takes the polar opposite of the GCC countries’ grain supply approach, as it is nearly self-sufficient in wheat and continues to attempt to enhance domestic grain output at the expense of serious groundwater depletion.

V. How Key Gulf Countries’ Food Security Policies Stress the Food-Water-Energy Nexus

The Gulf countries share a heavy reliance on wheat as a staple food. Saudis consume an average of 109 kg per capita each year, while Iranians consume approximately 187 kg of wheat. To put that number in perspective, US per capita wheat consumption in 2011 was closer to 60 kg, according to the US Department of Agriculture (USDA).³¹ Yet despite dietary commonalities, Iran and the GCC countries display broad disparities in population and, more importantly, per capita economic output, a proxy for a country’s capacity to ensure food security through international trade. Ensuring grain supply security entails

²⁹ Rob Bailey with Robin Willoughby, “Edible Oil: Food Security in the Gulf,” Chatham House Briefing Paper, November 2013, <https://www.chathamhouse.org/sites/files/chathamhouse/public/Research/Energy,%20Environment%20and%20Development/bp1113edibleoil.pdf>.

³⁰ “GCC Food Industry,” Alpen Capital, April 28, 2015, http://futuredirections.org.au/wp-content/uploads/2015/07/GCC_Food_Industry_Report_April_2015.pdf, 23.

³¹ “US Wheat Use,” United States Department of Agriculture Economic Research Service, accessed November 16, 2016, <http://www.ers.usda.gov/topics/crops/wheat/background.aspx>.

using a combination of strategies, including domestic cultivation where feasible, imports, storage, and at times, acquisition of farmland or farming companies abroad.

The analysis below will assess how the region's largest countries by population—Iran and Saudi Arabia—and a trend-setting smaller country—Qatar—are grappling with the chief stress points in the food-water-energy nexus in the Gulf region. These key focal points include the energy intensity of water supplies needed for grain cultivation and behavioral dynamics that affect consumers and policymakers. The analysis will then discuss possible palliative measures, including expansion of storage capacity and acquisition of farming assets abroad.

A. Energy Cost of Obtaining Water to Grow Crops

On the most obvious level, growing grain requires significant amounts of water. Barley and wheat, the least thirsty staple grains, consume 520 mm of water during the growing season in Southern Iraq—where the climate closely approximates that of Eastern Saudi Arabia, Qatar, Bahrain, and much of South-Central Iran (Figure 4).³²

Given the region's low rainfall (roughly 75 mm per year), low soil water content, and low humidity that accelerates evapotranspiration by plants, intensive irrigation is required. At this point, energy and water begin to closely interact. For example, delivering 10 million liters of water—the amount needed for 1 ha of irrigated corn—from a lake or river requires approximately 880 kWh of fossil fuel energy.³³ By contrast, pumping groundwater from a 100-meter-deep aquifer to irrigate 1 ha of corn boosts the energy need to 28,500 kWh—more than 32 times the energy required to utilize surface water.³⁴ When a country's farming sector is large enough, these energy demands can have a systemic national impact due both to their scale and timing (i.e., power and fuel demand peaking during growing seasons). For instance, agricultural water pumping—primarily from tube wells—has been estimated to account for nearly one-third of India's total power consumption.³⁵

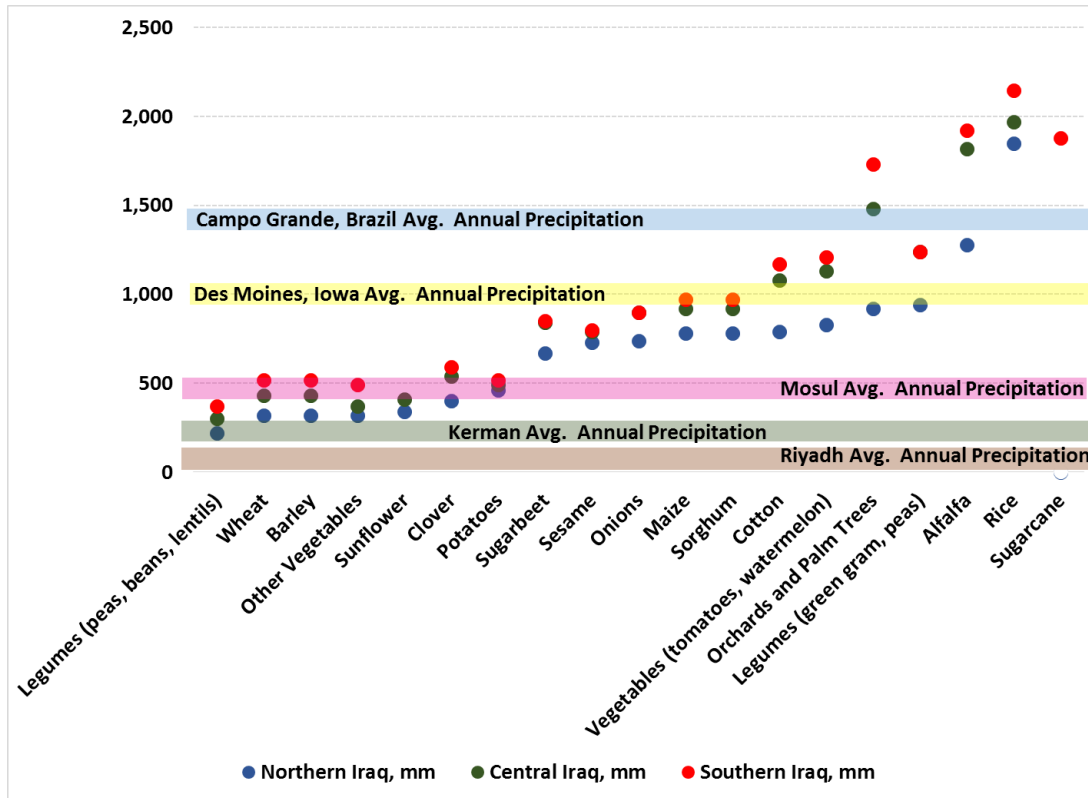
³² N.S. Kharrufa, G.M. Al-Kawaz, and H.N. Ismail, "Studies on Crop Consumptive Use of Water in Iraq," in *Irrigation and Agricultural Development*, ed. S.S. Johl, (Oxford: Pergamon Press, 1980).

³³ Shahbaz Mushtaq, Tek Narayan Maraseni, Jerry Maroulis, and Mohsin Hafeez, "Energy and water tradeoffs in enhancing food security: A selective international assessment," *Energy Policy* 37 (2009): 3635–3644.

³⁴ *Ibid.*

³⁵ M.D. Kumar, "Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: analysis from Western India," *Energy Policy* 33, 1 (2005): 39–51.

Figure 4. Total Consumptive Water Use of Key Crops Under Approximate Arabian Gulf Climate Conditions



Note: Figure depicts millimeters consumed during growing season.
 Source: N.S. Kharrufa et al., "Studies on Crop Consumptive Use of Water in Iraq."

Most farming in the Arabian Gulf region is groundwater dependent and taps aquifers much deeper than 100 meters, making energy usage commensurately higher than the above example. For instance, some farmers in Saudi Arabia now pump water from wells more than one kilometer deep.³⁶ Lifting water from such depths is massively electricity intensive, and because Saudi Arabia generates virtually all of its electricity from oil and gas, hydrocarbons intensive as well. In 2012, Saudi Arabia generated 35% of its electrical power from crude oil, 20% from diesel fuel, 6% from fuel oil, and 39% from natural gas.³⁷

Saudi researchers estimate that each hectare of wheat cultivated in Saudi Arabia during the early 1990s at the peak of the kingdom’s farming activity required 13,173 cubic meters of

³⁶ Lester R. Brown, “Plan B 3.0: Mobilizing to Save Civilization: Chapter 4. Emerging Water Shortages: Water Tables Falling,” Earth Policy Institute, http://www.earth-policy.org/books/pb3/PB3ch4_ss2.

³⁷ Bassam Fattouh, “Summer Again: The Swing In Oil Demand In Saudi Arabia,” Oxford Institute for Energy Studies, July 2013, <https://www.oxfordenergy.org/publications/summer-again-the-swing-in-oil-demand-in-saudi-arabia/>.

water.³⁸ At Saudi Arabian average wheat yields of approximately 5 tonnes per hectare, each tonne of wheat grown thus would need approximately 2,634 cubic meters of water—roughly the same amount needed to fill an Olympic swimming pool.³⁹ We estimate that lifting 2,634 cubic meters of water from 1,000-meter-deep wells would require the use of more than 10,000 kWh of electrical energy, accounting for pump efficiency factors and transmission line losses between generating stations and the pumps.⁴⁰ Given the fuel structure of the Saudi electricity generation system, that amount of electricity would equate to approximately 7 barrels of crude oil, 3.8 barrels of diesel fuel, 1.1 barrels of fuel oil, and nearly 33,000 cubic feet of natural gas (Figure 5).

Figure 5. Energy Requirements to Pump Deep Groundwater in East/Central Saudi Arabia

Electric Pump		Diesel Pump	
1,000	kg/cubic meter	-	-
1,000	Lift distance, meters	-	-
9,800,000	Work performed per cubic meter pumped, J	-	-
3,600,000	J per kWh	-	-
2,722	Theoretical kWh used per 1,000 Cubic Meters Pumped	68	Theoretical Gallons of Diesel Used per 1,000 Cubic Meters Water Pumped
35.0%	Pumping Hardware Mechanical Losses	35.0%	Pumping Hardware Mechanical Losses
7.0%	Electricity Transmission Line Losses	n/a	n/a
		3,414	BTU/kWh
		137,381	BTU/gal
		42	gal/bbl
3,866	kWh used per 1,000 Cubic Meters Pumped	2.17	Bbl of diesel per 1,000 Cubic Meters Pumped

Source: Bill Peacock, "Energy and Cost Required to Lift or Pressurize Water"; US Department of Energy; World Bank.⁴¹

In January 2017, the crude oil and associated refined products needed to pump enough water to grow one tonne of wheat were worth roughly \$607, versus a US No. 2 soft red

³⁸ Hamad M. H. Al-Sheikh, "Appendix 8: Country Case Study-Water Policy Reform in Saudi Arabia," FAO, <http://www.fao.org/docrep/006/ad456e/ad456e0e.htm>.

³⁹ Yields calculated using USDA data from the 1988 through 2016 crop years.

⁴⁰ Our model results track the findings for specific groundwater pumping energy use found by A.K. Plappally and J.H. Lienhard V, "Energy requirements for water production, treatment, end use, reclamation, and disposal," *Renewable and Sustainable Energy Reviews* 16, 7 (September 2012): 4818–4848. <http://dx.doi.org/10.1016/j.rser.2012.05.022>.

⁴¹ Bill Peacock, "Energy and Cost Required to Lift or Pressurize Water," University of California Cooperative Extension Tulare County, Pub. IG6-96; "Alternative Fuels Data Center: Fuel Properties Comparison," US Department of Energy, http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf; World Bank (power transmission line losses), <http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS>.

winter wheat export price of approximately \$170/tonne at the US Gulf Coast. This implies that wheat self-sufficiency would have a “social cost” on the order of \$440 per tonne. To boot, the implied social cost only counts the value of direct energy inputs needed to pump water. It does not even begin to touch the substantial subsidies for other necessary items such as fertilizer and machinery, much less the artificially high prices at which a government may purchase grain in order to encourage greater domestic cultivation of key cereals. Commodity prices move on a daily basis, but the fundamentally unfavorable ratio between energy-intensive domestic wheat cultivation versus importing from more efficient producers endures.

The dual challenges of high domestic energy use for groundwater pumping and the accompanying depletion of slow recharge aquifers affect other countries in the region as well. Iranian farmers currently use at least 16 kbd of crude oil, 35 kbd of heavily subsidized diesel fuel, and the equivalent of 1.6 million tonnes of LNG on an annual basis to pump groundwater for irrigation.⁴² To put this in plain language, Iran’s agricultural sector uses the following amounts of energy to pump groundwater each year: enough crude oil to keep Qatar Petroleum’s QP Refinery running at full capacity for a month and a half; enough diesel fuel to drive 3,663 average American 18-wheelers around the earth at the equator; and enough natural gas to power New York City—the world’s thirteenth-largest economy (nearly as large as Canada’s)—for nine days.⁴³

Because the Arabian Gulf region lacks surface water resources on a scale needed to irrigate commercial farms, only two other high-volume water sources exist. Reuse of municipal effluent is one option. But this approach must overcome consumer aversion to “toilet-to-field” water, and it also cannot supply enough water to enable grain farming on a meaningful scale. That leaves desalination of seawater (“desal”), a very energy-intensive process. The World Bank estimates that in 2010, desal accounted for 9.4% of Saudi Arabia’s total primary energy use.⁴⁴ Put another way, Saudi Arabia expended the energy equivalent

⁴² Poolad Karimi, Asad Sarwar Qureshi, Reza Bahramloo, David Molden, "Reducing carbon emissions through improved irrigation and groundwater management: A case study from Iran," *Agricultural Water Management* 108 (2012): 52-60,

https://www.researchgate.net/publication/251586834_Reducing_carbon_emissions_through_improved_irrigation_and_groundwater_management_A_case_study_from_Iran.

⁴³ For data on Iran’s energy consumption to pump irrigation water, see Karimi et.al, "Reducing carbon emissions through improved irrigation and groundwater management: A case study from Iran"; Arash Farnoosh, "On the Economic Optimization of National Power Generation Mix in Iran: A Markowitz Portfolio-Based Approach," Centre de Recherche en Economie et Droit de l’Energie, March 7, 2016; For data on heavy truck fuel economy, see <http://energy.gov/eere/articles/supertruck-making-leaps-fuel-efficiency>; For a natural gas demand perspective, see “Assessment of New York City Natural Gas Market Fundamentals and Life Cycle Fuel Emissions,” http://www.nyc.gov/html/om/pdf/2012/icf_natural_gas_study.pdf, and Richard Florida, “If U.S. Cities Were Countries, How Would They Rank?,” *The Atlantic*, July 21, 2011, <http://www.theatlantic.com/business/archive/2011/07/if-us-cities-were-countries-how-would-they-rank/241977/>; For data on the Qatar Petroleum refinery, <https://www.qp.com.qa/en/QPActivities/QPOperations/Pages/QPRefinery.aspx>.

⁴⁴ “Renewable Energy Desalination: An Emerging Solution to Close the Water Gap in the Middle East and North Africa,” MENA Development Report, The World Bank, 2012, http://water.worldbank.org/sites/water.worldbank.org/files/publication/water-wpp-Sun-Powered-Desal-Gateway-Meeting-MENAs-Water-Needs_2.pdf, 75.

of approximately 400,000 barrels per day of crude oil on desalination in 2010, and that number has since increased.⁴⁵

Farmers in Spain and Israel utilize desalinated water for the commercial-scale cultivation of high-value vegetable and fruit crops (often using greenhouses). For instance, by the 2006–07 period, 22% of desalinated water in Spain was used for irrigation.⁴⁶ There are important horticultural implications farmers must consider, since desalination removes many minerals such as calcium and sulfur that are essential to plant growth, while concentrating others such as boron that can be toxic to plants.⁴⁷ That being said, with proper adjustments—including post-treatment mineral additions and blending with other water sources—desalinated water is clearly feasible for farming. The more fundamental question is whether an Arabian Gulf country would prefer to incur the energy opportunity cost of growing vegetables and fruits domestically with desalinated seawater, or would it rather export the hydrocarbons and trade the earnings for food goods imported from abroad.

For its part, Qatar’s National Food Security Programme has decided that “desalination is the answer to how Qatar will secure water for agriculture...groundwater extraction has to be discontinued and the aquifers need to be recharged with desalinated water.”⁴⁸ Desalination of seawater in Qatar requires as much as 20 kWh of energy per cubic meter of water produced via multi-stage flash distillation, including pumping demands and thermal inputs.⁴⁹ Analysts estimate that more efficient reverse osmosis units can desalinate water for approximately 4.0 kWh/M³, but even this process still uses at least as much power to produce a tonne of wheat than would be expended irrigating with groundwater from a depth of 1 km.⁵⁰

Irrigation data from Saudi Arabia suggest that in a climate similar to Qatar’s, each hectare of wheat could require as much as 13,000 cubic meters of irrigation water. At an average yield of 5.6 tonnes of wheat per hectare and with a 25 km horizontal movement of water from the desal plant to the wheat farm, this would imply a total energy requirement of between 9,400 kWh and 47,000 kWh of energy per tonne of wheat produced, depending

⁴⁵ Calculated based on World Bank figure stating that 9.4% of primary energy is used for desalination, and the BP Statistical Review of World Energy 2016 figure finding that Saudi Arabia’s primary energy consumption in 2010 was equal to 216.1 million tonnes of oil equivalent.

⁴⁶ U. Yermiyahu, A. Tal, A. Ben-Gal, A. Bar-Tal, J. Tarchitzky, and O. Lahav, “Rethinking Desalinated Water Quality and Agriculture,” *Science Magazine* 318, November 9, 2007, http://www.ildesal.org.il/pdf/gwri_abstracts/2007/2007-42.pdf.

⁴⁷ Ibid.

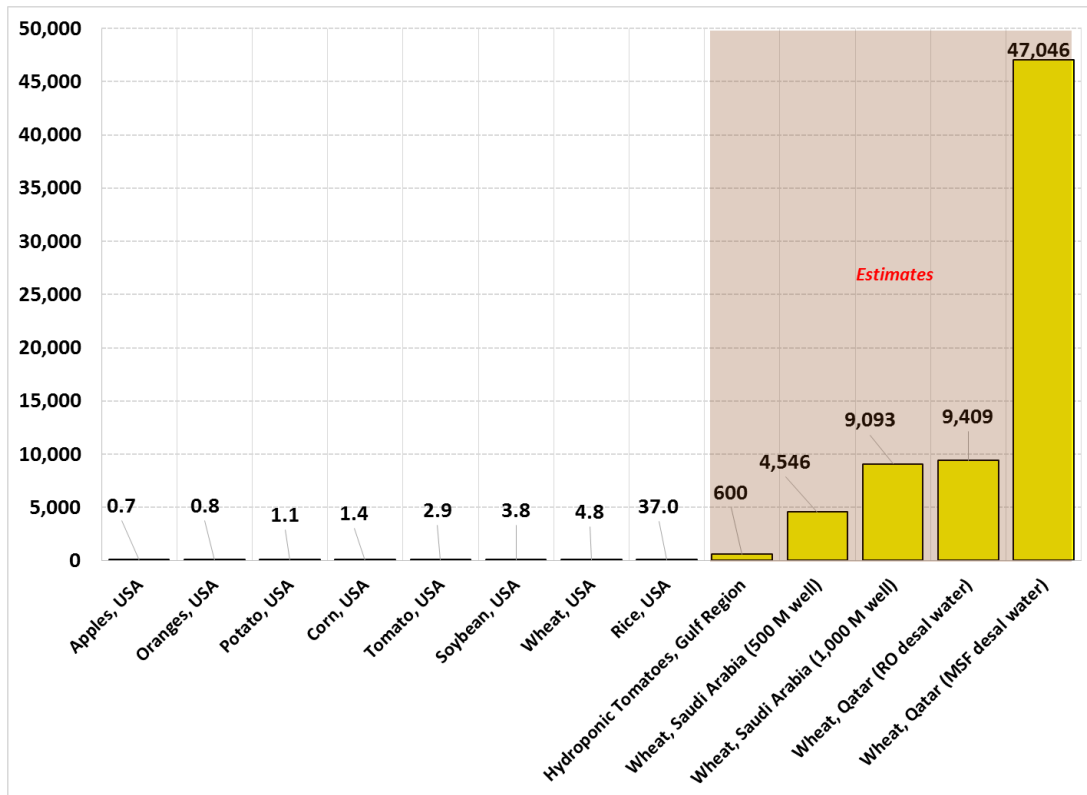
⁴⁸ “National Food Security Program,” Hukoomi (Qatar e-government), <http://portal.www.gov.qa/wps/portal/topics/Environment+and+Natural+Resources/National+Food+Security+Program>.

⁴⁹ M.A. Darwish and Rabi Mohtar, “Qatar water challenges, Desalination and Water Treatment,” 2012, DOI:10.1080/19443994.2012.693582, http://wefnexus.tamu.edu/files/2015/01/Qatar_water_challenge_Journal_paper.pdf.

⁵⁰ Heather Cooley and Matthew Heberger, “Key Issues for Seawater Desalination in California: Energy and Greenhouse Gas Emissions,” The Pacific Institute, 2013, <http://pacinst.org/app/uploads/2013/05/desal-energy-ghg-full-report.pdf>, 5.

on the water source used (Figure 6).⁵¹ In a nutshell, grain cultivation in a severely arid climate like the Arabian Gulf requires two orders of magnitude more energy per tonne of grain produced than would be the case in a temperate climate like Canada, Russia, Ukraine, or the United States. In the hypothetical case of using desalinated seawater to produce grain, there would be an increase of energy intensity of nearly three orders of magnitude between the temperate countries and the Arabian Gulf (i.e., roughly 5 kWh/tonne versus nearly 50,000 kWh/tonne).

Figure 6. Electricity Intensity of Growing Various Crops in the United States and the Arabian Gulf Region, kWh/tonne produced



Source: David Pimentel, “Energy Inputs in Food Crop Production in Developing and Developed Nations;” Practical Hydroponics & Greenhouses; author’s models.⁵²

⁵¹ Derived from average Saudi yield data from the 1988–89 crop year through the end of large-scale cultivation in the 2016–17 crop year, as reported by the USDA. Water movement energy expenditures calculated from Arani Kajenthira, A. Siddiqi, and L.D. Anadon, “A new case for promoting wastewater reuse in Saudi Arabia: Bringing energy into the water equation,” *Journal of Environmental Management* 102 (2012): 184-192, 188 (0.00024 kWh/m³ per km of horizontal transport).

⁵² David Pimentel, “Energy Inputs in Food Crop Production in Developing and Developed Nations,” *Energies* 2 (2009): 1-24, doi:10.3390/en20100001; Elly Nederhoff and Ceclia Stanghellini, “Water Use Efficiency of Tomatoes,” *Practical Hydroponics & Greenhouses*, November/December 2010, <http://edepot.wur.nl/156932>.

Cultivating higher value-added crops such as tomatoes with desalinated water is still energy-intensive relative to vegetable farming in temperate regions of the world, but consumes far less energy and yields far greater value per tonne of output than grain farming would in an Arabian Gulf climate. To put the energy intensity numbers listed in Figure 6 in perspective, consider that for Qatar to replace its planned 2016 wheat imports of approximately 250,000 metric tonnes with wheat grown domestically and irrigated with desalinated water, the direct energy use to provide the water would be roughly 9.2 kbd of crude oil and at least 1.4 million tonnes per year of potential LNG exports (Figure 7).

At January 2017 prices, the hydrocarbons inputs to grow 250,000 tonnes of wheat would be worth an estimated combined total of \$642 million. In contrast, it would cost roughly \$46 million to import that same volume of wheat at global benchmark prices: a 13-fold difference. These numbers indicate that wheat substitution would have a “social cost” of at least \$2,200/tonne in Qatar. To put domestic costs in contrast, Hassad Australia’s existing farming operations can supply at least 179,000 tonnes per year of grain from a property investment of approximately USD \$470 million, according to the company and Australian media.⁵³

After the initial capital investment, Hassad Australia’s assets can operate at a much lower variable cost because they are largely rain fed and thus do not need to incur the massive energy expenditures that growers in the Arabian Gulf region would have to undertake in order to procure water supplies.⁵⁴ Based on these numbers, it becomes apparent why Qatar is taking the approach of importing wheat and hedging by investing in farmland located in countries where conditions are more amenable to efficient industrial-scale grain cultivation, rather than trying to make the desert bloom domestically.

⁵³ Laurissa Smith, “Middle East company adds spice to Australian grain,” *ABC Rural*, December 8, 2013, <http://www.abc.net.au/news/rural/2013-12-06/foreign-investment-australian-grains/5140084>; Hassad Australia, <http://www.hassad.com/English/Pages/Hassad-Australia.aspx>.

⁵⁴ See, for instance, data for Yupiri, a major Hassad Food grain farm holding in Western Australia <http://hassad.com.au/yupiri-wa/>: “Esperance: Climate statistics for Australian locations,” Australian Government Bureau of Meteorology,” accessed December 21, 2016, http://www.bom.gov.au/climate/averages/tables/cw_009789.shtml.

Figure 7. Estimated Energy Used to Produce 250,000 Tonnes of Wheat With Desalinated Water in Qatar

Qatar electricity generation fuels												
Fuel	Share of Powergen	BTU/bbl	kWh/bbl	kWh/mcf	kWh of power consumed	kWh contributed	Power Plant Thermal Efficiency	Transmission Losses	BCF to generate given power level	Bbl to generate given power level	Adjusted for plant efficiency and transmission losses	
Crude oil	18%	5,729,000	1,678			2,117,724,413	31%	6.2%	0	1,261,985	3,360,632	bbl
Diesel	0%	5,770,002	1,690		11,765,135,625	0	31%	6.2%	0	0	0	bbl
Fuel Oil	0%	5,817,000	1,704			0	31%	6.2%	0	0	0	bbl
Natural Gas	82%			293		9,647,411,213	42%	6.2%	33	0	68	BCF
Fuel	Bbl	Tonnes of LNG	Price, 31 January 2017	Units	Value	Total	Hydrocarbon Input Value per Tonne of Wheat	Likely Wheat Import Price, cif (USD/tonne)	Implied social cost per tonne			
Brent Crude Oil	3,360,632	-	\$55.25	bbl	\$185,674,917							
Diesel	0	-			\$0							
Fuel Oil	0	-			\$0							
Natural Gas, Qatar Netback to Japan (Poten and Partners via Bloomberg)	-	1,404,349	\$325.00	tonnes	\$456,413,518	\$642,088,435	\$2,568	\$185	\$2,383			

Source: M.A. Darwish and Rabi Mohtar, "Qatar water challenges, Desalination and Water Treatment"; Omar Saif, "The Future Outlook of Desalination in the Gulf: Challenges & opportunities faced by Qatar & the UAE"; Bloomberg; EIA; World Bank; and USDA.

Desalination in the Arabian Gulf Region Likely to Remain Fossil Fuel Dependent Beyond 2020

The Qatar National Food Security Programme has for several years now contemplated using solar and wind energy to desalinate water and use it to supply agricultural projects and also re-inject it into depleted aquifers to replenish them and establish strategic reserves of freshwater.⁵⁵ The country's plans to move away from fossil fuel-based desalination thus far appear to be aspirational, as it added a multi-stage flash distillation plan at Ras Abu Fontas in 2015 and broke ground on a reverse osmosis desal plant in the same area in November 2015.⁵⁶

In Qatar, as well as in Saudi Arabia and the UAE, the close relationship between water production and power generation caused by the use of cogeneration facilities to produce both water and electricity poses tough challenges to policymakers who seek to reduce fossil fuel consumption by the water sector. To reduce domestic demand for potentially exportable hydrocarbons, the UAE has partnered with a consortium led by Korea Electric Power Corporation (KEPCO) to build a \$20 billion nuclear plant that is slated to have four reactors online by 2020, capable of generating 5,600 MW of electricity.⁵⁷

⁵⁵ See, for instance, Patrick Linke, "Sustainable water planning for food security," Qatar National Food Security Programme, Gulf Water Conference, April 22, 2012, http://wstagcc.org/en/wp-content/uploads/sites/2/2014/05/S1_L5_Sustainable_water_planning_Partick_Linke.pdf.

⁵⁶ See "Ras Abu Fontas (RAF) A2 Seawater Desalination Plant, Qatar," Water-Technology, accessed November 16, 2016, <http://www.water-technology.net/projects/ras-abu-fontas-raf-a2-seawater-desalination-plant/>, and "ACCIONA takes part in the opening ceremony of the construction work for its first desalination plant in Qatar," Acciona, November 12, 2015, <http://www.acciona.com/news/acciona-takes-part-opening-ceremony-construction-work-first-desalination-plant-qatar/>.

⁵⁷ "Nuclear Power in the United Arab Emirates," World Nuclear Association, October 2016, <http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx>.

At a 90% annual capacity utilization, the nuclear plant could ultimately supplant approximately 1.25 BCF/day in potential natural gas demand—nearly 20% of the UAE’s daily consumption in 2015.⁵⁸ However, the Abu Dhabi Transmission and Despatch Company (TRANSCO) worries that as nuclear power comes online, solar power capacity will also increase, and future desalination plants will move toward greater use of reverse osmosis technology that requires electricity but not direct natural gas inputs. TRANSCO fears that the resultant de-coupling of the water and electricity supply systems could destabilize Abu Dhabi’s entire water and power supply ecosystem.⁵⁹ As a result, interested parties in Abu Dhabi are reportedly negotiating to limit nuclear plants to only a 60% capacity utilization.⁶⁰

A conclusive policy decision has not been reported as of the time of this report’s publication. That said, promoting power exports from the UAE to its neighbors would likely be a much more rational and effective solution, since nuclear plants are optimized to provide baseload electricity supplies at a high capacity utilization factor and restricting their operation risks stranding capital.

The UAE’s situation is not unique. Qatari policymakers have a learning opportunity, as their country would likely face similar challenges if it moves to use reverse osmosis to supply a greater proportion of the country’s desalinated water and generate more electricity at stand-alone facilities, perhaps including utility-scale solar and nuclear plants.

B. Major Oil Consumers’ Biofuel Policies Globalize the Food-Water-Energy Nexus

While water itself is typically not directly tradable across regions due to logistical constraints, it is traded through food and energy proxies. For instance, when Saudi Arabia uses petrodollars to pay for a cargo of Brazilian soybeans for use as chicken feed, it is effectively importing water from the humid cerrado of southern Brazil. Things get more complicated when major consumers adopt policies that leverage one competitive advantage—for instance, abundant farmland and water in the US Midwest—to try and reduce their reliance on an imported good (oil) through subsidized ethanol production.

Here we speak of biofuels. Water and/or food supply disruptions in key energy exporting countries that are severe enough to trigger social unrest also risk disrupting energy supplies. In turn, energy supply disruptions—whether intentional or involuntary—can

⁵⁸ Nuclear plant capacity data comes from from the Nuclear Energy Institute, “US Nuclear Capacity Factors,” accessed January 11, 2017, <https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-Capacity-Factors>. A plant with 5,600 MW of capacity running at an average annual capacity factor of 90% would generate approximately 44 billion kWh per year of power. EIA data suggest an average heat rate of 10,408 BTU per kWh generated for US plants, which we use here as an approximate benchmark to derive data for facilities in the UAE (See “How much coal, natural gas, or petroleum is used to generate a kilowatt hour of electricity?,” U.S. Energy Information Administration, accessed January 11, 2017, <https://www.eia.gov/tools/faqs/faq.cfm?id=667&t=3>). This yields an annual energy need of 460 trillion BTU, equal to 460 billion cubic feet of natural gas, or approximately 1.25 BCF/d. Natural gas consumption data for the UAE comes from the BP Statistical Yearbook 2016.

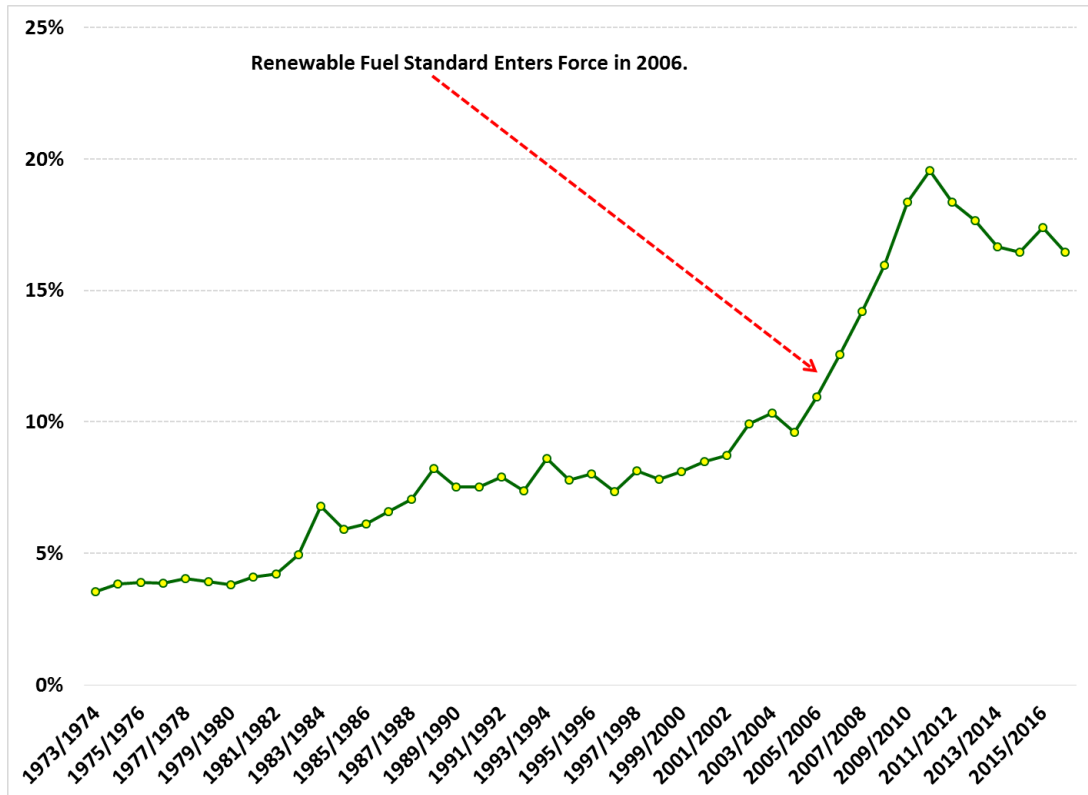
⁵⁹ Laura Parmigiani, “Water and Energy in the GCC: Securing Scarce Water in Oil-Rich Countries,” l’Ifri Center Énergie, September 2015,

https://www.ifri.org/sites/default/files/atoms/files/water_energy_gcc_parmigiani.pdf

⁶⁰ Ibid.

cause price movements that prompt energy importer countries to take steps to boost biofuel use with the stated aim of reducing dependency on oil imports.⁶¹ Such policies have more than tripled the share of US corn used for ethanol production, reduced the availability of corn for feed purposes, and more tightly tied the price of corn crude oil prices (Figure 8).

Figure 8. US “Feed, Seed, Industrial” Corn Use as a Proportion of Total Global Corn Production



Note: In the United States, FSI corn use is dominated by ethanol production.
 Source: US Department of Agriculture; author’s analysis.

To illustrate the magnitude of the rise in ethanol-driven corn demand, global corn production increased from 330 million tonnes in the 1973 crop year to more than 1 billion tonnes in the 2016 crop year. Distortions in the corn markets may in turn create disruptive pricing and availability swings in the markets for potential substitute grains, including

⁶¹ One such policy is the US Renewable Fuels Standard (RFS), which requires refiners and gasoline importers to blend ethanol into the gasoline supply pool. The RFS was authorized under the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act of 2007. Although the stated aim was to reduce greenhouse gas (GH) emissions and reduce dependence on imported oil, the RFS also created a massive market for US corn producers. CFR §80.1100-1167, http://www.ecfr.gov/cgi-bin/text-idx?SID=fecd1c93dc121c4b988dc16ae53a7d26&node=40:17.0.1.1.9&rgn=div5 - se40.19.80_11105.

barley, sorghum, and wheat, all of which are important staples in the Middle East and North Africa (MENA) region.

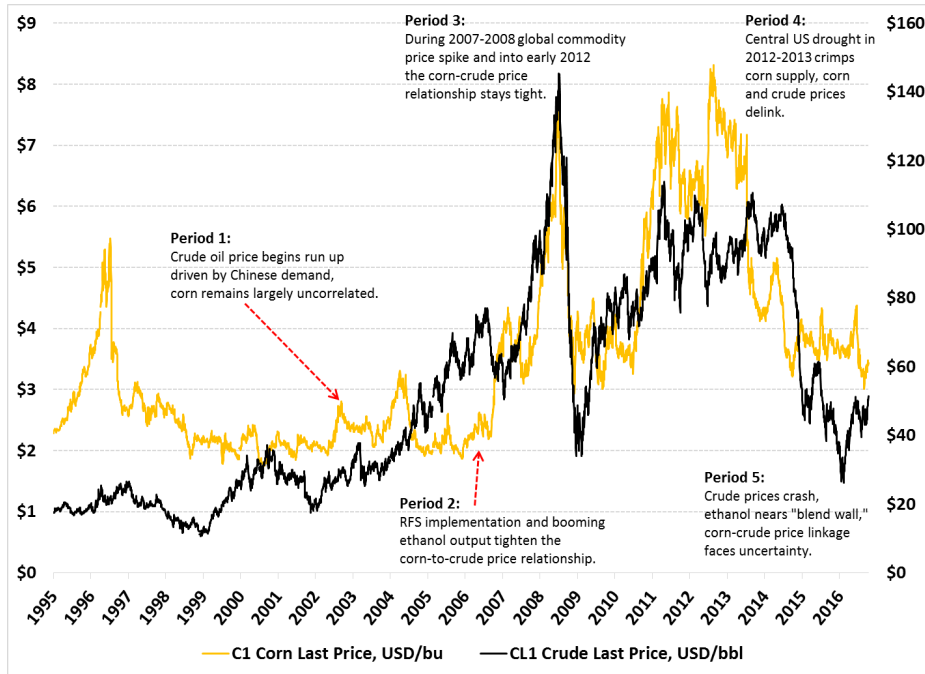
While the economics of large-scale substitution of ethanol for crude oil in the US gasoline supply do not “make sense” in economics terms, in physical terms the abundant land and water resources of the US Corn Belt can generally sustain ethanol production while also providing sufficient corn to meet animal feeding needs in the United States and abroad. The core problem is that when corn supplies are crimped—as happens during the droughts that inevitably strike—price increases can be sharp and sudden. Such market movements shake consumer (and policymaker) confidence in other regions, especially those that depend on imported grains.

The high proportion of global corn demand being used to produce fuel ethanol has helped create a situation in which corn prices—and by extension, other substitute feed grains—are much more correlated to crude oil prices than was the case prior to the US implementation of the Renewable Fuel Standard (RFS) in 2006 (Figure 9). Before 2006, corn and crude oil prices were tangentially linked through fertilizers, fuel, and other inputs. But the linkage was weak, as evidenced by the nearly two year run-up in crude oil prices on the back of Chinese demand from January 2004 to January 2006, during which WTI crude oil prices increased by nearly 87% but No.2 yellow corn futures prices on the CBT actually declined by 13%.

The RFS changed this situation by forcing gasoline sellers to blend a minimum proportion of ethanol into their fuel stock, creating a massive demand that dramatically tightened the price relationship between corn and crude oil during the 2006–07 period. From that period through 2012, the relationship remained tight. Subsequently, a serious drought in the US Corn Belt tightened supplies and drove corn prices up, de-linking them from price trends in the crude oil market.⁶²

⁶² Robert Wisner, “Ethanol, Gasoline, Crude Oil and Corn Prices: Are the Relationships Changing?,” Iowa State University, Agricultural Marketing Research Center Renewable Energy & Climate Change Newsletter, March/April 2014, <http://www.agmrc.org/renewable-energy/ethanol/ethanol-gasoline-crude-oil-and-corn-prices-are-the-relationships-changing/>.

Figure 9. Crude Oil and Corn Price Relationship, 1995–2016

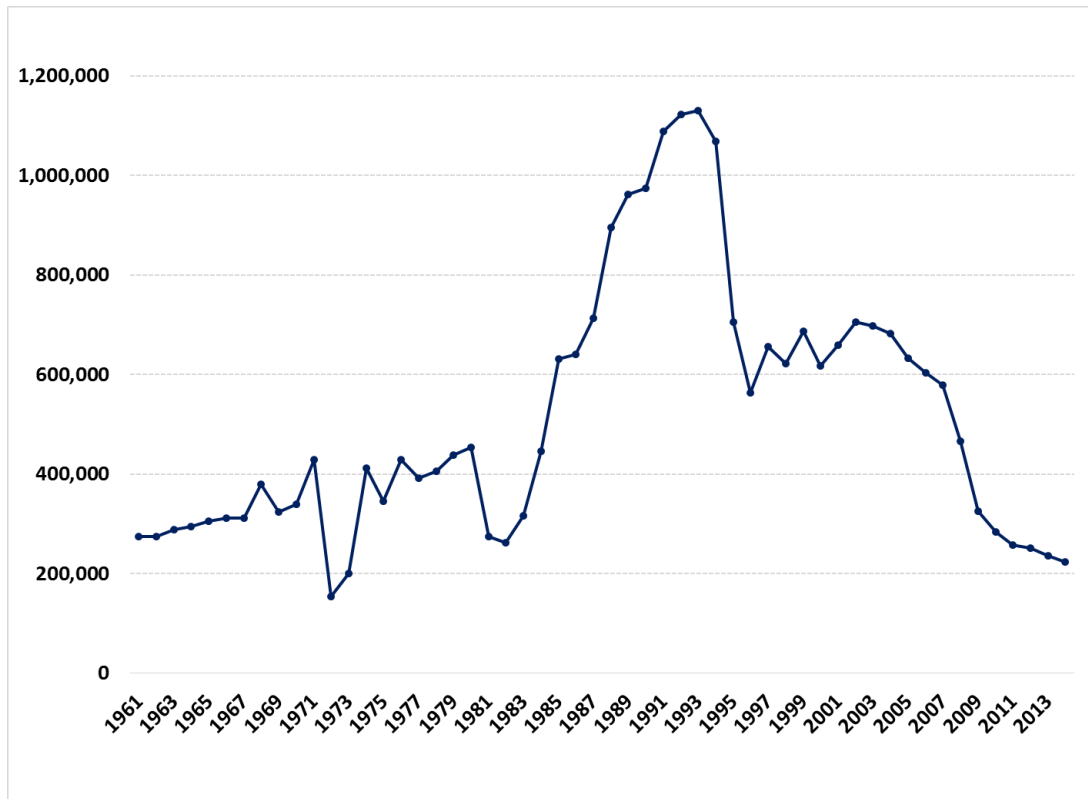


Source: Bloomberg; author’s analysis.

VI. Policy Responses and How They Tie into the Food-Water-Energy Nexus

To the Saudi government’s credit, it has recognized the hydrological unsustainability and the economic irrationality of its attempt to make the desert bloom and has dramatically reduced domestic grain cultivation. The kingdom’s policy shift has brought the area of land under cereal cultivation back to levels not seen for more than 50 years and helps significantly reduce agricultural groundwater use (Figure 10).

Figure 10. Land Area Under Cereal Cultivation in Saudi Arabia, in Hectares



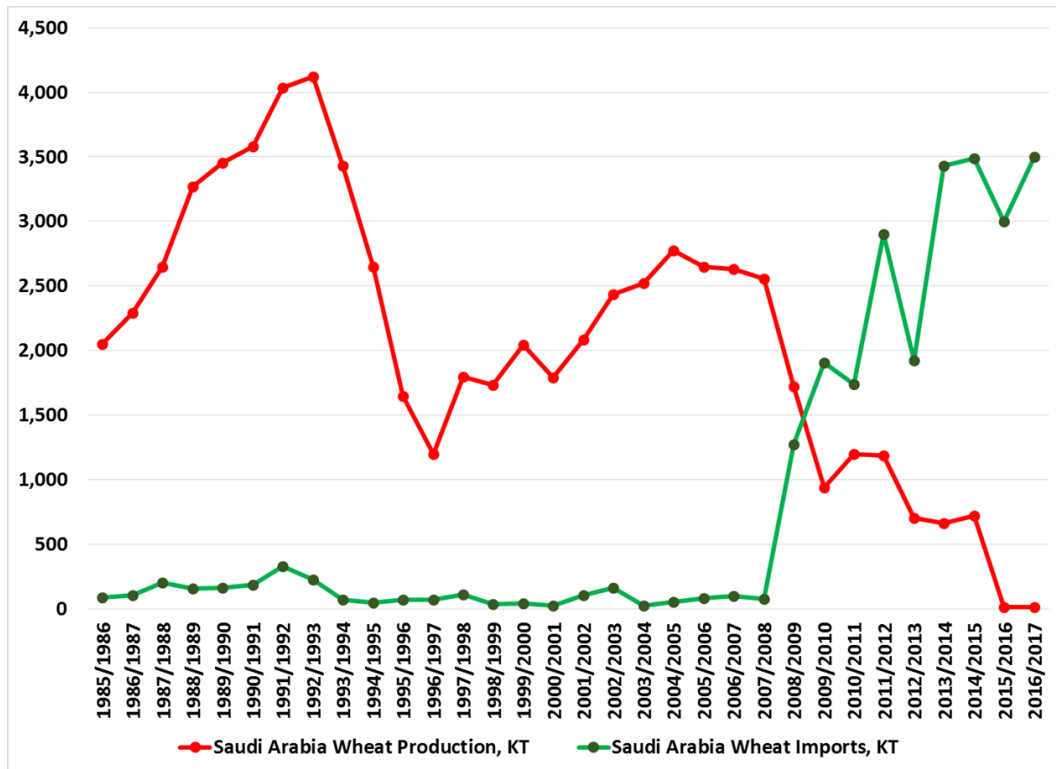
Source: World Bank.

Saudi Arabia’s grain cultivation cutback is particularly apparent for wheat. In the 2015–16 agricultural market year, the kingdom finally ended its three-decade domestic wheat production and purchase program and became fully dependent on imports to supply its wheat needs.⁶³ The Saudi government began to dial back domestic wheat procurement in the 2007 market year per decree #335, which stipulated that each successive market year would see the Saudi Grain Silos and Flour Mills Organization (GSFMO) reduce registered farmers’ wheat production quotas by 12.5% in order to eliminate domestic sourcing by the 2015 market year.⁶⁴ As a result, the kingdom is now fully dependent on the global market for its wheat supply (Figure 11).

⁶³ “Saudi Arabia ends domestic wheat production program,” World Grain News, March 18, 2016, http://www.world-grain.com/articles/news_home/World_Grain_News/2016/03/Saudi_Arabia_ends_domestic_whe.aspx?ID=%7B50E0E390-7C3F-46A6-B832-54FA58F140B2%7D&cck=1.

⁶⁴ Ibid.

Figure II. Saudi Arabia Abandons Wheat Cultivation, Goes Completely Import Dependent



Source: USDA.

The overuse of Iran’s increasingly strained groundwater resources is unlikely to relent in the near future. Indeed, the country’s leadership has made rising wheat production (much of which is irrigated with groundwater) a point of pride. For instance, in September 2016, President Hassan Rouhani noted that “We had a good year that led Iran to stop importing wheat. We are planning to export wheat in the coming months.”⁶⁵ Rouhani’s statement clearly reflects the Iranian government’s strong support for continued, robust domestic wheat cultivation, even if doing so is not hydrologically sustainable.

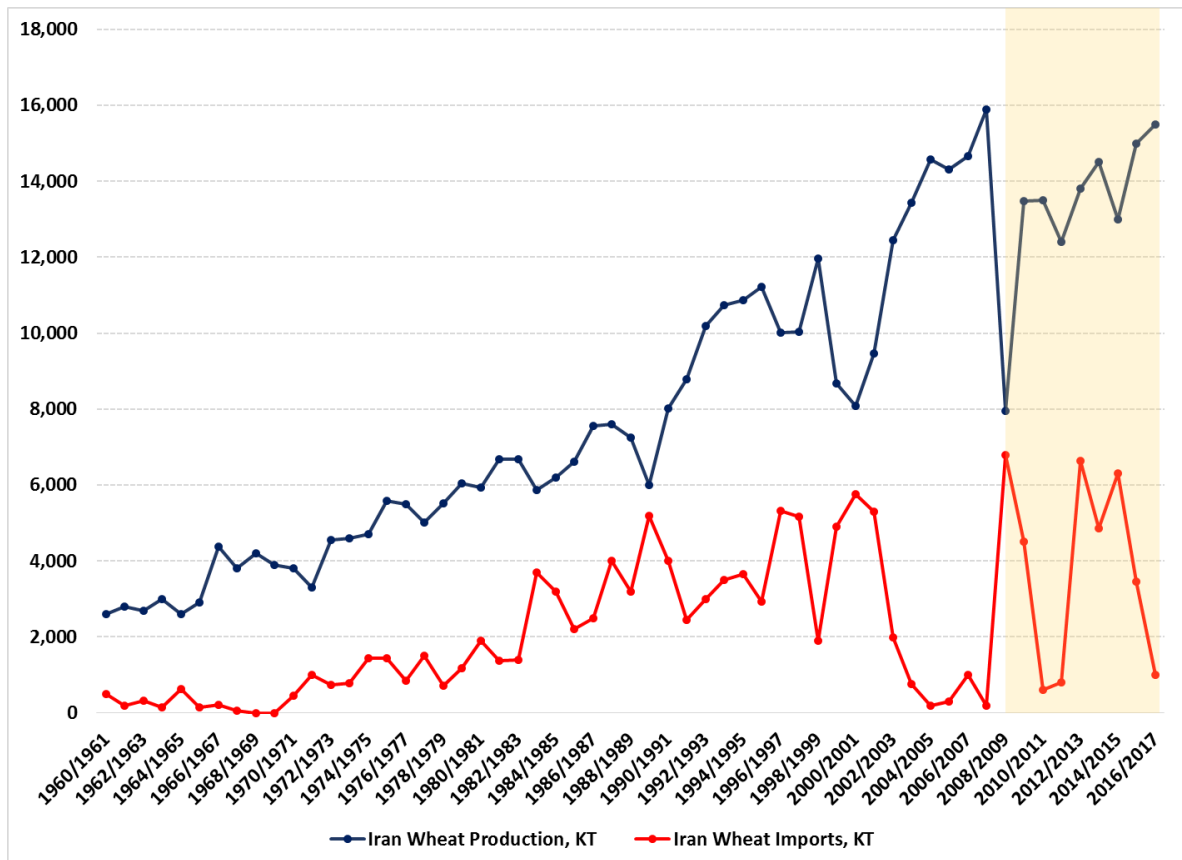
Iran’s farming sector is becoming increasingly groundwater dependent. Data from the FAO show that the area equipped for surface water irrigation in Iran declined by 15% between 1993 and 2007, while the area irrigated with groundwater increased by 39%. During that same time, Iranian wheat production rose by nearly 50%, which strongly suggests that increased use of groundwater irrigation helped underpin the growth of domestic wheat output.

As the irrigated area increased, the number of private tube wells climbed at a nearly exponential rate, from 40,000 to 50,000 registered tube wells in the 1970s to 500,000

⁶⁵ Parisa Hafezi, “Iran now self-sufficient in wheat, hopes to export soon: president,” *Reuters*, September 22, 2016, <http://www.reuters.com/article/us-iran-wheat-sufficiency-idUSKCN11S2OR>.

registered wells by 2006.⁶⁶ And these reported numbers may undercount the total. Iranian researchers believe there are a vast number of unregistered wells—equal to as much as one-third of the total number of registered wells—implying that Iran could have as many as 665,000 tube wells: in other words, one for every 7.6 hectares of groundwater irrigated farmland in the country.⁶⁷

Figure 12. Iran Continues to Seek Wheat Self-Sufficiency Despite Drought and Growing Strain on Aquifers



Source: USDA.

Iran currently shows no sign of backing off its policy of maximizing domestic wheat production, and the government may encourage farmers to push output even higher to maximize self-sufficiency, particularly if relations with the United States worsen during the Donald Trump presidency. Emphasizing robust grain production also can help placate powerful internal interests. Foremost among these are the bonyads—basically, religious foundations—that ostensibly focus on religious and charitable works, but also are deeply engaged in many aspects of the Iranian economy, including agriculture.

⁶⁶ Karimi et al., "Reducing carbon emissions through improved irrigation and groundwater management: A case study from Iran."

⁶⁷ Ibid. Wells per area ratio calculated based on 2007 vintage FAO data for the irrigated agricultural land area in Iran.

For instance, Astan Quds Razavi reportedly owns 75% of the land in Iran's second-largest city, Mashhad, as well as "vast tracts" throughout other parts of the country.⁶⁸ While the precise role the foundations play in Iranian grain cultivation is not well documented, ownership of land strongly implies the ability to (1) collect rental payments on the land itself and/or (2) collect a portion of the crops produced, either in kind or as a portion of sales proceeds. Both of these potential revenue generation channels would strongly incentivize the farmers who are tenants on the land to maximize wheat production so as to have sufficient income to pay rents and still have a profit left over.

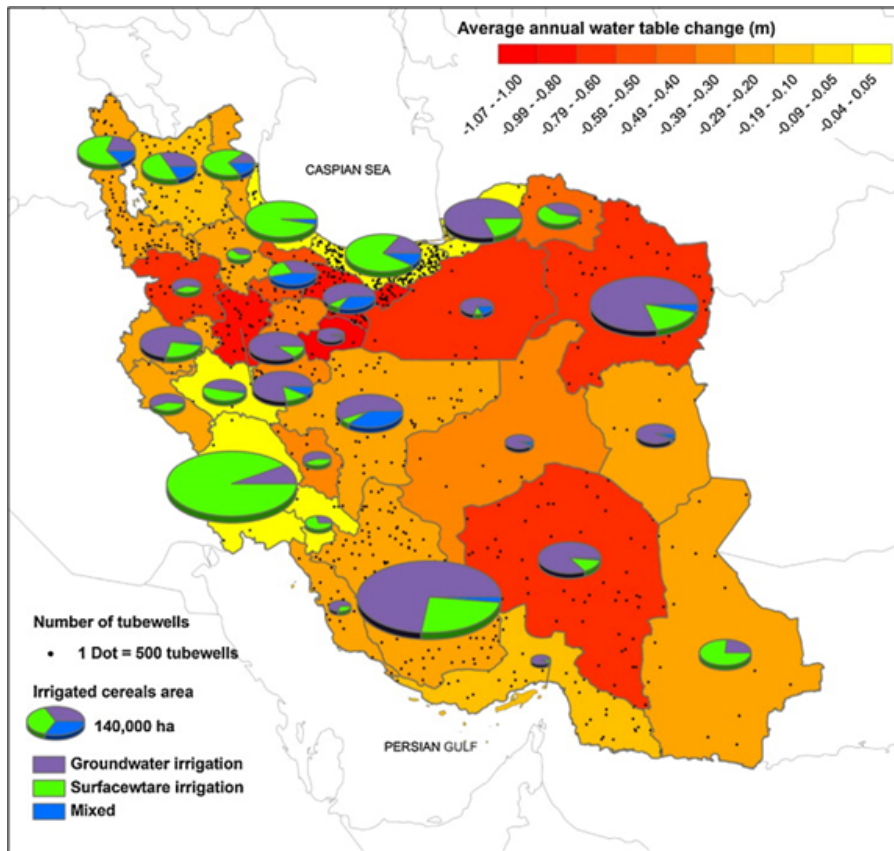
There are also more prosaic—but equally powerful—incentives at the level of the individual farmer that tie into the motivations described above. The advent of private tube wells confers a high degree of independence upon farmers who formerly often had to rely on communal water supplies from local *qanat* systems, which consist of underground canals constructed and managed by local communities and from which withdrawals were closely regulated in order to ensure that all members had access to water.⁶⁹

Private tube wells, on the other hand, offer groundwater to farmers whenever and however they want it, up to the well's maximum production capacity. In turn, such dynamics often create a tragedy of the commons as aquifers are drawn down as farmers race to maximize their grain harvests, depleting a public resource in order to secure a private gain. Accordingly, many of Iran's core farming areas are suffering significant groundwater depletion rates, sometimes exceeding one meter per year (Figure 13).

⁶⁸ Andrew Higgins, "Inside Iran's Holy Money Machine," *The Wall Street Journal*, June 2, 2007, <http://www.wsj.com/news/articles/SB118072271215621679>. The Imam Reza Shrine is one of the largest mosques in the world.

⁶⁹ Paul Ward English, "Qanats and Lifeworlds in Iranian Plateau Villages," *Yale Forestry & Environmental Studies Bulletin* 103 (1998): 187-205. Available at: <https://environment.yale.edu/publication-series/documents/downloads/0-9/103english.pdf>.

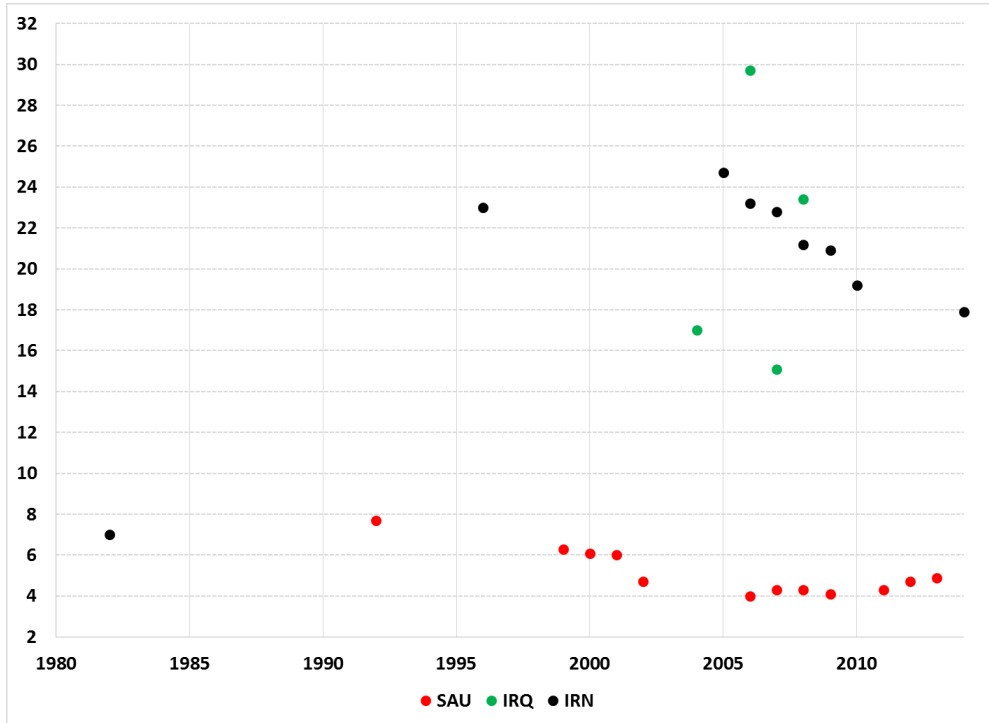
Figure 13. Geographical Distribution of Tube Wells and Water Table Changes in Different Provinces of Iran



Source: Karimi et al., “Reducing carbon emissions through improved irrigation and groundwater management: A case study from Iran.”

Finally, reducing domestic grain cultivation to preserve Iran’s depleting aquifers could engender additional political consequences because so much of the country’s workforce is employed in the agricultural sector. While agriculture’s share of total employment in Saudi Arabia has fallen from just under 8% in 1990 to approximately 5% in 2013, roughly 18% of Iran’s workforce remains employed in the agricultural sector, according to World Bank data (Figure 14).

Figure 14. Agriculture’s Share of Total National Employment in Iran, Iraq, and Saudi Arabia (%)



Source: World Bank.

Embargo risk helps highlight what probabilities mean to a leader considering food security issues, as well as their attendant water and energy trade-offs. With respect to water security, leaders in a country like Iran where political turnover (aside from the clerical ranks) is more regular than it is in a system such as that of Saudi Arabia may decide that allowing extensive mining of groundwater today is acceptable if it yields the impression of food security and social tranquility, even though it leaves a much more serious set of problems for coming generations of political leaders. In a hereditary dynasty such as Saudi Arabia, the calculation is different because the royal family presumably desires to stay in power and will take a longer-term view.

Taken together, the combination of bonyad influence, subsidized energy and other inputs for farmers, high-level political support for wheat self-sufficiency, farmers’ abilities to control their own short-term productivity using private tube wells, and the agricultural sector’s role as a core strategic employer of nearly one in every five Iran workers suggests groundwater depletion will continue. Iran will likely only reduce staple grain cultivation if the decision is forced by irresistible natural factors, first and foremost continued drought and second, aquifers becoming depleted to a point that industrial-scale water extraction is no longer feasible.

VII. Policy Responses That Could Reduce Stress Across The Food-Water-Energy Nexus in the Arabian Gulf Region

1. *Deeper Integration with The Global Grain Market*

Grain self-sufficiency has not historically been a policy goal of the smaller GCC countries because they simply lack the water resources, have too harsh climates, and are generally sufficiently flush with hydrocarbons revenues that reliance on the global grain market offers a sensible and feasible path to food security.

Widely accepted energy security definitions count “diversity of suppliers” as a critical factor, and grain supply security is no different.⁷⁰ Wheat supplies now come from a range of producers, with 11 core exporters now accounting for 95% of wheat volumes traded internationally across the globe. In a development that should alleviate the concerns of countries such as Iran who fear that the United States might impose sanctions on grain exports, the US share of the global wheat export supply has declined from nearly 34% in 1993–94, to an average of approximately 15% over the past five crop years (Figure 15).

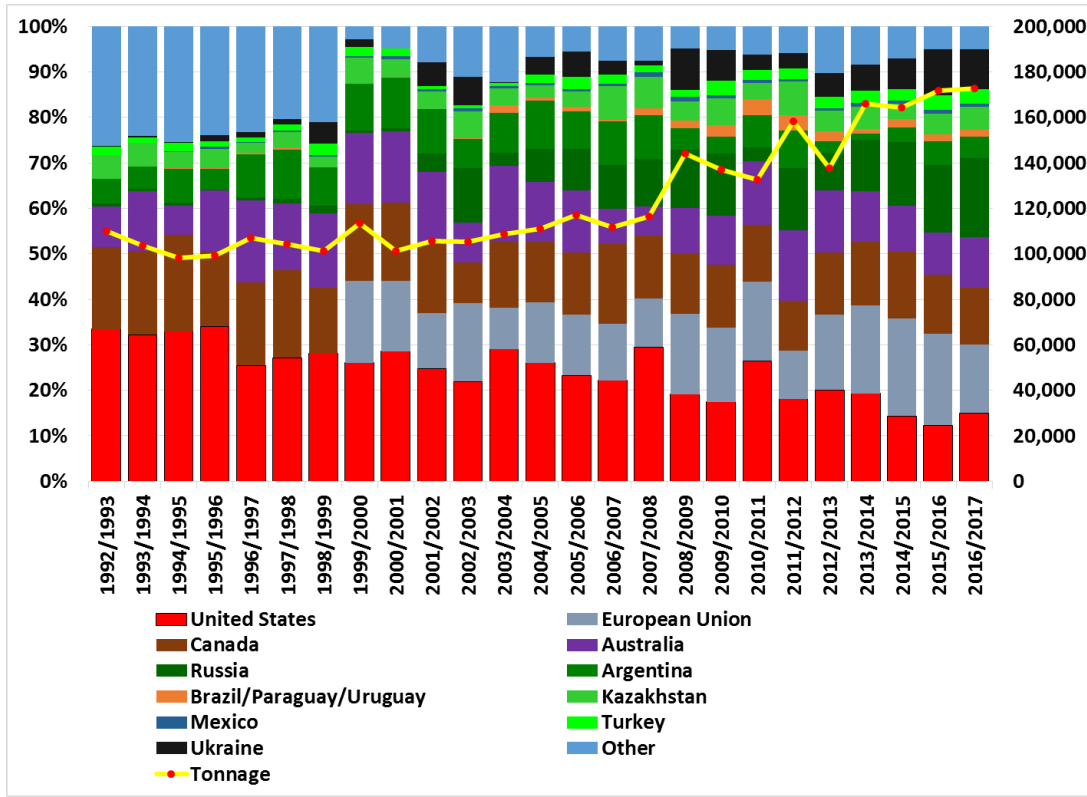
Countries that use the specter of potential US sanctions to justify sacrificing domestic water resources to pursue wheat supply self-sufficiency should note that the share of countries in the global wheat export market that are unlikely to align with potential US attempts to restrict trade with Iran (or other Arabian Gulf countries, for that matter) has risen from 13% in the 1992 crop year to more than 40% in the 2016 crop year.⁷¹

⁷⁰ “Quantifying Energy Security,” IEA, accessed February 21, 2017,

<https://www.iea.org/topics/energysecurity/subtopics/whatisenergysecurity/>.

⁷¹ For the purposes of this analysis, the “non-aligned” wheat exporter countries are: Argentina, Brazil, Kazakhstan, Paraguay, Russia, Turkey, Ukraine, and Uruguay. Other suppliers doubtless exist, but these are drawn from our sample set of 12 countries and one regional bloc (European Union) that now account for 95% of global wheat export tonnage, according to the USDA.

Figure 15. The Global Wheat Export Market is Increasingly Diverse

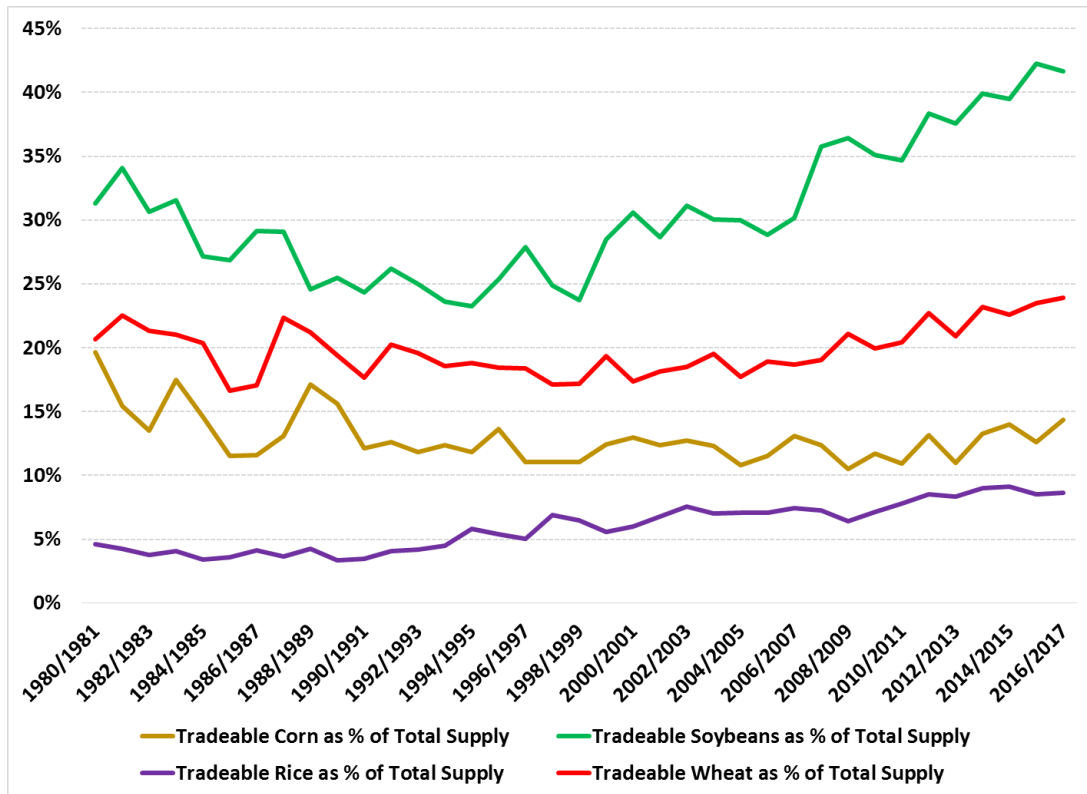


Note: Left axis=% of global export market, right axis=total global wheat tonnage exported.
 Source: USDA; author’s calculations.

The combination of a diverse global wheat exporter base and the fact that an increasing proportion of export supplies come from countries whose foreign policies typically diverge sharply from Washington’s strongly suggests that significant grain-focused sanctions against any country in the Arabian Gulf region would be extremely difficult—if not practically impossible—to enforce on a sustained basis.

The wheat market is also highly liquid, with a substantial portion of total production made available in global export markets. The “tradability” of a grain—in other words, its availability on the global export market—offers a useful metric for assessing how feasible it is for a country to procure needed supplies. In the latest crop year, USDA data show that nearly one in every four tonnes of wheat produced globally enters the export market (Figure 16). This suggests that, barring a major supply disruption such as simultaneous crop failures in multiple major producing countries, supplies will be economically accessible to a country like Iran that can use oil sales to generate hard currency.

Figure 16. Tradable Proportion of Key Staple Grains as % of Total Global Supply



Source: USDA; Baker Institute Center for Energy Studies.

2. Expanding Strategic Grain Stocks

While staple grain supplies from the global market are—barring major regional crop failures—likely to be available on a medium- and long-term basis, short-term disruptions are a much higher probability risk. Potential sources of such disruptions in the Arabian Gulf region can range from weather (a cyclone offshore along key trade routes south of the Arabian Peninsula) to a military conflict between Iran and an outside power that temporarily halts shipping traffic through the Strait of Hormuz.⁷²

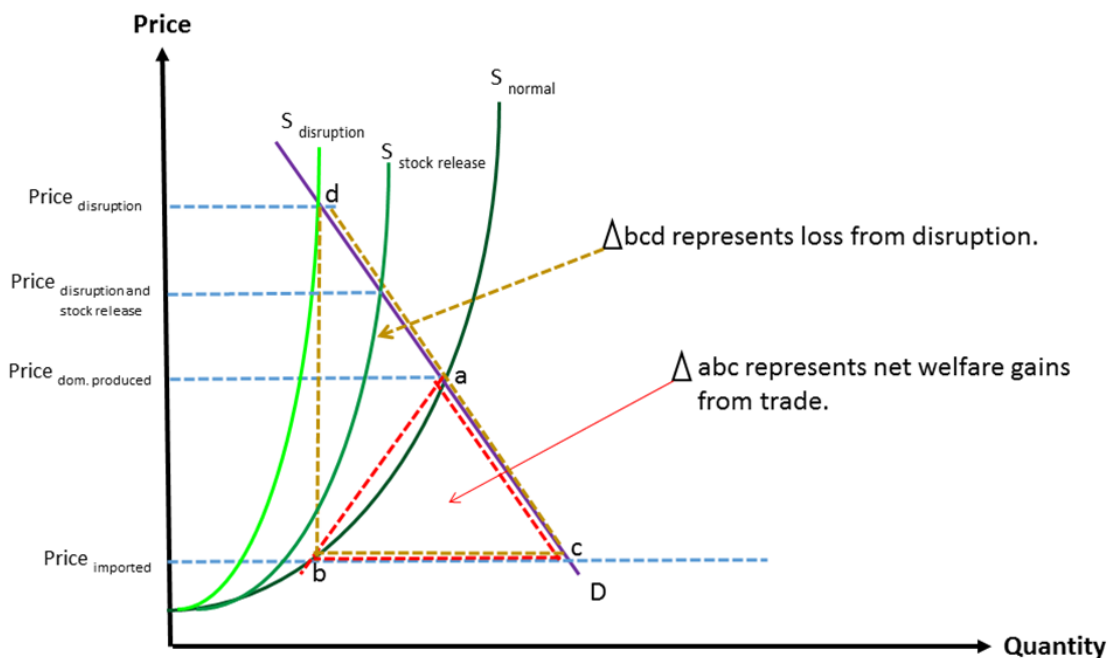
Worries about maritime chokepoints vulnerable to the effects of confrontations between regional powers (i.e., the United States, Saudi Arabia, and Iran in the Strait of Hormuz) may be a key contributor to Saudi Arabia’s apparent decision to geographically hedge its seaborne wheat import orientation by taking wheat through two main ports, Jeddah (Red Sea) and Dammam (Arabian Gulf). Furthering this point, much of the Saudi Grains

⁷² Rob Bailey with Robin Willoughby, “Edible Oil: Food Security in the Gulf,” Chatham House Briefing Paper, November 2013, <https://www.chathamhouse.org/sites/files/chathamhouse/public/Research/Energy,%20Environment%20and%20Development/bp1113edibleoil.pdf>.

Organization’s near-term wheat import capacity addition plans emphasize the Red Sea ports of Diba, Jazan, and Yanbu.⁷³

Expanded grain storage offers the most logical, feasible, and cost-effective response to short-term supply disruptions. Releasing grain from storage during a supply shortfall (the scenario contemplated in this analysis), bolsters local grain availability and, by pushing out the supply curve, helps lower prices and insulate consumers from the full impact of a price spike (Figure 17). To illustrate the importance of the buffering role played by stocks, consider that during the 1972–73 crop year, a global wheat production shortfall of only 2% caused prices to nearly double because stocks were “almost negligible” at the time.⁷⁴

Figure 17. Effect of Stock Release During Supply Disruption



Source: Baker Institute Center for Energy Studies.

Storage-oriented solutions are especially important in the Arabian Gulf region, where a military contingency that disrupts grain imports (i.e., blockage of the Strait of Hormuz) would also temporarily deprive countries of most—if not all—of the hydrocarbons export

⁷³ Hussein Mousa, “Saudi Arabia: Grain and Feed Annual (2016),” USDA GAIN Report, March 14, 2016, https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Annual_Riyadh_Saudi%20Arabia_3-14-2016.pdf.

⁷⁴ Ibid.

revenues that they use to fund grain imports.⁷⁵ It is important to consider the costs of storing grain, since capital tied up by inventory and storage costs by definition cannot be deployed for other, possibly higher value-added purposes. World Bank analysts have noted that storing wheat in the MENA region generally costs between \$1.50 and \$3.50 per tonne per month, or \$18 to \$42 per tonne to store wheat for a year.⁷⁶ As such, storing a 12-month supply of wheat (3.66 million tonnes) would cost between \$65 million and \$151 million per year.⁷⁷ Importing 3.66 million tonnes of No. 2 soft red winter wheat at the average 2016 US Gulf Coast spot price of \$4.50/bushel (\$165.30/tonne) would cost approximately \$604 million, for a maximum all-in annual cost of \$755 million, or roughly \$207/tonne for purchase and storage for a year.

To put that number in perspective and illustrate the potential losses imposed by agricultural autarky, consider that between 1984 and 2000 when Saudi Arabia was emphasizing domestic wheat production, direct government subsidies alone led to wheat costs in Riyadh of \$502 per tonne, while the prevailing international price was \$120 per tonne.⁷⁸ It is likely that a similar ratio of disparity would afflict Arabian Gulf autarkic wheat cultivation programs in the present. Moreover, the direct subsidy cost does not even begin to price the value of vast amounts of water used in wheat cultivation, nor does it include opportunity cost losses caused by using subsidized petroleum to generate electricity and power water wells rather than exporting the oil and refined products at premium international market prices.

Because the climate in much of Saudi Arabia approximates the hot and dry conditions found elsewhere in the Arabian Gulf region, we believe its all-in domestic wheat and staple grain production costs offer a solid proxy for those likely to be encountered in other GCC countries, as well as large swathes of Iran. A World Bank analysis notes that under good conditions—such as drier climates—wheat can be stored for at least a year before requiring stock rotation.⁷⁹ Thus, it appears appropriate to think of wheat storage costs in annual terms. Using the data cited above, storing a million tonnes of wheat for a calendar year in the Arabian Gulf region will likely cost somewhere between \$18 million and \$42 million.

Therefore, smaller countries such as Qatar, which are wealthy and consume less than one million tonnes per year of wheat, can easily afford storage-based grain security solutions. For a larger country with a smaller per capita economic endowment such as Iran (18.5

⁷⁵ Brian Wright and Carlo Cafiero, “Grain Reserves and Food Security in MENA Countries,” http://siteresources.worldbank.org/DEC/Resources/84797-1288208580656/7508096-1288208619603/Wright_Grain_Reserves_and_Food_Security_in_MENA_Countries_PAPER.pdf.

⁷⁶ Donald F. Larson, Julian Lampietti, Christophe Gouel, Carlo Cafiero and John Roberts, “Food Security and Storage in the Middle East and North Africa,” Policy Research Working Paper 6031, The World Bank, April 2012, <http://documents.worldbank.org/curated/en/293221468275336547/pdf/WPS6031.pdf>, 5.

⁷⁷ Based on USDA’s estimate that Saudi Arabian wheat domestic consumption would be 3.655 million tonnes during the 2016–17 crop year.

⁷⁸ Elhadj, “Camels Don’t Fly, Deserts Don’t Bloom: An Assessment of Saudi Arabia’s Experiment in Desert Agriculture.”

⁷⁹ Hans G.P. Jansen, “Technical Assistance to the Agriculture Development Task Force in Afghanistan,” Final Report, November 2008 to May 2009, World Bank/FAO Cooperative Program, 2009, <http://documents.worldbank.org/curated/en/700321467989999272/text/684030ESW0whitORT0submitted0to0govt.txt>, 38.

million tonne wheat consumption in the 2016–17 crop year), storing a year’s worth of demand coverage could cost close to \$800 million per year before counting the capital costs of building millions of tonnes of additional grain silo capacity. Yet even in the case of Iran, the annual costs of storing 12 months of wheat supply coverage would still likely be significantly less than the cost of crude oil, refined products, and natural gas consumed directly and via electricity use for pumping groundwater to supply farms, many of which are growing grain.

a. Would Regional-Level Strategic Storage of Staple Grains Make Sense?

The Arab countries might consider a GCC-wide strategic grain storage system.⁸⁰ Such an arrangement would be attractive at first glance because it not only would spread the cost, but also could use a site such as Fujairah in the UAE or ports in Oman, neither of which would be subject to restrictions on transit through the Strait of Hormuz. That said, for the immediate future, practical logistical constraints will almost certainly forestall creation of such regional-level strategic grain storage. GCC governments have scaled back their respective plans for rail segments that were originally intended to form integral parts of a pan-GCC rail network slated for completion by 2018.⁸¹ In January 2016, the UAE’s Etihad Rail suspended Stage II tenders for its domestic rail system buildout, and in May 2016, Oman delayed plans for a line linking Sohar port to the UAE.⁸²

The delays—thought to be caused by low oil and gas prices—come at an early stage in the proposed projects and likely add at least four years to the timetable of rail projects linking ports outside the Strait of Hormuz to areas in the Arabian Gulf-facing UAE. Oman Rail’s chief commercial officer noted in March 2016 that building Oman’s first rail line would likely require at least four years from first planning to first freight moved: a year for assessment and planning, an additional year for tendering, and at least 2.5 years of actual construction work.⁸³ As such, until sometime post-2020, a GCC multi-national strategic grain storage system is unlikely to materialize.

3. Conserve Water by Reducing Domestic Grain Production Subsidies

Subsidies in Arabian Gulf countries have tended to focus more intensely on grain cultivation (especially via guaranteed payments to farmers) than they have on ensuring basic sustenance-level access to food supplies, as has been the case in the poorer and more populous MENA countries, in particular, Egypt. Subsidies that encourage farmers to maximize water-intensive staple grains output despite arid local climate conditions are a major stressor on regional water supplies. As discussed above, Saudi Arabia recently ended its domestic wheat production and purchase programs due to severe aquifer depletion that was reaching crisis levels. Iran, however, presses ahead with a guaranteed price program that induces farmers to mine depleting aquifers in order to sustain large-scale wheat

⁸⁰ Given the substantial historical and current tensions between Saudi Arabia and Iran, it is highly unlikely that Iran would be willing to enter into grain storage agreements with the Gulf Cooperation Council.

⁸¹ Bab Umar and Fahad Al Gadhani, “Brakes put on Oman’s rail project,” *Times of Oman*, May 2, 2016, <http://timesofoman.com/article/82844/Oman/Transport/Brakes-put-on-Oman's-GCC-rail-project>.

⁸² Ibid.

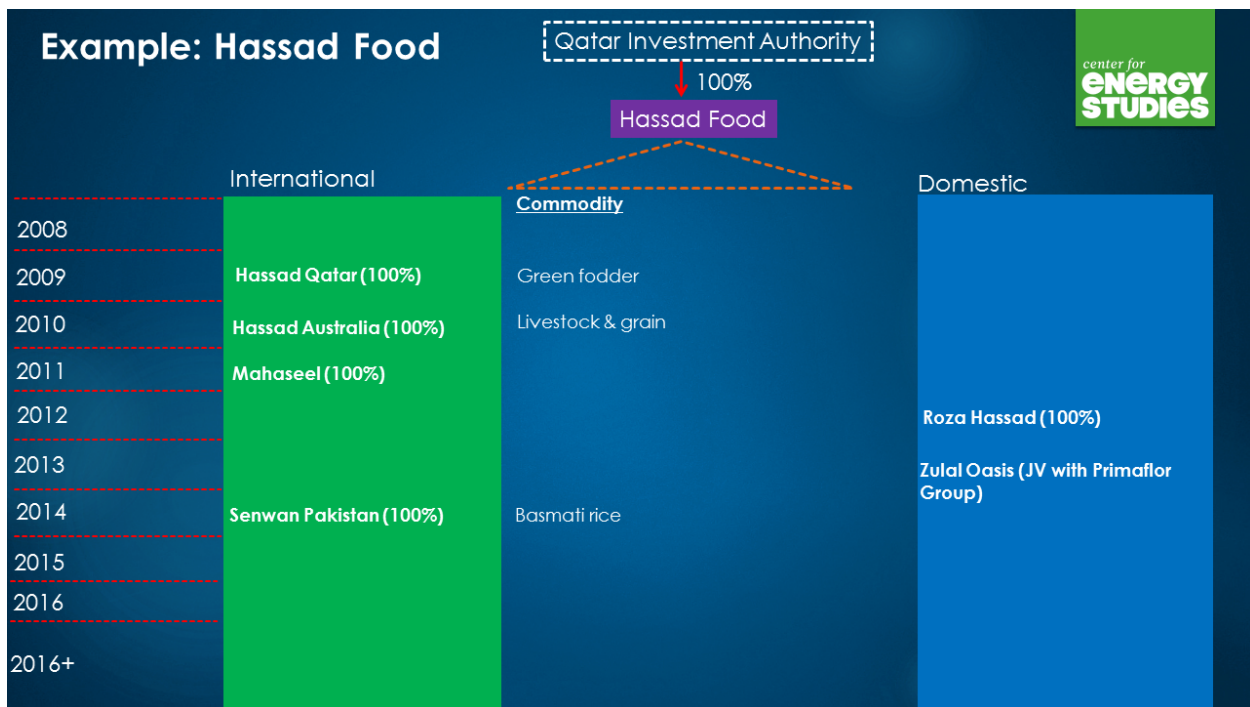
⁸³ Michael Fahy, “Oman Rail stays on track but first line may roll out only after 4 years,” *The National*, March 8, 2016, <http://www.thenational.ae/business/economy/oman-rail-stays-on-track-but-first-line-may-roll-out-only-after-4-years>.

cultivation. Indeed, local media report that in 2016, of the 14 million tonnes of wheat grown by farmers in Iran, nearly 12 million (roughly 85%) were purchased by the government at guaranteed prices.⁸⁴

4. *Hedge Against Supply and Price Disruptions by Investing in Farmland and Farming Operations Abroad*

There are two fundamental approaches an Arabian Gulf region country can use to vertically integrate its grain supply through acquiring interests in overseas grain production. First, the country can create a corporate entity charged with using money from the country’s sovereign wealth fund to acquire farming assets abroad. For example, Qatar created Hassad Food in 2008, a wholly owned subsidiary of the Qatar Investment Authority (QIA), and tasked Hassad with investing in agricultural assets domestically and abroad (Figure 18).

Figure 18. Hassad Food



Source: Hassad Food.

The second fundamental approach is to invest in professionally managed third party farm investment ventures, many of which are publicly traded on North American or European stock exchanges. Qatar has also used this approach, with the QIA purchasing a nearly 13%

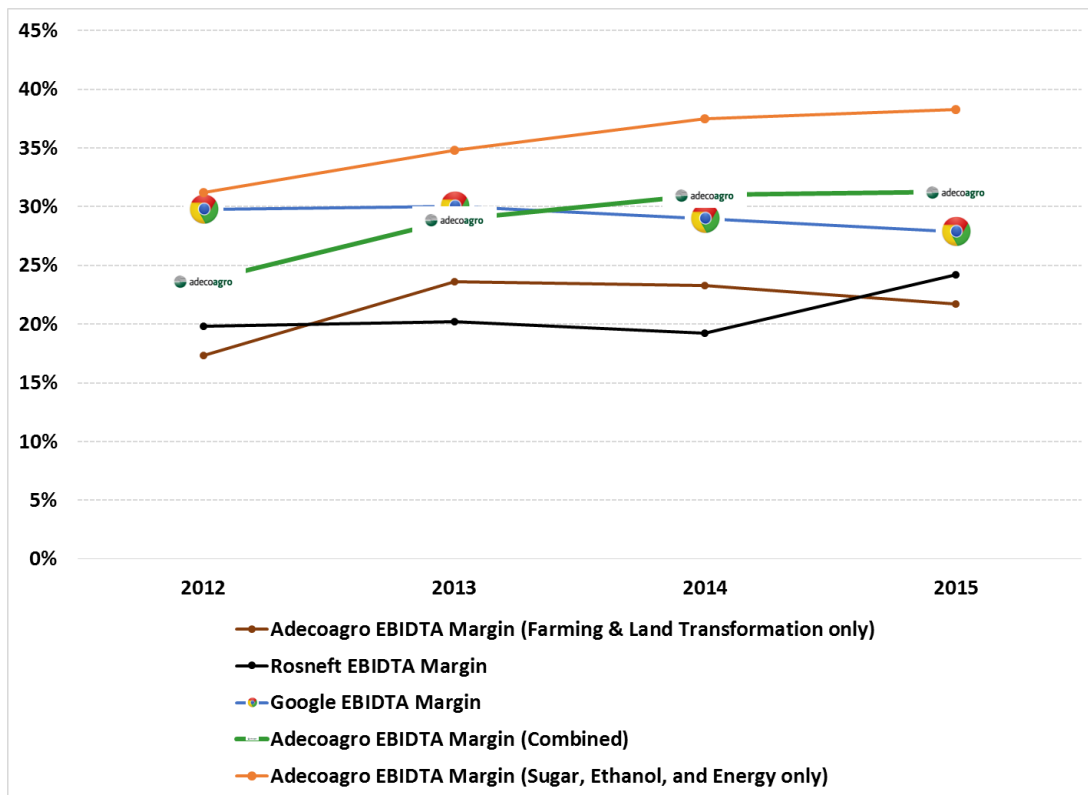
⁸⁴ “Gov’t Wheat Purchases Surpass 11 Million Tons,” *Financial Tribune*, September 28, 2016, <https://financialtribune.com/articles/economy-business-and-markets/50617/gov-t-wheat-purchases-surpass-11m-tons>.

equity stake in Adecoagro, an agriculture company focused on farming, land upgrading, and ethanol/energy production in Argentina, Brazil, and Uruguay.

There are several factors that support investing in farmland or farm asset holding companies abroad. For one, investing in farmland abroad creates a natural hedge against price spikes, provided that a country’s sovereign wealth fund acquires a sufficiently large physical and/or financial position in production of the target grains. In the event of a price shortage/price spike, farmland owners can potentially take grain in kind or trade it on the global market to the highest bidder and then recycle the funds earned into procuring grain cargoes closer to home for local consumption.

Farmland investment can also offer useful economic diversification for oil and gas-dependent economies. With proper inputs, agricultural land is effectively a renewable resource and can yield grain crops for many years, as opposed to hydrocarbons, which can only be extracted and sold once. The renewable rents from investment stakes in professional farmland managers can also be substantial. For instance, Adecoagro’s enterprise-wide earnings before interest, tax, depreciation, and amortization (EBITDA) margin between 2012 and 2015 consistently exceeded that of Russia’s Rosneft (which the Qatar Investment Authority recently teamed with Glencore to buy a substantial minority stake in) and in some years, surpassed Google’s EBIDTA margin (Figure 19).

Figure 19. Sample EBITDA Margins for Major Global Farm Asset Manager, Oil and Gas Producer, and Tech Company



Source: Company reports.

Vertical integration of grain and meat supplies—especially when production assets abroad are combined with domestic processing capacity—can also help ensure the integrity of food supply chains, an important issue in the wake of recent food contamination scandals involving Chinese suppliers.

With the benefits of vertical integration in mind, there are also a range of potential downsides. At their most extreme, these drawbacks could render the approach unworkable for some countries in the region and at best, mean vertical integration should be thought of as part of a broader diversified food security strategy.

First and foremost are the physical and political security risks. Owning or investing in farmland abroad means a country is placing its food security at the mercy of the host country's politics and human complexity. Even the most productive grain fields cannot directly advance the investor country's food security if the host country restricts or prohibits food exports amidst a crisis.⁸⁵

Second, large foreign investors often have different priorities than local communities and can find themselves embroiled in conflicts between local groups and central governments, as has occurred with the Saudi Star's farming investments in Ethiopia's restive Gambela region.⁸⁶ Overseas food investments are also subject to a range of weather and climate risks. Purchasing land locks an investor in to a specific area, with commensurate exposure to the risk of climate shifts.

Third, grain shipments destined for the Arabian Gulf region can still face transit risks. Some of these risks arise in the producing country—for instance, grain shipments from locations such as Gambela in Ethiopia's interior or remote parts of Sudan must contend with hundreds of miles of underdeveloped transport infrastructure in order to reach sea ports. Once grain is loaded on a ship, other—albeit, lower probability—risks persist. Other than Oman and Saudi Arabia's Red Sea ports, the remainder of the GCC countries remain vulnerable to grain supply disruptions if a military conflict were to ever close the Strait of Hormuz.

Fourth, countries seeking to partner with existing farmland asset managers may find that (1) the market is not deep enough to accommodate them and (2) new farmland investment entities they back would likely be pushed toward more “frontier” regions, such as sub-

⁸⁵ This is no trifling concern. Between 2007 and early 2011, a period marked by fears of supply scarcity and heightened food price volatility, at least 33 countries imposed some form of food export restrictions. See, for instance Ramesh Sharma, “Food Export Restrictions: Review of the 2007-2010 Experience and Considerations for Disciplining Restrictive Measures,” FAO Commodity and Trade Policy Research Working Paper No.32, May 2011, http://www.fao.org/fileadmin/templates/est/PUBLICATIONS/Comm_Working_Papers/EST-WP32.pdf.

⁸⁶ “The Great Land Rush, Ethiopia: The Billionaire's Farm,” *FT Investigations*, March 1, 2016, <https://ig.ft.com/sites/land-rush-investment/ethiopia/>. For an example of general unrest in Gambella that could complicate farmland investment there, see Paul Schemm, “Ethiopia vows to pursue South Sudan gunmen who killed 200 in cross-border raid,” *Washington Post*, April 18, 2016, https://www.washingtonpost.com/world/ethiopia-vows-to-pursue-south-sudan-gunmen-who-killed-200-in-cross-border-raid/2016/04/18/5b074bb4-0565-11e6-bfed-ef65dff5970d_story.html?utm_term=.4c4029f3a34a.

Saharan Africa, where the upside of fertile land is often counterbalanced by serious security and political risks.

Fifth, potential sovereign investors must consider whether a given set of existing market entities has sufficient depth and liquidity to accommodate their potentially multi-billion-dollar entry in a reasonable timeframe. Preqin reports that between 2006 and 2016, more than 100 unlisted agriculture and farmland-focused investment funds had raised a total of approximately \$22 billion in capital.⁸⁷ The 10 largest funds accounted for approximately \$12 billion of this total as of July 20, 2016 (Figure 20).⁸⁸ The combined market depth of existing listed and non-listed farmland investment vehicles worldwide, plus the Arabian Gulf countries' potential opportunity to form their own private equity entities and hire skilled technical experts to help them actually operate farm assets, suggests there is room to run a strategy component that emphasizes investing in such entities as a physical and financial hedge against future grain supply disruptions.

⁸⁷ "Preqin Special Report: Agriculture," September 2016, <https://www.preqin.com/docs/reports/Preqin-Special-Report-Agriculture-September-2016.pdf>.

⁸⁸ Ibid.

Figure 20. Ten Largest Unlisted Agriculture and/or Farmland Focused Funds Closed Globally Since 2006 (as of July 20, 2016)

Fund	Firm	Headquarters	Fund Size (mn)	Final Close Date	Geographic Focus
TIAA-CREF Global Agriculture II	TIAA Asset Management	US	3,000 USD	Jul-15	Global
TIAA-CREF Global Agriculture	TIAA Asset Management	US	2,000 USD	May-12	Global
NCH Agribusiness Partners	NCH Capital	US	1,205 USD	Dec-07	Central & East Europe
Paine & Partners Capital Fund III	Paine & Partners	US	1,204 USD	Apr-07	Global
Altima One World Agriculture Development Fund	Altima Partners	UK	756 EUR	Nov-08	Global
Mahaseel Agricultural Investment Fund	Kenana Agriculture	Sudan	1,000 USD	Nov-12	MENA
Paine & Partners Capital Fund IV	Paine & Partners	US	893 USD	Dec-14	Global
Macquarie Pastoral Fund	Macquarie Infrastructure and Real Assets (MIRA)	UK	700 AUD	Apr-11	Australia
Black River Food Fund 2	Proterra Investment Partners	US	700 USD	Nov-14	Emerging Markets
AMERRA Agri Fund II	AMERRA	US	535 USD	Jan-13	North America, Latin America

Source: Preqin.

5. Bolster Domestic Grain Milling Capacity

Three fundamental premises underpin this strategy. First, other than rice, the other staple grains require various degrees of processing to transmute them into forms suitable for human consumption. Second, milling is not a water-intensive activity, but generates local economic activity and helps create jobs, benefits any of the various Arabian Gulf region

governments would presumably welcome. Third, milling grain locally means that the “grind spread” (i.e., the price of finished flour minus the price of raw wheat) stays in the local economy instead of being paid to a middleman who is likely domiciled abroad.

Conclusion

Lessons being learned and applied in the Arabian Gulf region will offer valuable policy examples across the globe as many other arid regions such as the North China Plain, Western United States, India, and Pakistan struggle with similar stress points in the food-water-energy nexus. If properly conceived and executed, the policy responses by Arabian Gulf governments can provide global best practice examples of how to balance competing stresses on the food-water-energy nexus. Conversely, Iran’s decision to continue emphasizing wheat self-sufficiency in the face of climate conditions clearly unsuited for growing sufficient wheat to feed more than 80 million people is very likely sowing the seeds of a serious environmental and humanitarian crisis that could begin producing serious regional—and perhaps even global—consequences over the next five years absent significant policy shifts.⁸⁹

⁸⁹ Gabriel Collins, *Iran’s Looming Water Bankruptcy*, Rice University’s Baker Institute for Public Policy, Houston, Texas, 2017, <http://www.bakerinstitute.org/files/11586/>.