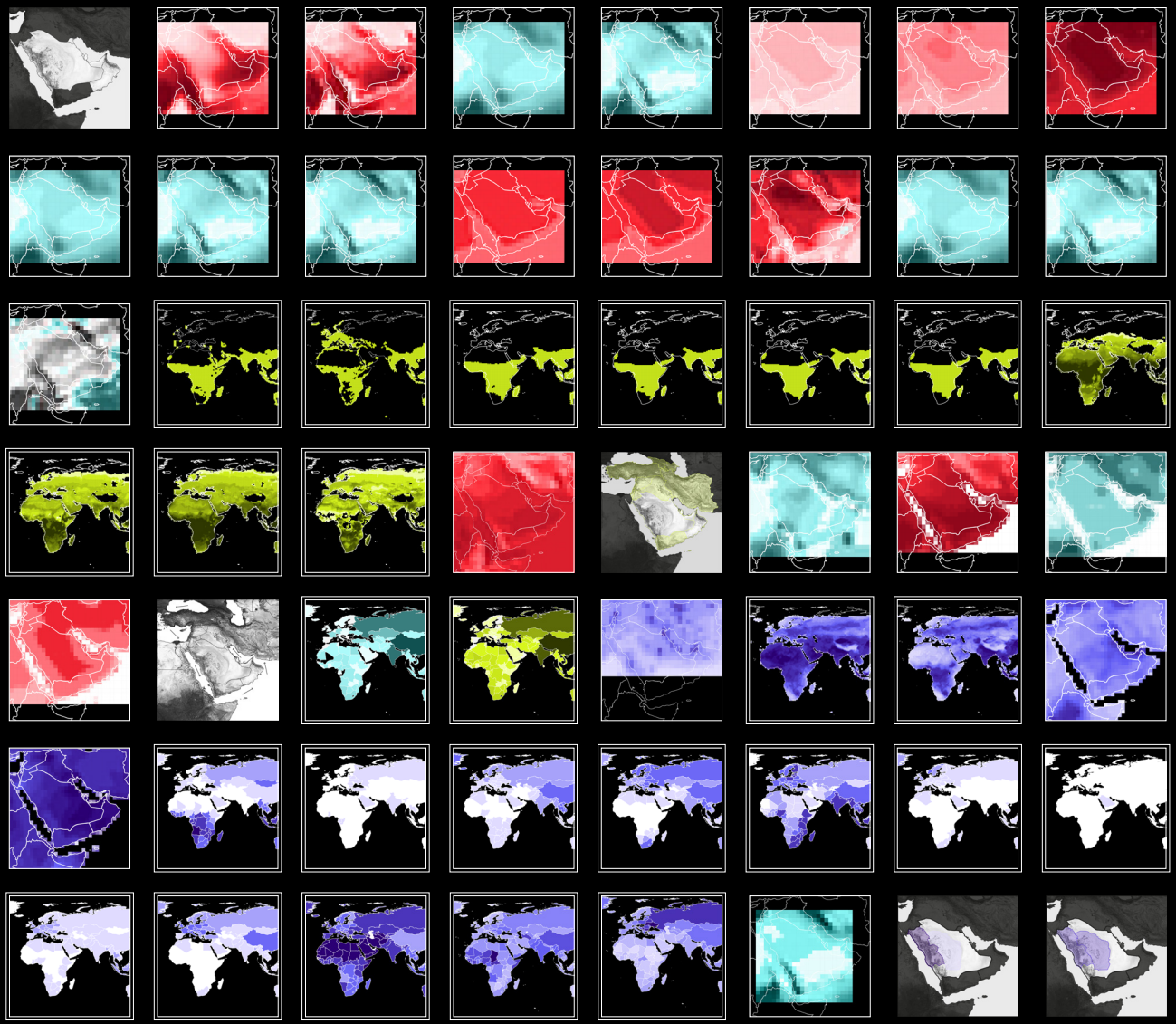

THE STATE OF CLIMATE AND HEALTH RESEARCH IN GCC

AEON COLLECTIVE X COMMUNITY JAMEEL

DESIGNED BY ACCURAT

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2.4

IMPLICATIONS ON FOOD SECURITY IN HIGH FOOD IMPORTING COUNTRIES: FOOD IMPORT VULNERABILITY IN THE GULF COOPERATION COUNCIL

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KEY MESSAGES

- → Domestic food production cannot meet most of food demand in the GCC.
- → Imports are the key to Food Security in the GCC.
- → Future climate and demographic changes will impact world market prices and food supply from traditional trading partners of the GCC.
- → GCCs food imports for some commodities are limited to a few supplying nations making the GCC vulnerable geo-political events and supply chain issues.
- → It is crucial that the GCC maintains it fossil fuel driven export economy or diversify by 2050 to absorb the food impact price shocks from climate change to maintain Food Security.

INTRODUCTION
FOOD SECURITY, CLIMATE CHANGE, AND HEALTH

Food security and human health are inextricably linked. The 2009 Declaration of the World Food Summit defines food security as, "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [1]. Food security is built on four pillars: availability (sufficient supply of food), access (sufficient resources and market availability), utilization (sufficient knowledge of food preparation and dietary diversity do achieve healthy nutritional status), and stability in achieving the other three dimensions over time [1-3]. Integral to the concept of food security is the achievement of positive nutritional outcomes [1].

TABLE 1 Global average of percent change in yield due to Climate Change (CC).

Commodity	% Change in yield
Grains	-8.6%
Oilseeds	-7.9%
Rice	-5.9%
Fruits and Veg.	-8.2%
Meat and Milk	-3.5%
Pr. Foods	Not available

-100% 0%

Source: IFPRI, 2019.

The effects of climate change pose a long-term threat to all four pillars of food security. The impacts relative to technological advances over the next 30 years will occur in multiple, interconnected ways, key among them: crop yields are predicted to decline for all major crops due to changes in precipitation patterns, extreme weather events, and increasing competition from weeds and pests on crops (TABLE 1) [4, 5] pests, disease, heat stress, reduced quality of animal feed, and changes in water temperature will affect livestock and fishery production [5, 6]; climate change-induced geopolitical instability and infrastructure damage could disrupt food distribution systems [5, 7]; the nutrient quality of many crops will decrease with elevated atmospheric CO_2 [5] and yield loss and supply chain disruption, in addition to population and economic growth, will drive increases in world market food prices TABLE 2. Additionally, in conditions of price-driven food insecurity, people cope by shifting their diets to calorie-rich but nutrient-poor foods and/or they endure hunger, leading to health related consequences ranging from micronutrient malnutrition to obesity [5].

TABLE 2 Changes in real world market prices from 2020-2050.
→ NO CC: Not factoring in Climate Change;
→ CC: Factoring in Climate Change impacts to world.

Commodity	Worldmarket prices (US$)			% Difference between NO CC and CC Worldmarket prices (US$)[4]
	2020	2050 NO CC	2050 CC	
Oilseeds	485	511	669	+31%
Grains	230	259	336	+30%
Rice	396	457	567	+24%
Pr. Foods	640	743	851	+14%
Fruits and Veg.	952	1,145	1,311	+14%
Meat and Milk	2,713	2,832	2,955	+4%

0 2,955 0 +100%

Source: IFPRI, 2019.

It is widely recognized that a country's food security increases with economic development. However, as the ripple effects of climate change accelerate through the complex and interdependent global food system, the future food security of even some wealthy nations is at risk. This threat is particularly relevant for countries with limited capacity for domestic food production and vulnernable non-agricultural export markets that rely heavily on imports to meet demand for food, such as the rich Arab Gulf countries. There is an imminent need for

these countries to assess food-related risk factors in order to guide domestic and foreign policy towards decisions that will ensure future food security. Here we look at the potential threats to food security in the Gulf Cooperation council (GCC) in the context of global food supply chains, with a particular focus on trade and geopolitical dynamics in the broader West Asian region. This analysis forms a foundation for analyzing the relationship between food security and climate change in other high net food importing nations.

METHODS

STUDY AREA: GULF COOPERATION COUNCIL (GCC) COUNTRIES

The GCC is a group of six Arab Middle Eastern countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) bordering the Gulf FIGURE 1. The countries cover a geographic area of 2.6 million km^2, have a total population of approximately 56 million people, and a combined GDP of approximately US$ 1.5 trn [8]. Their vast oil and gas reserves (30% of the proven oil and 22% of the proven natural gas reserves in the world) and relatively small populations have made the region one of the wealthiest in the world [3].

The GCC countries are ranked as the most food secure in the Arab world and are among the highest-ranking in the world for both food security and food affordability [9]. Their fiscal strength allows them to bridge limited capacity for domestic food production with food imports and provides them high buying power in international food markets, making them less vulnerable to price risk than other food importers [3,10]. However, the current situation masks a fragility in the long-term food security for the nations of the GCC.

The Council on Foreign Relations reports that countries at the greatest risk for food insecurity are those that rely heavily on food imports, lack diversity in food suppliers, and/or are already facing risks from climate change, conflict, or economic troubles [147]. The GCC states meet most of these conditions: domestic food production is capable of meeting only a small portion of food needs, a situation that will intensify with climate change; they are some of the most food import-dependent countries in the world, leaving them vulnerable to import price volatility and supply disruption; regional instability and geopolitical tensions increase the price and supply risk and have the potential to cause domestic unrest; and the ability of governments to continue to mitigate price risk is dependent on successful economic diversification away from oil and gas [12,14].

Capacity for domestic food production in the GCC is highly constrained by absolute water scarcity[2] (the region is the most water-stressed in the world), high temperatures, and poor soils [3,15].

FIGURE 2 Presents the historical climatic conditions that relate to water stress and limited agricultural potential.

[2] *Absolute water scarcity is defined as less than 500m³ per capita per year of renewable freshwater resources (https:// www.un.org/waterforlifedecade/scarcity.shtml)*

FIGURE 1 GCC countries and the broader West Asia region.

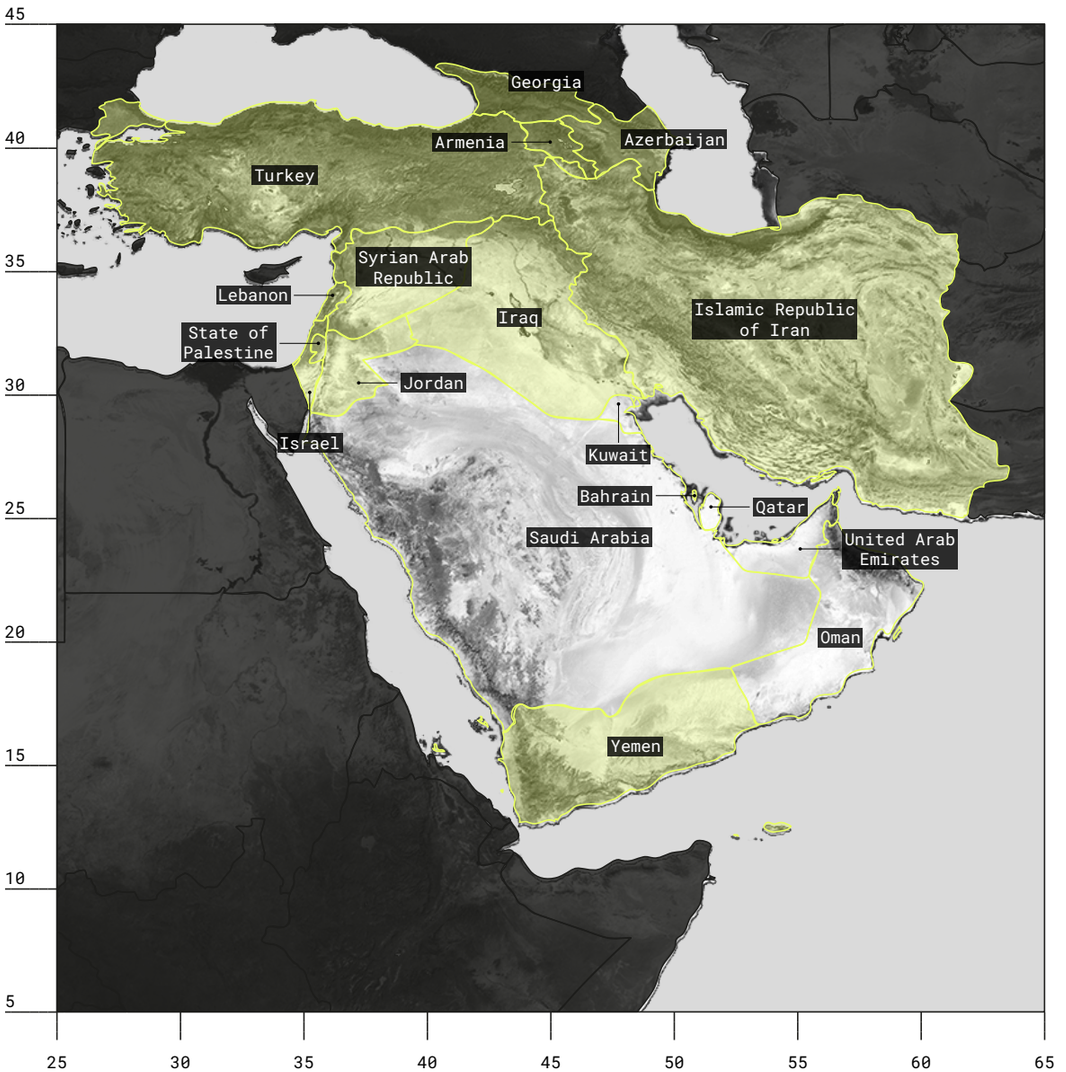
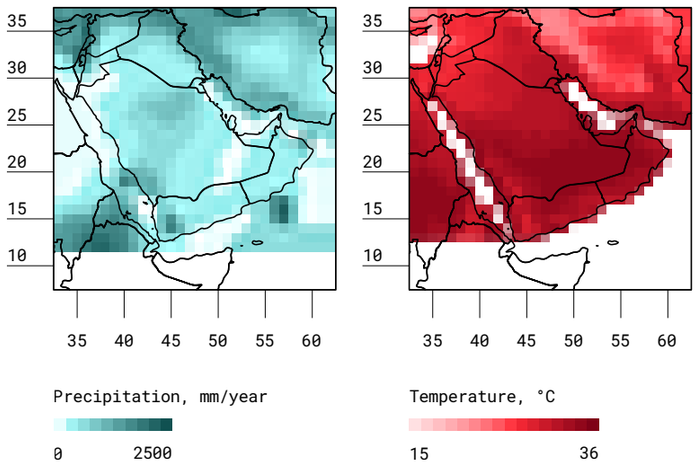


FIGURE 2 Historical Climate of the GCC Region.

A. HISTORIC MEAN ANNUAL PRECIPITATION

B. HISTORIC MEAN ANNUAL TEMPERATURE



Source: WorldClim, 2020[16].

Only 1% of the land area of the GCC is arable land suitable for crops, and only 19.5% of the land area of the GCC is considered agricultural land [3] [15]. There is limited potential to expand the area for agricultural production in the region. Fertile cropland and renewable water resources are nearly exhausted, and climate change impacts in the form of temperature rise, sea level rise, and drought is likely to tighten these constraints [9, 12]. The GCC countries also have relatively low irrigation efficiency ratios – 40% less efficient than Egypt for example [3].

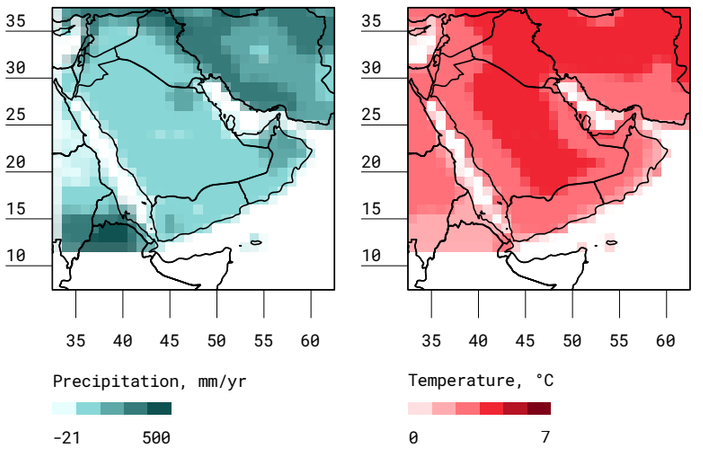
Any expansion of agricultural production in the GCC will depend on innovation for sustainable intensification on existing agricultural land and continued adoption of technological solutions. Approaches such as greenhouse vegetable production, indoor vertical farming, desalinated water irrigation for horticulture crops, treated wastewater irrigation, and drought and salt tolerant crop varieties can help increase domestic production. However, their potential remains marginal, and due to the higher cost of many of them, their economic viability is largely limited to higher value horticulture crops. Additionally, domestic production of some food products, especially meat and dairy, rely heavily on imports for animal feed, and thus does little to reduce market price risk [10]. Furthermore, gains in domestic production

[3] Arable land consists of the total area under temporary crops, temporary meadows and pastures, kitchen gardens, and land temporarily fallow. Agricultural land includes arable land, land under permanent crops, and land under permanent meadows and pastures [15, 17].

FIGURE 3 Climate Change in 2050 from CanESM5 Climate Model for the RCP 8.5 scenario.

A. CHANGE IN MEAN ANNUAL PRECIPITATION

B. CHANGE IN MEAN ANNUAL TEMPERATURE



Source: WorldClim, 2020[16].

are likely to be offset by population growth, rising income levels, and changes in dietary consumption, all but ensuring continued reliance on food imports to meet most of the demand [9].

Despite their wealth, the GCC countries' reliance on imports leaves them vulnerable to availability risk. This arises when an import-dependent country is not able to purchase food, even if it has the resources to do so. A number of factors may lead to availability risk including, climate shocks and natural disasters in exporting nations; export restrictions imposed by multiple food producers at once, such as what happened in the 2007-2008 food crisis; and political factors such as war, social unrest, or blockade [10].

Another important factor to consider is that populations of the GCC countries are not universally wealthy. Across the region, the poorest 10% of the population spend between 30-50% of their income on food [12]. Immigrants also make up a significant portion of the population in the region. Many of them are poor workers from East and Southeast Asia and other Arab countries who do not have access to the social safety nets available to GCC citizens, making them vulnerable to food price spikes [18]. This is particularly relevant when considering that rice, which is the main staple for most immigrant workers, is more vulnera-

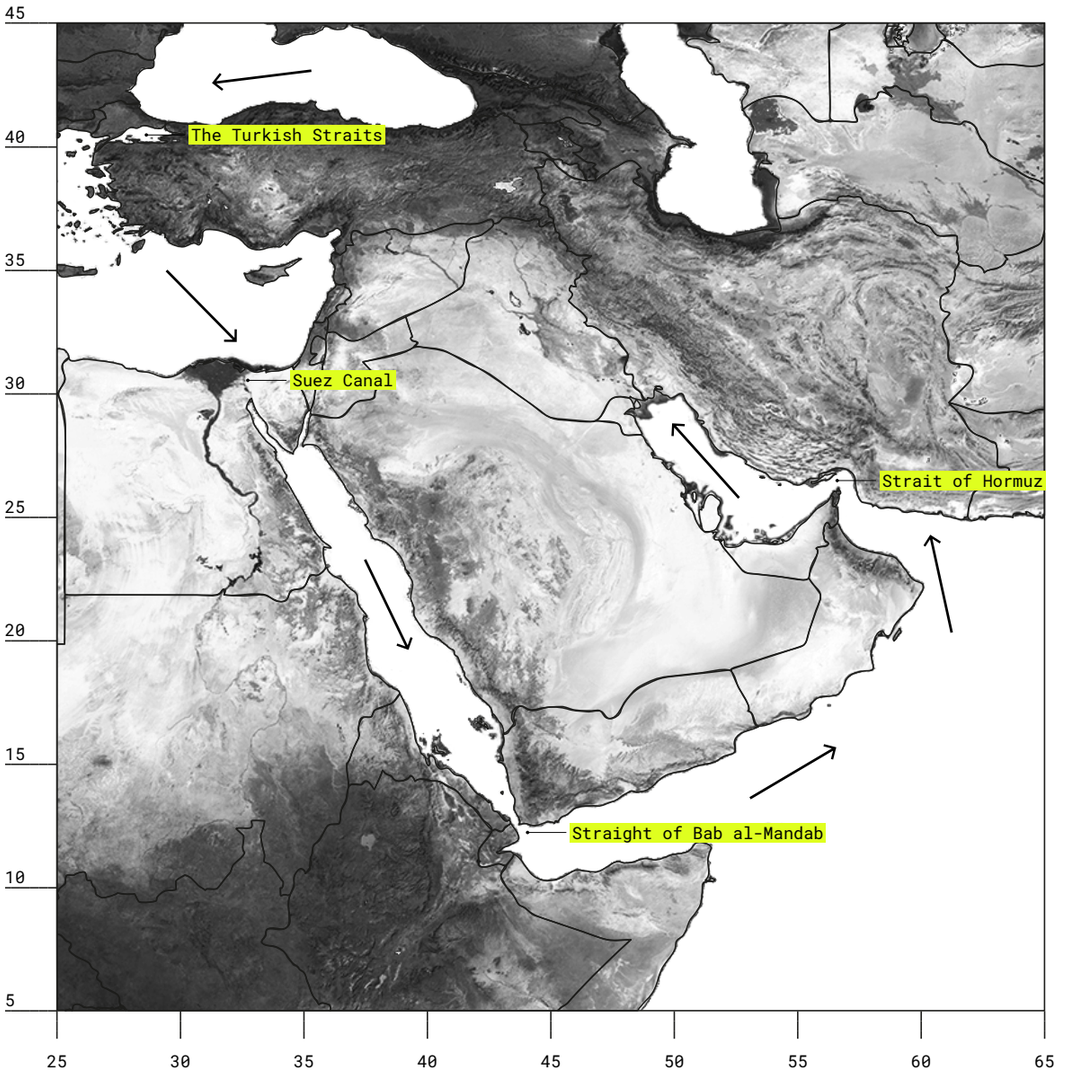
ble to price fluctuations than other commodities [12, 18]. If maritime shipping through the Gulf were to be disrupted for a prolonged period of time, this could cause a global price spike in rice, eroding food security for low-income immigrants and risking civil unrest – if trade disruptions exceed the capacity of strategic food reserves [18].

The situation in the previous paragraph describes a chokepoint disruption. The nations of the GCC are some of the most exposed in the world to potential food security risks from maritime chokepoints [3]. Over a third of all GCC food imports pass through at least one of four West Asia maritime chokepoints, for which no alternative routes exists (see FIGURE 4) [13]. The greatest threat to food security in the GCC is some form of regional conflict, instability, or disaster that disrupts two or three of the maritime chokepoints to the Arabian peninsula [19].

Over 80% of wheat must pass through at least one of these chokepoints for five of the six countries – the exception being Oman, for whom over 50% must pass through at least one [10]. This risk is particularly high for the Gulf countries of Kuwait, Bahrain, the UAE, and Qatar, for whom there is no alternative maritime route to the Strait of Hormuz. With its access to the Arabian Sea, only Oman has direct access to alternative shipping routes for food supplies from Asia, but closure of the Turkish Straits, the Suez Canal, or Bab Al Mandab, would still close off access to Oman's principal sources of wheat (See supplementary material) [10]. Some of the risk to the Persian Gulf countries has been ameliorated with the recent opening of a grain import and re-export hub on UAE's Gulf of Oman coast, but the recent diplomatic crisis between Qatar and other GCC countries and the associated closure of maritime and land borders demonstrates that overland transport routes may not prove a reliable alternative to maritime ones [19].

The focus of this paper is on the threats that climate change poses to food security in the region and does not fully address economic reforms currently underway or planned for the future. Thus, this analysis can be distilled down into two principal threats to: climate change impacts to yields and the resultant price increases to food imports. The remainder of this paper will focus on these factors.

FIGURE 4 Maritime chokepoints that could impact food security in the GCC.



Source: [149].

METHODS OF ANALYSIS:
There were three components used in the framework for this analysis:

→ International trade analysis.
→ Economic modeling of agricultural markets.
→ Modeling of climate change impact on crop yields and water resource supply and demand.

INTERNATIONAL TRADE ANALYSIS — The core of this analysis was the understanding of the current food self-sufficiency of the GCC nations. This was undertaken using the latest Global Trade, Assistance, and Production (GTAP) Data Base, version 10 (also referred to as GTAP 10) developed at Purdue University. The Data Base describes the world economy for four reference years (2004, 2007, 2011, and 2014) and distinguishes 65 sectors, in each of 141 countries/regions. For each country/region, the Data Base reports production, intermediate and final uses, international trade and transport margins, and taxes/subsidies [20].

To understand food security, it was decided to focus on six main food commodity groups: Grains, Rice, Fruits and Vegetables, Oil Seeds, Meat and Milk, and Processed Foods. GTAP 10 provides data for 65 commodity sectors and a subset of 16 sectors were aggregated to the six food security categories for this analysis. TABLE 3 Lists food commodity sectors categories.

The aggregation of the 16 GTAP sectors to the six-food security categories used in this analysis is listed below:

→ Grains: wht and gro
→ Rice: pdr
→ Fruits and Veg: vuf and ocr
→ Oil Seeds: osd
→ Meat and Milk: cmt, omt and mlk
→ Proceed Food: pcr, sgr,ofd,bot, and vol

After aggregating the sectoral data, analytical tools were developed that processed the GTAP data to provide a set of data for each GCC country. These data included:

→ The exporting countries to each GCC country for each food security
→ The volume of exports from each exporting country
→ The volume of exports from each GCC country to other regional and global countries
→ The total demand for each food security sector for the GCC nations
→ The data used was from 2014 and provides the background data for understanding the current food security situation for the GCC nations.

TABLE 3 Key GTAP Food Commodity Sectors.

GTAP Food	Detailed makeup of GTAP Sector
pdr	Rice: seed, paddy (not husked)
wht	Wheat: seed, other
gro	Other Grains: maize(corn), sorghum, barley, rye, oats, millets, other cereals
v_f	Veg & Fruit: vegetables, fruit and nuts, edible roots and tubers, pulses
osd	Oil Seeds: oil seeds and oleaginous fruit
ocr	Other Crops
ctl	Cattle: bovine animals, live, other ruminants, horses and other equines, bovine semen
oap	Other Animal Products
smt	Cattle Meat: meat of: cattle, buffalo, sheep, goat, camels and horses
omt	Other Meat: meat of pigs, of poultry, fresh or chilled;
vol	Vegetable Oils: margarine and similar preparations; cotton linters; oil-cake, other residues
mil	Milk: dairy products
pcr	Processed Rice: semi- or wholly milled, or husked
sgr	Sugar and molasses
ofd	Other Food: prepared and preserved fish, vegetables, pulses and potatoes; fruits and nuts; wheat and meslin flour; other cereal flours; groats, mixes and doughs for the preparation of bakers' wares; starches and starch products; sugars and sugar syrups; bakery products; cocoa, chocolate and sugar confectionery; macaroni, noodles, couscous and similar farinaceous products;
ofd	Beverages and Tobacco products

Source: Aguiar et al. 2019 [20].

ECONOMIC MODELING OF AGRICULTURAL MARKETS — The International Food Policy Research Institute's (IFPRI) IMPACT model is an integrated system of linked economic, climate, water, and crop models that allows for the exploration of policies to reduce hunger and improve food security in a sustainable way. Using IMPACT to model alternative future scenarios and assessing their outcomes can help inform policy choices.

At IMPACT's core is a partial equilibrium, the multi-market economic model that simulates national and international agricultural markets. Links to climate, water, and crop models support the integrated study of changing environmental, biophysical, and socioeconomic trends, allowing for in-depth analysis of a variety of critical issues of interest to policy makers at national, regional, and global levels. FIGURE 5, 157

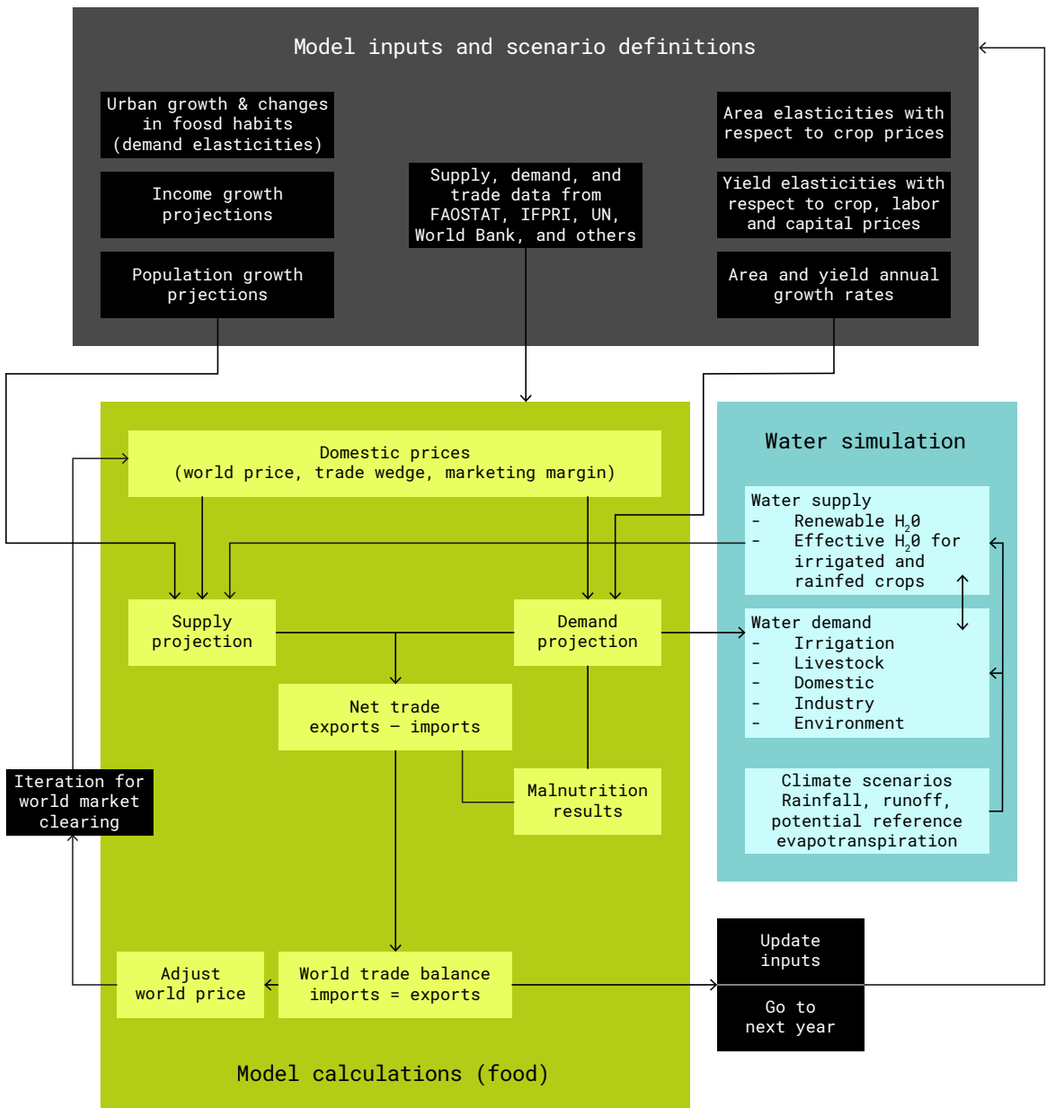
The global model runs at a monthly time step for crop and water modeling and at an annual time step for economic modeling. The spatial scale of the model has 320 Food Producing Units(FPU), which is the inspection of 154 River Basins with 159 Political/Economic policy regions FIGURE 6.

For this analysis dataset results for 2050 from IFPRI's IMPACT Projections of Food Production, Consumption, and Hunger to 2050, With and Without Climate Change: Extended Country-level Results for 2019 are used. Results are included for yields, production, and consumption for selected countries. The projections are for two "baseline scenarios" – one considers the impacts of climate change, while the other assumes no climate change (for comparison).

The IMPACT outputs used in this analysis include:

→ World market prices of 60+ food commodities
→ Trade of 60+ food commodities between 159 economic units
→ National Demand for 60+ Food Commodities
→ Feed demand of Food commodities for Livestock

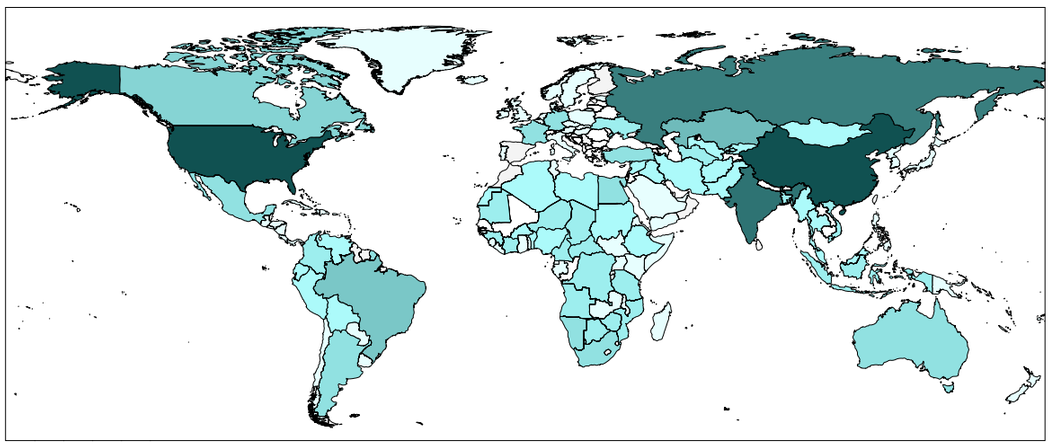
FIGURE 5 Schematic of IMPACT Modeling Framework.



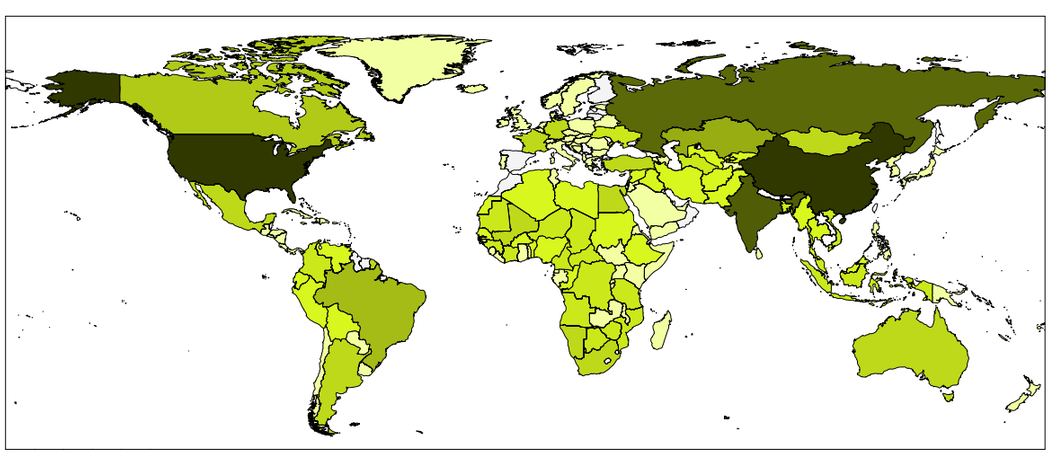
Source: From [22], IFPRI 2012.

FIGURE 6 Spatial resolution of the IMPACT Modeling Framework.

A. WATER BASINS



B. FOOD PRODUCTION UNITS



Source: From [22], IFPRI 2012.

MODELING OF CLIMATE CHANGE IMPACT ON CROP YIELDS AND WATER FOR IRRIGATION — Key elements of the IMPACT Modeling Framework FIGURE 5 are detailed biophysical models of crop yield (rainfed and irrigated) and water supply for irrigation driven by historic and climate change projections of monthly climate data. For crop yield modeling, IFPRI uses the DSSAT crop modeling systems for nine major crops, and this is linked to the IFPRI global water model that has a monthly hydrologic model and a monthly river basin water balance model for each of the 320 FPU. The 320 FPU follow the hydrologic topology into 126 river basins to assure regional hydrologic water balance.

The water and crop models within the IMPACT Modeling Framework provided the following data for this analysis for GCC countries and the exporting countries that they import from on Climate Change Impacts on:

→ Irrigation and rainfed crop yields
→ Irrigation water availability
→ Economically drive crop production
→ Feed demand for livestock.

These results are used directly in this analysis as well as indirectly through the economic modeling results (e.g. world market prices, per capita consumption).

RESULTS AND ANALYSIS

GCC SUMMARY — All GCC countries are severely water stressed (See “key demographic, agriculture, and water statistics” tables for each country in following sections). With negligible surface freshwater resources, nearly all water withdrawals from natural sources come from groundwater at rates far exceeding natural recharge or from fossil aquifers that have virtually no natural recharge. Additionally, the problem of seawater intrusion into coastal aquifers due to over pumping is a common problem in the GCC, a situation that sea level rise will further exacerbate [3, 23]. The region is effectively mining it’s groundwater.

All of the GCC countries have high import vulnerability index scores or greater for two or more food commodity groups TABLE 4. Even foods (excluding fresh fruits and vegetables) produced domestically do little to increase food security because they are highly reliant on foreign imports as inputs.

TABLE 4 Imports for key food commodities by GCC and West Asian Countries.

A. PERCENT OF DEMAND FOR KEY COMMODITIES

Region	Country	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
GCC	Bahrain	46	0	71	98	44	49
	Kuwait	99	89	77	99	78	65
	Oman	83	0	46	97	53	36
	Qatar	44	0	54	98	50	47
	Saudi Arabia	60	95	46	100	48	39
	United Arab Emirates	93	47	34	98	53	1
Rest of West Asia	Armenia	3	2	0	12	3	0
	Azerbaijan	10	1	0	3	9	7
	Georgia	20	34	0	58	17	0
	IM	32	0	0	15	1	14
	Israel	79	34	0	65	2	14
	Jordan	80	25	1	99	25	33
	Turkey	16	18	0	57	0	0
	Rest of West Asia	17	1	6	13	11	24

0 100

Source: [20] Aguiar et al. 2019. Author calculations for rice from: [24, 25] United Nations 2022; FAO 2022.

Note: Rest of West Asia includes Iraq, Lebanon, Palestinian Territory, Syria and Yemen.

TABLE 4 Imports for key food commodities by GCC and West Asian Countries.

B. NUMBER OF EXPORTING COUNTRIES PROVING ~80% OF IMPORTS

Region	Country	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
GCC	Bahrain	4	2	14	7	8	17
	Kuwait	3	5	13	4	11	18
	Oman	4	3	8	2	8	12
	Qatar	4	3	15	8	8	17
	Saudi Arabia	8	3	18	4	10	20
	United Arab Emirates	5	4	18	4	10	22
Rest of West Asia	Armenia	1	7	13	3	8	14
	Azerbaijan	2	4	8	3	9	6
	Georgia	1	3	9	2	11	11
	IM	6	2	5	6	3	7
	Israel	4	7	13	5	8	20
	Jordan	4	6	15	5	10	17
	Turkey	4	3	16	8	15	18
	Rest of West Asia	8	5	12	8	16	20

Max value is 22 (United Arab Emirates, Pr. Foods)

Source: [20] Aguiar et al. 2019. Author calculations for rice from: [24, 25] United Nations 2022; FAO 2022.

Note: The number of countries it takes to pass the 80% threshold (e.g. if 4 countries supply a total of 60% of imports and 5 countries supply a total of 82%, the number of countries will be 5). Rest of West Asia includes Iraq, Lebanon, Palestinian Territory, Syria and Yemen.

TABLE 4 Imports for key food commodities by GCC and West Asian Countries.

C. VULNERABILITY INDEX

Region	Country	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
GCC	Bahrain	12	0	5	14	6	3
	Kuwait	33	18	6	25	7	4
	Oman	21	0	6	49	7	3
	Qatar	11	0	4	12	6	3
	Saudi Arabia	8	32	3	25	5	2
	United Arab Emirates	19	12	2	25	5	0
Rest of West Asia	Armenia	3	0	0	4	0	0
	Azerbaijan	5	0	0	1	1	1
	Georgia	20	11	0	29	2	0
	IM	5	0	0	3	0	2
	Israel	20	5	0	13	0	1
	Jordan	20	4	0	20	3	2
	Turkey	4	6	0	7	0	0
	Rest of West Asia	2	0	1	2	1	1

Low Vulnerability (0-5) Medium Vulnerability (6-10)
High Vulnerability (11-15) Severe Vulnerability (>15)

Source: [20] Aguiar et al. 2019. Author calculations for rice from: [24, 25] United Nations 2022; FAO 2022.

Note: Vulnerability Index is created by dividing the percent of total demand for food commodity met from imports by the number of countries suppling ~80% of imports. Rest of West Asia includes Iraq, Lebanon, Palestinian Territory, Syria and Yemen.

For example, Saudi Arabia has a growing domestic meat and milk industry whose products it exports to the other countries in the GCC FIGURE 7, 8. It is reliant on imports to meet 60% of total demand for grain TABLE 4, but fully 68% of its grain is used to feed livestock FIGURE 8. The UAE is the largest food processor and re-exporter in the GCC FIGURE 7, for which it is highly dependent on foreign food imports.

Intra-GCC trade also means that food security in the region is layered. For example, Oman is heavily reliant on the UAE as a trade intermediary. The country imports 62% of its rice, 28% of its fruits and vegetables, 67% of its meat and milk, and 31% of its processed foods via the UAE. Thus, if the UAE experiences trade restrictions, Oman's food security is at risk. TABLE 5 shows. The Export to Import percentage for GCC and the rest of West Asia.

The IMPACT model estimates national food demand as function of population, economic wellbeing (GDP), and local and world market prices. For this analysis, a standard IPCC Shared Socio-economic Pathway was used to forecast population and GDP/capita to 2050, and food demand was estimate for historic climate and for climate change conditions to crop yields.

TABLE 6 Presents the results for 2050 without Climate Change and with Climate Change. The results show in 2050 a significant increase in per capita fruit and vegetable, oilseed, and meat consumption, while showing a slight decrease in cereal consumption compared to 2010. This is due to how the income effect on diet choices combines with price effects. Due to this demand shift, the increase in population, and the fact that the region imports cereals for livestock feed to produce local meat, the results show dramatic increases in cereal imports (200%) and significant imports of fruit and vegetable, oilseeds, and meat to the region.

The IPFRI analysis projects significant impacts of climate change on the global yields and production of the major commodities imported by the GCC TABLE 1. These production impacts result in major changes in world market prices TABLE 2. The potential increase in world market prices coupled with local GCC yield reductions from climate change suggests moderate decreases in per capita consumption of all food commodities. The reduced demand results in a mixed impact on imports, as the strong demand for meats results in increases of demand for cereals for feed and also meat as local production is impacted. There are significant decreases in fruits and vegetable and oil seed imports due to the world market price effects. The IFPRI reports significantly greater impacts on consumption for regions with lower economic wealth. For example the rest of West Asia Region neighboring the GCC shows a 16% and 9% decrease in cereal and meat imports, respectively due to climate change.

The projected increases in commodity food prices by 2050 highlights a key vulnerability of the GCC states: in a region with

FIGURE 7 Intra-GCC trade of key food commodities metric tonnes.

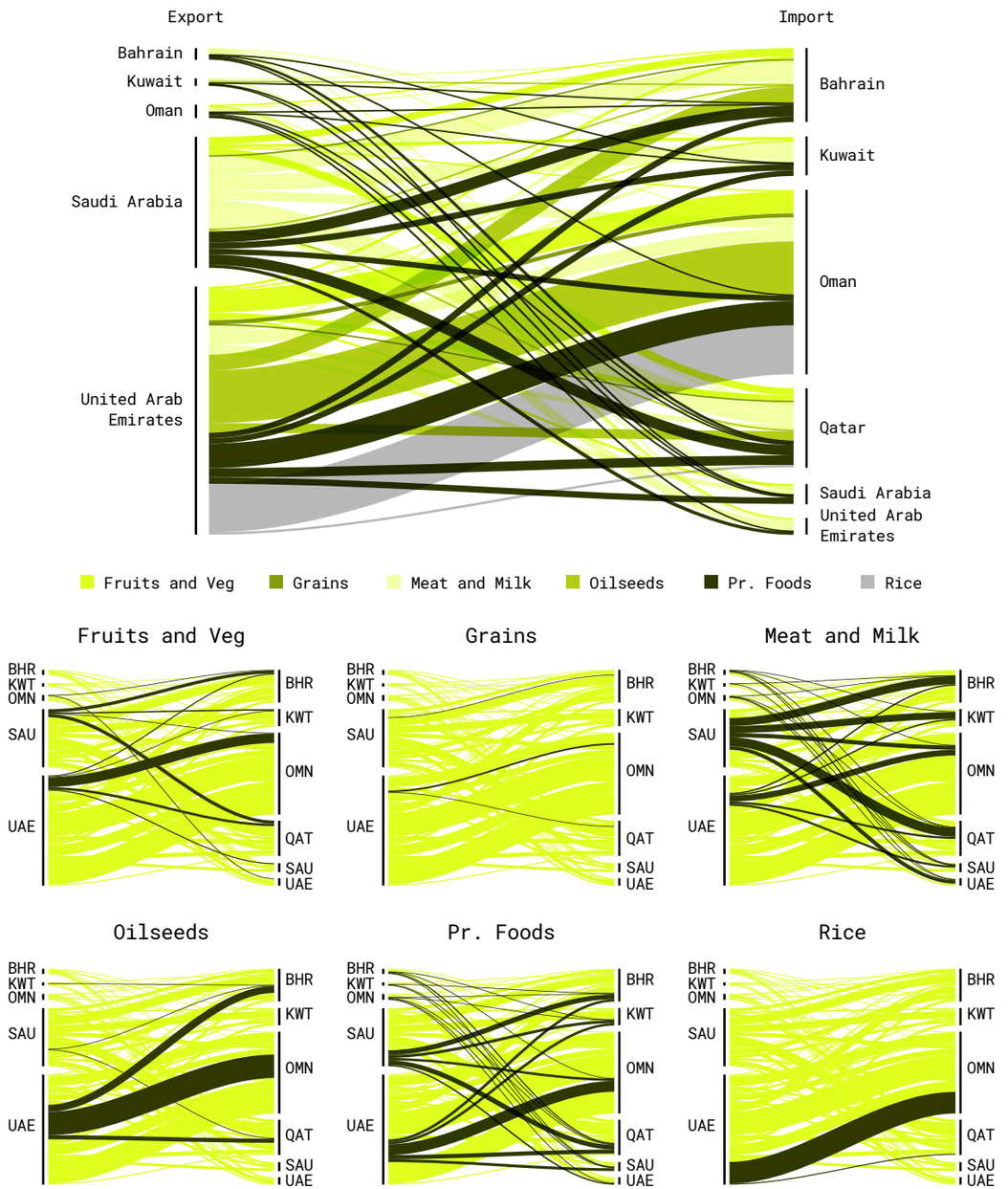
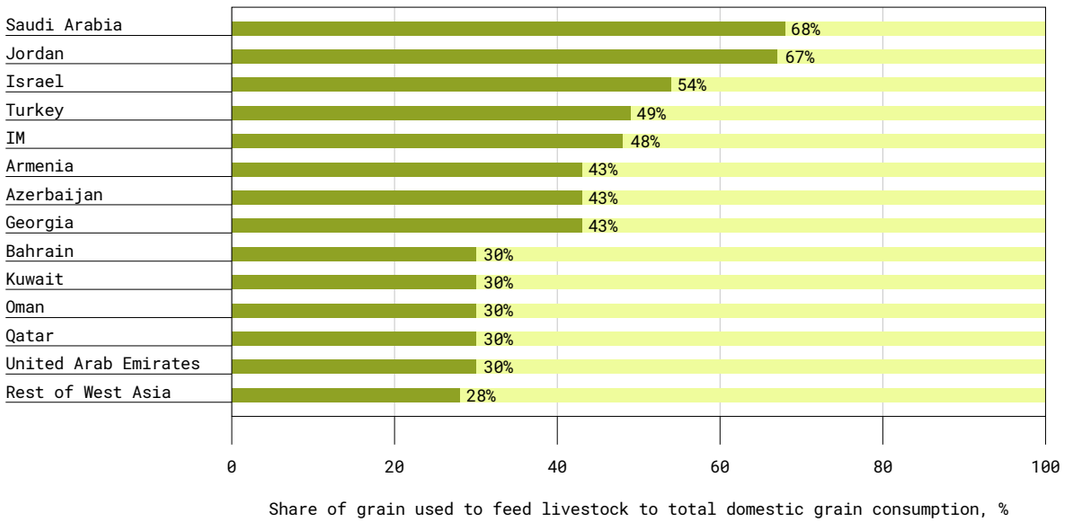


FIGURE 8 Ratio of grain used to feed livestock to total domestic grain consumption for GCC and other West Asian countries.



Source: [20] Aguiar et Al., 2019.

Note: Average for 5 GCC countries due to data aggregation from Aguiar et Al., 2019.
Rest of West Asia includes Iraq, Lebanon, Palestinian Territory, Syria and Yemen.

extremely limited capacity for domestic food production, the current high levels of food security are wholly dependent on the countries being able to maintain their wealth. If current efforts to diversify the oil and gas economies of the GCC are not successful, and if the prices of oil and gas remain low (which they are expected to do as renewables continue to grow), then food security and social stability are threatened. A demonstrative case for this is that of rice. Half of the GCC countries rank high on the import vulnerability index for rice TABLE 4C, and demand for rice in the Gulf region is expected to increase due to consumption from immigrants from Asia [15]. An inability to meet demand for rice could cause social unrest that could have ripple effects throughout the region.

TABLE 5 Export-Import Ratio: the ratio of exports to imports.

Region	Country	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
GCC	Bahrain	1	1	1	2	31	30
	Kuwait	0	0	1	1	11	10
	Oman	0	0	27	0	27	43
	Qatar	1	0	1	1	2	1
	Saudi Arabia	0	0	10	0	25	19
	United Arab Emirates	7	40	13	3	28	63
Rest of West Asia	Armenia	11	10	78	8	28	97
	Azerbaijan	1	1	127	0	5	29
	Georgia	3	0	127	2	5	54
	IM	1	127	127	2	44	9
	Israel	15	0	127	17	32	42
	Jordan	1	1	94	1	15	21
	Turkey	9	0	127	14	127	127
	Rest of West Asia	2	8	47	3	11	127

0 127

Note: Rest of West Asia includes Iraq, Lebanon, Palestinian Territory, Syria and Yemen.

TABLE 6 Changes in GCC per capita consumption and net imports from 2010-2050.
→ NO CC: Not factoring in Climate Change;
→ CC: Factoring in Climate Change impacts to world.

A. PER CAPITA CONSUMPTION

Commodity	Per Capita Consumption (Kg/year)			% Difference between NO CC and CC per Capita Consumption (Kg/year)
	2010	2050 NO CC	2050 CC	
Cereals	327	323	313	-3.3%
Fruits and Veg.	442	521	508	-2.4%
Oilseeds	8	9	9	-6.4%
Meats	116	143	142	-0.6%

0 521 -10% 0 +10%

Source: [4] IFPRI, 2019.

B. IMPORTS

Commodity	Imports (Million Metric Tons)			% Difference between NO CC and CC Imports (Million Metric Tons)
	2010	2050 NO CC	2050 CC	
Cereals	13.7	35.2	35.8	+1.6%
Fruits and Veg.	6.2	8.1	7.4	-8.3%
Oilseeds	1.2	2.2	2.1	-7.4%
Meats	1.4	2.6	2.6	+1.5%

0 40 -10% 0 +10%

Source: [4] IFPRI, 2019.

BAHRAIN

The island nation of Bahrain is severely water stressed, withdrawing 134% more freshwater than available sources. However, it is able to meet 61% of its demand for water withdrawal with desalinated seawater TABLE: BHR 130. While agriculture only accounts for 0.3% of GDP, it is responsible for over 30% of water withdrawals in the country. It has the second lowest irrigation efficiency ration in the GCC [3]. Bahrain reuses 10-15% of its treated wastewater for irrigation [10]. This imbalance is highly economically inefficient, and as table 8 shows, it is unsustainable in the long term for meeting domestic food demand.

With only 46,000km^2 of cultivated land (5.9% of total area), agricultural production in Bahrain is minimal and is primarily focused on high-productivity, high-value horticultural crops and livestock [8, 9] [4]. Climate change impacts to these agricultural products shown in TABLE BHR Indicate a 7% yield increase to fruit and vegetable horticulture crops and a 5% yield decrease for meat and milk. Yields for the limited grains grown in the country are expected to decrease by 13% and remain neutral for rice (see note) and the negligible amount of domestic oilseed production. Climate change yield impacts for processed foods are not applicable, as they are value added products that use agricultural products as inputs.

Bahrain exports (% of exports to imports in TABLE BHR) a net of 1% of its grain imports, 1% of rice, 1% of fruit and vegetables, 2% of oilseeds, 31% of meat and milk, and 30% of processed foods. Net exports are a measure of import passthrough activity and/or export of a different type of crop in a commodity category (e.g. importing grapes but exporting domestically produced dates). Bahrain is a moderate export intermediary for milk and meat and processed foods.

On the import vulnerability index (see methods section for description of metric), Bahrain ranks as low vulnerability for fruits and vegetables and processed foods, indicating either sufficient domestic production or sufficient diversity of import supplying nations. It ranks as medium vulnerability for meat and milk, high vulnerability for grains and oilseeds, and severe vulnerability for rice.

KUWAIT

Kuwait is the most water stressed country in the GCC, withdrawing 3,850% more freshwater than available resources TABLE: KWT 131. It only meets 35% of demand with seawater desalination. Kuwait does, however, reuse about 50% of its treated wastewater for irrigation [10]. Agriculture accounts for only about half a percent of GDP, while being responsible for over 60% of total withdrawals. This water use paradigm is the least sustainable of the GCC countries.

Only 0.9% of Kuwait's 18 million sq.km area is cultivated, and agriculture only accounts for half a percent of GDP [8]. The economically inefficient use of water is even more dramatic when considering

[4] The data from rice from the GTAP database [20] (Aguiar et al. 2019) used for TABLE BHR indicates that Bahrain is 94% self-sufficient for rice. It is unclear how much, rice production occurs in the country, and this potential discrepancy could be due to a lack of available data for Bahrain and data aggregation in the GTAP database. The Bahrain import vulnerability index number for rice is likely sufficiently higher than indicated in the table.

that Kuwaiti agriculture produces four times less USD per hectare than Bahrain's [15], meaning that it is producing lower value crops or producing higher value crops less efficiently under conditions of extreme water stress. Kuwait also has the lowest irrigation efficiency ratio in the GCC [3].

Kuwait is the most import dependent of the GCC countries for meeting food demand TABLE 4. It produces very little food domestically, relying on imports to meet 99% of demand for grains, 95% for rice, 77% for fruits and vegetables, 99% for oilseeds, 78% for meat and milk, and 65% for processed foods TABLE KWT. Despite being one of the most food secure countries in the world, price risk could pose a serious threat to food security because the majority of the population consists of immigrant labor from low-income countries [3, 27].

On the import vulnerability index TABLE KWT, Kuwait has a low vulnerability score for only processed foods, and medium vulnerability for fruits and vegetables and meat and milk, largely as a result of its diversified supply chains for these food commodities. It is severely import vulnerable for grains (having just three suppliers for 81% of demand), rice (five suppliers for 89% of demand), and oilseeds (four suppliers for 84% of demand). Kuwait is a still a net exporter of 11% of meat and milk and 10% of processed foods, two of its least import vulnerable food commodities.

OMAN

Oman has the highest per capita renewable water resources in the GCC [10], but it is still withdrawing 117% of renewable resources TABLE: OMN P132. It meets 18% of demand with desalination, but the Omani government is planning to increase desalination capacity by 66% in the near future TABLE OMN AND 10. Oman is also the only GCC country for whom the majority of their water does not come from nonrenewable groundwater resources [29].

Only 0.3% of Oman's 310 million km^2 area is cultivated, and agriculture accounts for only 2.2% of GDP but is responsible for over 85% of water withdrawals [8]. Oman has the highest irrigation efficiency ratio in the GCC [3]. While Omani agriculture accounts for only 8% of total GCC food production, it is sufficient to meet over one third of domestic demand TABLE OMN AND 26. Oman is reliant on imports to meet 83% of its demand for grains, 90% for rice, 46% for fruits and vegetables, 97% for oilseeds, 53% for meat and milk, and 36% for processed foods TABLE OMN.

To improve food self-sufficiency, government policies have focused on increasing local agricultural production and domestic production of processed foods [26]. Some climate change models also project an increase rainfall for the country, which may increase yields for some crops [15]. However, temperature increases will likely offset any gains from additional resources, which may explain why [4] and GTAP database [20] data indicate yield decreases in the country for all major

crop categories except fruits and vegetables.

On the import vulnerability index TABLE OMN, Oman has low vulnerability scores for processed foods and medium vulnerability for fruits and vegetables and milk and meat, largely due to its domestic production. It has severe vulnerability for grains, rice, and oilseeds, due to its high reliance on imports and limited number of suppliers. The UAE is its principal exporter for rice, fruits and vegetables, oilseeds, meat and milk, and processed foods (See supplemental materials). It has net exports of 27% for fruits and vegetables and meat and milk, and 43% for processed foods.

QATAR

Qatar is severely water stressed, withdrawing over 432% more freshwater than available resources TABLE: QAT P133. It is able to meet 71% of demand with desalination and reuses only 10-15% of treated wastewater for irrigation [8, 10]. Agriculture contributes only 0.2% to GDP but is responsible for 32% of water withdrawals TABLE QAT. Qatar's irrigation efficiency ratio is nearly 50% lower than the GCC average [3]. Only 1.5% of Qatar's total area of 11.5 million sq. km is cultivated [8] .

Qatar is ranked as the most food secure country in the GCC and the thirteenth in the world [9]. However, much like Kuwait, its food security is susceptible to price because the majority of its population consists of immigrant labor from low-income countries [3, 28]. Qatar is reliant on imports to meet 44% of demand for grains, 99% for rice, 54% for fruits and vegetables, 98% for oilseeds, 50% for meat and milk, and 47% for processed foods TABLE QAT.

Despite being one of the most food secure countries in the world, Qatar's vulnerability to food insecurity became very clear during the diplomactic crisis between Qatar, Saudi Arabia, UAE, Bahrain, and Egypt and the closure of maritime and land borders from 2017 to early 2021. Diplomatic ties have been restored, but the event is demonstrative of the long-term challenges to food supply chains to the regions.

On the import vulnerability index TABLE QAT, Qatar has low vulnerability for fruits and vegetables and processed foods. It has medium vulnerability for meat and milk, high vulnerability for grains and oilseeds, and severe vulnerability for rice. It has negligible net exports for every food commodity category except rice.

SAUDI ARABIA

Saudi Arabia is the third most water stressed country in the GCC, withdrawing almost 900% more freshwater than available resources TABLE: SAU P134. It meets only about 9% of its demand with desalinated water, but like Kuwait, reuses about 50% of its treated wastewater for irrigation TABLE SAU AND KWT. Agriculture accounts for only 2.5% of GDP but is responsible for over 80% of withdrawals. Only 1.7% of Saudi Arabia's 2.1 billion sq. km area is cultivated [8]. Saudi Arabia has the second highest irrigation efficiency ratio in the GCC [3].

Saudi Arabia is reliant on imports to meet 60% of demand for grain, 95% for rice, 46% for fruits and vegetables, 100% for oilseeds, 48% for meat and milk, and 39% for processed foods TABLE SAU. The country has a growing meat and milk industry and is the largest producer and exporter of these goods in the GCC FIGURE 7. It is the principal exporter of meat and milk to Bahrain, Kuwait, and Qatar and a major exporter to other West Asian countries (See supplementary materials).

Saudi Arabia is the second largest food processing and food re-exporter in the GCC [26]. It is the principal exporter of processed food for Bahrain and a top exporter for Kuwait and Qatar (See supplementary materials). Despite being a major producer of these foods, their domestic production does not do much to reduce the county's reliance on food imports. As FIGURE 8 shows, fully 68% of Saudi Arabia's grain is used to feed livestock. As a result, domestic meat and milk production actually increases the demand for imports of strategic grain commodities, leaving the country vulnerable to global price increases in grain. In fact, Saudi Arabia consumes nearly two-thirds of global barley exports just to feed its sheep [12].

On the import vulnerability index TABLE SAU, Saudi Arabia has low vulnerability for fruits and vegetables, meat and milk, and processed foods. It has medium vulnerability for grains, and high vulnerability for rice and oilseeds. The low vulnerability scores for meat and milk and for processed foods are somewhat misleading, as the domestic production for these relies on continued access to and purchasing power for other import markets, such as grain.

UNITED ARAB EMIRATES

The UAE is second only to Kuwait in its degree of water stress and in the unstainable use of its water resources for agriculture. It withdraws approximately 1,700% more freshwater than available resources TABLE: UAE P135. It meets 44% of freshwater demand with desalination. Agriculture only contributes 0.8% to GDP but accounts for approximately 83% of water withdrawals.

Only 1.2% of its 71.2 million sq. km area is cultivated land [8]. The UAE's irrigation efficiency ratio is in line with the mean for the GCC. Intensive use of groundwater, mainly for irrigation, over the past 30 years caused severe saltwater intrusion into coastal aquifers and has led to extensive salinization of agricultural lands irrigated with this groundwater.

The UAE has the highest per capita food consumption in the GCC and accounts for 20% of total food consumption (largely driven by tourism), yet it only accounts for approximately 12% of total food production in the region [26]. The country is reliant on imports to meet 93% of demand for grains, 95% for rice, 34% for fruits and veget-

Wables, 98% for oilseeds, 53% for meat and milk, and 22% for processed foods [TABLE UAE].

The UAE is the top food processing and re-exporting country in the GCC [12, 26]. It is the top supplier of processed foods to Oman, and is a major exporter to Bahrain, Kuwait, Qatar, and Saudi Arabia. It is also the principal supplier of rice, fruits and vegetables, and meat and milk to Oman, and of oilseeds to both Oman and Bahrain ([FIGURE 7] and Supplementary materials). [TABLE UAE] Shows that much of this is through the UAE's role as a re-exporting intermediary.

On the import vulnerability index [TABLE UAE], the UAE has a low vulnerability for fruits and vegetables, meat and milk, and processed foods. It has a severe vulnerability for rice, grains, and oilseeds. As with most of the other GCC countries, its low vulnerability score for processed foods and meat and milk in particular masks the reality that it is highly dependent on imports as inputs for production. It is, however, able to hedge this risk through its diversified supply chains, which demonstrates that food security can be achieved for some food commodities even under conditions of high imports.

BAHRAIN

BHR

KEY DEMOGRAPHIC, AGRICULTURE, AND WATER STATISTICS

Total population 1M inhabitants	1.5
Percentage of population immigrants, est. %	48.0
Population growth %	0.9
GDP per capita current US$/inhab	23,739.0
Agriculture, value added % GDP	0.3
Water Stress %	134.0
Agricultural water withdrawal as % of total renewable water resources %	125.0
Agricultural water withdrawal as % of total water withdrawal %	33.3
Percentage of withdrawls that are from desalination %	61.0

KEY FOOD SECURITY INDICATORS RELATED TO FOOD IMPORTS

Indicator, %	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
Imports of Total Demand	46	98	71	98	44	49
Imported from major exporters	83	80	81	80	81	81
Exports to Imports	1	1	1	2	31	30
Domestic 2050 CC Yield Impact	-13	ND	7	0	-5	NA
Grain to Feed	30	–	–	–	–	–
CC Impact on WM Prices	30	24	14	31	4	15

-100% 0% 100%

Number of Major Exporters	4	2	14	7	8	17

Max value is 22

Import Vulnerability Index	12	49	5	14	6	3

Low Vulnerability (0-5) Medium Vulnerability (6-10)
High Vulnerability (11-15) Severe Vulnerability (>15)

Source: Population Reference Board, 2020; FAO, 2021a; CIA World Factbook, 2021;
Note: Grain to feed data is an average across all GCC countries due to data aggregation from GTAP Database [4, 20].

KUWAIT KWT

KEY DEMOGRAPHIC, AGRICULTURE, AND WATER STATISTICS

Total population 1M inhabitants	4.7
Percentage of population immigrants, est. %	70.0
Population growth %	1.2
GDP per capita current US$/inhab	28,897.0
Agriculture, value added % GDP	0.5
Water Stress %	3.8
Agricultural water withdrawal as % of total renewable water resources %	3.9
Agricultural water withdrawal as % of total water withdrawal %	62.3
Percentage of withdrawls that are from desalination %	35.0

KEY FOOD SECURITY INDICATORS RELATED TO FOOD IMPORTS

Indicator, %	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
Imports of Total Demand	99	95	77	99	78	65
Imported from major exporters	81	80	81	84	81	82
Exports to Imports	1	0	1	1	31	10
Domestic 2050 CC Yield Impact	-13	ND	7	0	-5	NA
Grain to Feed	30	–	–	–	–	–
CC Impact on WM Prices	30	24	14	31	4	15

-100% 0% 100%

Number of Major Exporters	3	5	13	4	11	18

Max value is 22

Import Vulnerability Index	33	19	6	25	7	4

Low Vulnerability (0-5) Medium Vulnerability (6-10)
High Vulnerability (11-15) Severe Vulnerability (>15)

Source: Population Reference Board, 2020; FAO, 2021a; CIA World Factbook, 2021;
Note: Grain to feed data is an average across all GCC countries due to data aggregation from GTAP Database [4, 20].

OMAN OMN

KEY DEMOGRAPHIC, AGRICULTURE, AND WATER STATISTICS

Total population 1M inhabitants	4.7
Percentage of population immigrants, est. %	46.0
Population growth %	1.9
GDP per capita current US$/inhab	17,099.0
Agriculture, value added % GDP	2.2
Water Stress %	117.0
Agricultural water withdrawal as % of total renewable water resources %	115.0
Agricultural water withdrawal as % of total water withdrawal %	85.8
Percentage of withdrawls that are from desalination %	18.0

KEY FOOD SECURITY INDICATORS RELATED TO FOOD IMPORTS

Indicator, %	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
Imports of Total Demand	83	90	46	97	53	36
Imported from major exporters	82	83	80	82	84	81
Exports to Imports	0	0	27	0	27	43
Domestic 2050 CC Yield Impact	-13	ND	7	0	-5	NA
Grain to Feed	30	–	–	–	–	–
CC Impact on WM Prices	30	24	14	31	4	15

-100% 0% 100%

Number of Major Exporters	4	3	8	2	8	12

Max value is 22

Import Vulnerability Index	21	30	6	49	7	3

Low Vulnerability (0-5) Medium Vulnerability (6-10)
High Vulnerability (11-15) Severe Vulnerability (>15)

Source: Population Reference Board, 2020; FAO, 2021a; CIA World Factbook, 2021;
Note: Grain to feed data is an average across all GCC countries due to data aggregation from GTAP Database [4, 20].

QATAR QAT

KEY DEMOGRAPHIC, AGRICULTURE, AND WATER STATISTICS

Total population 1M inhabitants	2.8
Percentage of population immigrants, est. %	88.0
Population growth %	1.2
GDP per capita current US$/inhab	63,249.0
Agriculture, value added % GDP	0.2
Water Stress %	432.0
Agricultural water withdrawal as % of total renewable water resources %	503.0
Agricultural water withdrawal as % of total water withdrawal %	32.0
Percentage of withdrawls that are from desalination %	71.0

KEY FOOD SECURITY INDICATORS RELATED TO FOOD IMPORTS

Indicator, %	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
Imports of Total Demand	44	99	54	98	50	47
Imported from major exporters	83	84	81	81	80	81
Exports to Imports	1	0	1	1	2	1
Domestic 2050 CC Yield Impact	-13	ND	7	0	-5	NA
Grain to Feed	30	–	–	–	–	–
CC Impact on WM Prices	30	24	14	31	4	15

-100% 0% 100%

Number of Major Exporters	4	3	15	8	8	17

Max value is 22

Import Vulnerability Index	12	49	5	14	6	3

Low Vulnerability (0-5) Medium Vulnerability (6-10)
High Vulnerability (11-15) Severe Vulnerability (>15)

Source: Population Reference Board, 2020; FAO, 2021a; CIA World Factbook, 2021;
Note: Grain to feed data is an average across all GCC countries due to data aggregation from GTAP Database [4, 20].

SAUDI ARABIA SAU

KEY DEMOGRAPHIC, AGRICULTURE, AND WATER STATISTICS

Total population 1M inhabitants	35.0
Percentage of population immigrants, est. %	38.0
Population growth %	1.6
GDP per capita current US$/inhab	20,905.0
Agriculture, value added % GDP	2.5
Water Stress %	883.0
Agricultural water withdrawal as % of total renewable water resources %	800.0
Agricultural water withdrawal as % of total water withdrawal %	82.2
Percentage of withdrawls that are from desalination %	9.0

KEY FOOD SECURITY INDICATORS RELATED TO FOOD IMPORTS

Indicator, %	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
Imports of Total Demand	60	95	46	100	48	39
Imported from major exporters	82	82	82	84	80	81
Exports to Imports	0	0	10	0	25	19
Domestic 2050 CC Yield Impact	-10	ND	-8	0	-7	NA
Grain to Feed	30	–	–	–	–	–
CC Impact on WM Prices	30	24	14	31	4	15

-100% 0% 100%

Number of Major Exporters	8	3	18	4	10	20

Max value is 22

Import Vulnerability Index	8	32	3	25	5	2

Low Vulnerability (0-5) Medium Vulnerability (6-10)
High Vulnerability (11-15) Severe Vulnerability (>15)

Source: Population Reference Board, 2020; FAO, 2021a; CIA World Factbook, 2021;
Note: Grain to feed data is an average across all GCC countries due to data aggregation from GTAP Database [4, 20].

UNITED ARAB EMIRATES

UAE

KEY DEMOGRAPHIC, AGRICULTURE, AND WATER STATISTICS

Total population 1M inhabitants	9.8
Percentage of population immigrants, est. %	88.0
Population growth %	0.6
GDP per capita current US$/inhab	40.18
Agriculture, value added % GDP	0.8
Water Stress %	1.7
Agricultural water withdrawal as % of total renewable water resources %	2.2
Agricultural water withdrawal as % of total water withdrawal %	82.8
Percentage of withdrawls that are from desalination %	44.0

KEY FOOD SECURITY INDICATORS RELATED TO FOOD IMPORTS

Indicator, %	Grains	Rice	Fruits and Veg	Oilseeds	Meat and Milk	Pr. Foods
Imports of Total Demand	93	5	34	98	53	22
Imported from major exporters	84	88	81	81	81	81
Exports to Imports	7	40	13	3	28	63
Domestic 2050 CC Yield Impact	-13	ND	7	0	-5	NA
Grain to Feed	30	–	–	–	–	–
CC Impact on WM Prices	30	24	14	31	4	15

-100% 0% 100%

Number of Major Exporters	5	4	18	4	10	22

Max value is 22

Import Vulnerability Index	19	24	2	25	5	0

Low Vulnerability (0-5) Medium Vulnerability (6-10)
High Vulnerability (11-15) Severe Vulnerability (>15)

Source: Population Reference Board, 2020; FAO, 2021a; CIA World Factbook, 2021;
Note: Grain to feed data is an average across all GCC countries due to data aggregation from GTAP Database [4, 20].

SUMMARY & CONCLUSION

It is clear that domestic food production cannot currently meet most of demand in the GCC and that climate and demographic changes will further challenge the ability of these countries to achieve food self-sufficiency with domestic production. Climate change will make this more challenging, as it is projected to cause a slightly negative net impact on agricultural production in the GCC. The changing climate is also projected to push average global yields down for the food commodity categories discussed in this paper [TABLE 1]. Yield decreases are also projected in many of the countries that export food to the GCC (see supplementary material). Even absent climate change, world population growth and changing diets are likely to cause food price increases. Models suggest that the impacts of climate change will further drive-up food prices significantly – by an average of 20% across the major food commodity categories [TABLE 2].

This analysis demonstrated that sufficient diversification of food import suppliers–and increasing food storage capacity and improving supply chain security–can hedge the risk of relying on imports for achieving food security (see e.g. analysis for Bahrain and UAE above). Food consumption in the GCC is projected to remain relatively flat. So theoretically, the GCC countries should be able to maintain their high levels of food security, even with their high reliance on imports, if they sufficiently diversify their food import supply chains.

A key assumption to this analysis is that SSP scenario assumes the GCC maintains it fossil fuel drive export economy and has the income to pay for the dramatic increase in imports by 2050 and can also absorb the price shocks from climate change. The model results show that food prices will continue to increase through 2050, and if the countries of the GCC are not successful in diversifying their economies away from oil and gas, their food security will be at risk. Under current economic conditions, GCC food security is directly tied to world hydrocarbon prices.

Additionally, most food imports to the GCC must pass through four politically tenuous maritime chokepoints, and regional instability and geopolitics are constraining factors on land-based food import routes. Recent political tensions between Qatar and other GCC members further demonstrates that maintaining good relations within the block of nations has important implications for food security. Further political unrest in the broader West Asia region could place additional strain on supply routes and lead to influxes of refugees that could cause internal sociopolitical tensions. The current war between Ukraine and Russia, principal sources of wheat to many West Asian countries, clearly demonstrates the food security risks from conflict in major food exporting countries.

Related to this is the growing practice of acquisition of agricultural land in foreign countries to produce food for the GCC. This topic

is largely outside the scope of this paper, but it is worthwhile to note that land acquisition may not produce the food security that is intended. Many countries where this agricultural land is purchased are developing countries with weak political institutions and where climate change could have negative impacts on food production. If climate change leads to food insecurity in these countries, social unrest could staunch the flow of food exports to the GCC, even if the land is legally owned. Some of these arrangements are also still vulnerable to the maritime chokepoints.

All GCC countries include expanding the desalination of seawater and saline groundwater to reduce water stress. Increasing desalination capacity could help meet urban water demand and, in some cases, could provide a source of irrigation water for highly efficient production of high value horticulture crops. This may moderately reduce the demand for imports, but horticulture crops are not the foundation of diets in the region. The crops that are most in demand are grains, rice, and animal products, which due to the agroecology of the region will continue to be imported.

There are some implications to the expansion of desalination. Higher water temperatures, a likely outcome of climate change, can promote algal blooms that are problematic for desalination plants and can reduce the ability of certain types of plants to function. The potential conflict with Iran poses a physical security risk to desalination plants, and cyber security threats to plant computer systems is a large and growing issue.

Finally, one area that holds promise for reducing the demand of imports is reducing food waste which is beyond the scope of this analysis. However, about one-third of all food is wasted globally, and the GCC countries stand out as among the highest per capita food wasters in the world [39, 40]. In higher income countries, food waste occurs on the consumer side of the food system, and wealthier countries generally consume more food per capita, generating more waste per capita. Reducing food waste could reduce the pressure on food imports. However, the GCC countries are not homogenous in the make-up of their populations, and thus strategies for addressing food waste will need to be tailored differently based on the country. In the UAE for example, addressing food waste may be more challenging due to the large tourism sector and that industry's reluctance to change the guest experience in any way [29]. We point the reader towards other studies focused on food waste in the GCC for more in-depth analysis of this issue [29, 39, 40].

AREAS OF FURTHER RESEARCH

- → Address the uncertainty in climate change and socio-economic projections.
- → Develop a global linked economic modeling system to allow for addressing balance of payments for food importing nations.
- → Develop a global bi-lateral trade model focused on food and agriculture.
- → Extension of the Food Security and Trade Vulnerability Index to Global coverage and actionable for policy.
- → Develop a framework to provide for the projection of the index for future global change scenarios.