

# Agricultural Production in Qatar

Subjects: Agronomy

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Starting in the 1970s, Qatar had almost entirely based its economic growth on resource exploitation of the hydrocarbon sector, with agriculture being considered only as a “hobby”, rather than an important economic activity. The real driver of change affecting Qatar’s agricultural sector is the issue of food security, after the 2017 embargo (imposed by neighboring countries that made Qatar’s government critically aware that it cannot rely on other countries to secure its food basket), and thus highlighted the need to produce in the country.

The factor that has most hindered the development of productive agricultural and horticultural systems in the past has been the availability of land, with suitable soils. This is a consequence of Qatar’s harsh climate; it is in a hot arid zone characterized by sparse precipitation; high summer temperatures; together with high humidity in the late summer months that makes working outside very difficult; very high solar radiation; strong winds; and limited freshwater availability for irrigation causing dependency on desalinated abstracted groundwater, and/or (more recently) on desalinated sea-water.

Keywords: hot arid climate ; Qatar food security ; agricultural policy

## 1. Importance of the Agricultural Sector in Qatar and Trends

Qatar’s agricultural sector has expanded in recent years due to the country’s increased food demands caused by its rapid population growth and economic development. The number of active and operational farms has increased by 12.8% from 822 in 2010 to 916 in 2017 (see [Table 1](#)), although the number of registered farms in the country shows a small increase of 2.7% during the same period. Thus, farms that were previously registered in the Ministry of Municipality and Environment increased production. Active farms include plant production from both open field and greenhouse cultivation and also include animal farms.

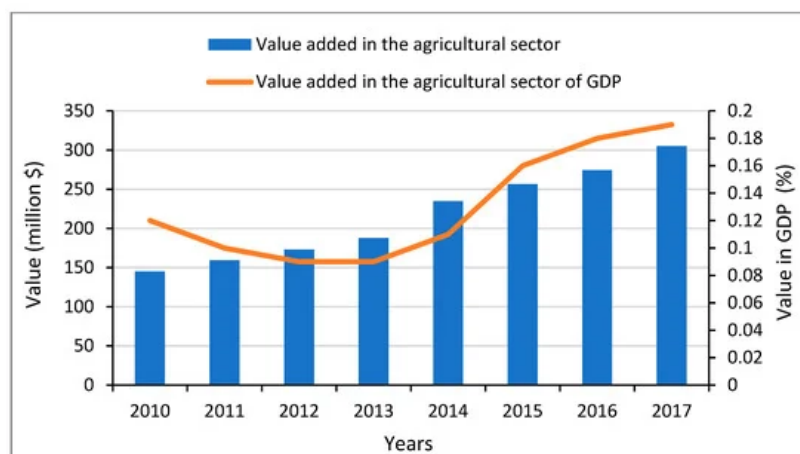
Small-scale farms (<20 ha) are usually oriented towards local market demand, whereas medium (20–100 ha) and large farms (>100 ha) also export produce like dates, cereals, eggs, milk, and milk products <sup>[1]</sup> to neighboring countries and other markets like Europe. The total arable area that could potentially be cultivated in Qatar is 65,000 ha and this area has been constant over the past few years <sup>[1]</sup>. However, the actual cultivated land area, which includes green fodder, date palms, fruits, vegetables, and cereals has increased by approximately 23% from 2010 to 2019 ([Table 1](#)). In 2019, the agricultural and fisheries labor force was composed of 0% of Qatari and 1.4% of non-Qatari males of the total national labor force <sup>[2]</sup>.

**Table 1.** Cultivated land area (ha), number of registered farms, number of active farms and food self-sufficiency index (self-sufficiency = local production/available for consumption %) in Qatar (2010–2019) <sup>[1][3][4]</sup>.

2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
Cultivated land area (ha)	10,506	9020	10,532	12,610	11,663	11,571	11,021	11,590	13,203	12,907
Number of registered farms	1275	1281	1318	1340	1282	1290	1307	1310	-	-
Number of active farms	822	831	833	839	872	910	902	916	-	-
Food self-sufficiency (%)	10.7	10.3	11	15.3	13.5	12.7	10.7	11.5	-	-

Although agriculture is an emerging economic activity in Qatar, contributing to just 0.2% of GDP in 2017, the value-added as a contribution to GDP from the agriculture, forestry, and fisheries sector, increased from 145 million United States Dollars (\$) in 2010 to 305 million \$ in 2017, an increase of 110% over these seven years (see [Figure 1](#)). However, to put this trend in context, in 2017 the country imported 1.3 million tonnes of agricultural products with a value of approximately 1 billion \$ and exported 14,157 tonnes of produce from the sector with a value of 9.5 million \$ as shown in [Figure 2](#). Agricultural produce dominates the share in quantity (tonnes) and consequent, value (\$) among fisheries and forestry products (please note there is no forestry activity in the country). Fisheries accounted for 33,841 tonnes out of 1.3 million

tonnes of total agricultural product imports and 773 tons out of 14,157 tonnes of total exports in 2017. The remaining share is agricultural production which includes plant, meat, dairy products, and eggs [5]. Agricultural product imports increased by 43.9% in tonnes and 50% in value over the 5 years from 2012 to 2017 and follow Qatar's population increasing trend over this period, which was 24% from 2.2 million to 2.7 million [6].



**Figure 1.** Value added (million \$) and value added of GDP (%) of agriculture, forestry and fishery sector for the Qatari economy Qatar (1 QR = 0.27\$) (2010–2017) [4][5].



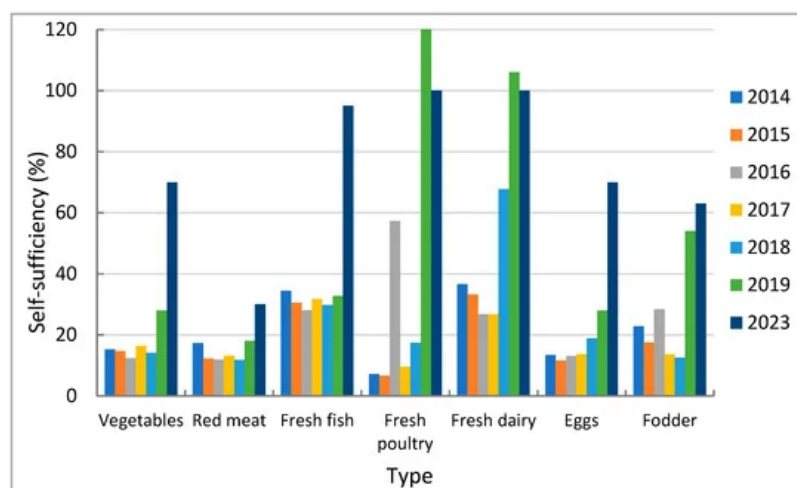
**Figure 2.** Exports and imports amount (tonnes) and exports and imports value (\$) of agricultural products in Qatar (1 QR = 0.27\$) (2012–2017) [5].

Because of Qatar's limited resources and harsh climate, it has traditionally imported more than 90% of food requirements from more than 100 countries, e.g. the Netherlands, Kenya, South Africa, New Zealand, India, etc. [7]. Consequently, Qatar has always been sensitive to the issue of food security and set up a National Food Security Program (QNFSP) in 2008 to reduce the state's reliance on food imports through self-sufficiency and domestic production [8]. Since the 2017 air and sea blockade imposed on Qatar by the same neighboring countries and their allies within the MENA region who supplied the bulk of Qatar's food requirement [7][9], the issue of food security has understandably become an acute national concern.

On 5 June 2017, Saudi Arabia, the United Arab Emirates (UAE), Egypt, and Bahrain, all of which are neighboring countries and allies in the region, cut diplomatic and trade ties with Qatar and imposed a land, sea, and air blockade. The four countries claimed Qatar supported "terrorism", had close ties to Iran, and interfered in the internal affairs of their nations. Before 2017, 27.4% of Qatar's food imports came from Saudi Arabia and the UAE as well as 60% of dairy products. Moreover, 40% of food imports passed through Saudi Arabia [10][11] before entering Qatar.

Although the blockade ended on 4 January 2021, during the blockade period Qatar rapidly developed relationships with many new food product suppliers. However, local food production was also rapidly prioritized, and the percentage of food produced within Qatar went up from 10.7% in 2016 to 11.5% in 2017 the same year as the blockade (Table 1). This was particularly true of perishable products such as vegetables and milk, which has nearly tripled [3][12] since 2017. Self-sufficiency in many food products like meat, dairy products, and vegetables has increased from 15.2% in 2014 to 28% for vegetables in 2019 with a growth of 16 local varieties, while the Ministry of Municipality and Environment (MME) has

targeted ambitious goals for 2023, reaching 70% self-sufficiency in vegetables, as shown at [Figure 3](#). It is noteworthy that Qatar was greater than 100% self-sufficient for fresh dairy products and poultry in 2019 with 106% and 124%, respectively ([Figure 3](#)).



**Figure 3.** Self-sufficiency (self-sufficiency = local production/available for consumption%) of major food groups (vegetables, red meat, fresh fish, fresh poultry, fresh dairy, eggs, fodder) in Qatar (2014-2023) <sup>[1][13][14]</sup>.

Using modern production methods applied to both outdoor and indoor cultivation, local farms are making considerable efforts to improve their agricultural production. This also includes the rapid development of equipment and practices suitable for use in hot arid climates such as:

- greenhouse structures;
- efficient water-conserving irrigation techniques; and
- advanced cooling technologies to increase the shelf life of products.

These efforts have been remarkably successful, achieving high yields and meeting the goals for food security <sup>[13][15]</sup> set by MME. As a result, the greenhouse market in Qatar is growing, reaching a value of \$97.9 million in 2018; the market value is further expected to reach \$216 million by 2024 <sup>[16]</sup>. Greenhouse crop production uses both soil cultivation and hydroponic techniques, as the soilless cultivation systems have been developed as a sustainable solution to food production and food security.

Hydroponic farming is considered more sustainable than traditional farming as it maximizes overall output and minimizes the use of space, soil, water, and other resources. More specifically, hydroponic crop production

- reduces the quantity of agricultural land-take;
- minimizes the use of chemicals needed as fertilizer;
- uses approximately 70% less water, and
- produces a greater yield of fruits and vegetables in a shorter time<sup>[17]</sup>

Also, combining hydroponics with aquaculture has the potential to tackle both Qatar's sustainability issues and contribute to Qatar attaining its food security targets <sup>[18]</sup>.

Several local companies are following organic farming principles as the demand for organic products is increasing with consumers becoming more aware of the benefits of locally grown organic produce and follow a healthier lifestyle. Moreover, some companies like Agrico Agricultural Development, in addition to their current use of sustainable farming methods, are applying circular economy principles. Their aim is to transform business processes into sustainable, closed-loop resource systems <sup>[19]</sup>, e.g. of their waste management by composting and reusing the organic waste generated on their farms.

Qatar's organic product market is growing and organic packaged food and beverage consumption reached approximately \$14.4 million in 2020 [20]. The number of organic farms and farmers' markets is also increasing in Qatar [21] and the key farms are shown in Table 2. Some farms hold international organic certifications like USDA Certification by Agrico Agricultural Development and IFOAM Certification by Al Safwa Farms. Although there are national legislation standards for the organic agricultural sector in Qatar, there is no national certification body to certify the organic farms.

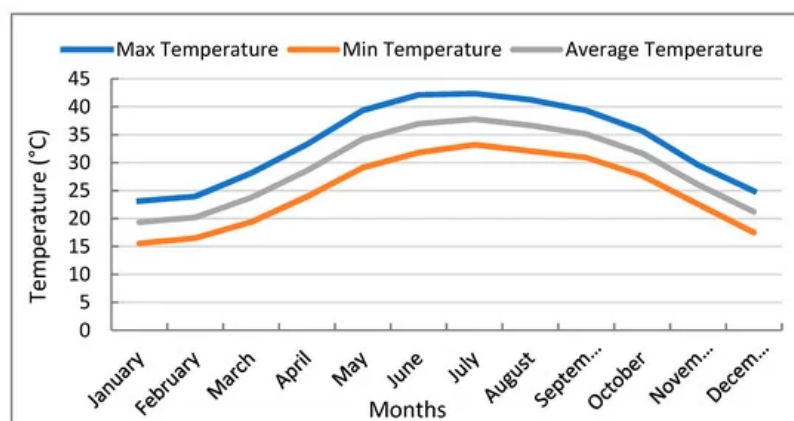
**Table 2.** Key farms following organic farming methods, year of establishment, and location in Qatar [22][23][24][25][26][27][28].

Farm	Year of Establishment	Location
Agrico Agricultural Development	2011	Al-Khor
Al Mustafawi Organic Vegetable Farm	2014	Umm Ammad
Al Safwa Farm	1965 organic since 2012	North of Doha
Al Sulaiteen Industrial Complex (SAIC)	1998	Umm Salal Ali
Global Farm	-	Umm Salal Ali
Jerry Smeih Farm	1930s	North West of Al-Khor
Torba Farm	1900s	Abu Thaylah region

## 2. Challenges

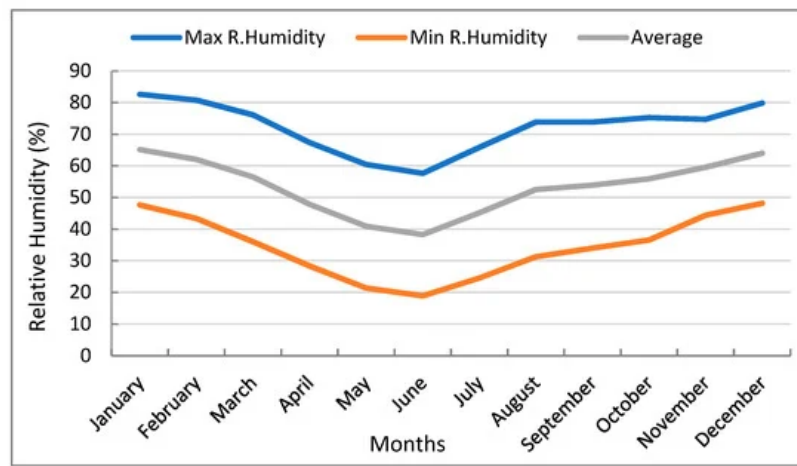
### 2.1. Climate

Qatar has a hot desert climate (BWh) according to Köppen's classification [29]. Hyper-arid countries like Qatar, are characterized by sparse precipitation and high summer temperatures often experienced together with high humidity, high solar radiation, poor soil, and strong winds [5][10]. These environmental conditions present considerable problems for agricultural production and in Qatar agriculture has been traditionally limited to the months between October and April. Although, this period of production can be slightly extended for summer crops like melons, okra, and eggplants. Figure 4 shows the 10-year average temperatures over an annual cycle; starting from March temperatures start to increase, peaking in July, and start to decline in August.



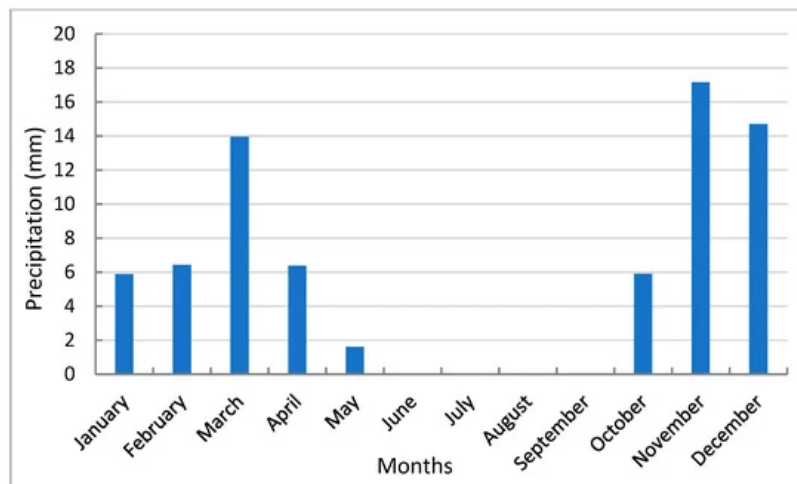
**Figure 4.** Average Temperature in Qatar over a period of 10 years (2009–2019) [30][31][32].

Humidity is very high as well, marking 42.5% average relative humidity around Doha International Airport in 2019 [30], with the period from November to February recording the highest rates, 60–65% on average, as shown in Figure 5 for a 10-year period.

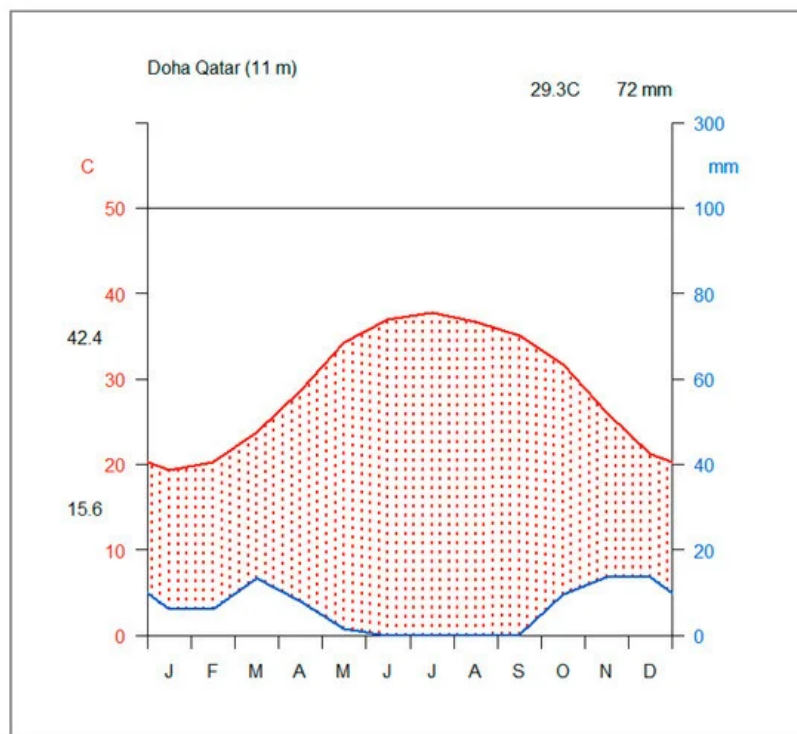


**Figure 5.** Average Relative Humidity in Qatar over a period of 10 years (2009–2019) [30][31][32].

Doha Airport is located 4 km south of Qatar's capital, Doha with a latitude of 25.25 degrees and a longitude of 51.57 degrees, while its elevation is 11 m [33]. The land next to the airport will be developed in the future, as approximately 100 hectares will host an Airport City including a free trade zone, office and business park, hotels, and a retail mall. The small amount of precipitation that does fall occurs often in the winter and spring (specifically from October to May). In 2018, torrential rain caused extensive flooding across Qatar, as it received approximately the annual rainfall amount (84 mm) in one day. This rare phenomenon was not unprecedented as it was recorded previously in 2015 and tends to become more frequent, as sudden, and heavy scattered rain hit the country every year [34]. These events which were observed in November 2015 and October 2018 were extreme. It is noteworthy that the average monthly precipitation for October was 9.6 mm and 13.65 mm for November for the reference period of 2009–2019 (Figure 6). It rarely rains during the summer months. In Qatar, the rainfall takes the form of short (and often heavy) showers that can rapidly fill the wadis (riverbeds that are dry most of the year) and cause floods and is usually less than 100 mm per year. Figure 6 shows the average rainfall precipitation over a period of 10 years. During the month of November, the average precipitation is 17.15 mm, which marks it as the month with the highest rainfall recorded over the past 10 years. Generally, from the month of October up to May (winter and spring), small amounts of precipitation are recorded; however, all year round is considered a dry season in Qatar as there is no rain season (Figure 7).



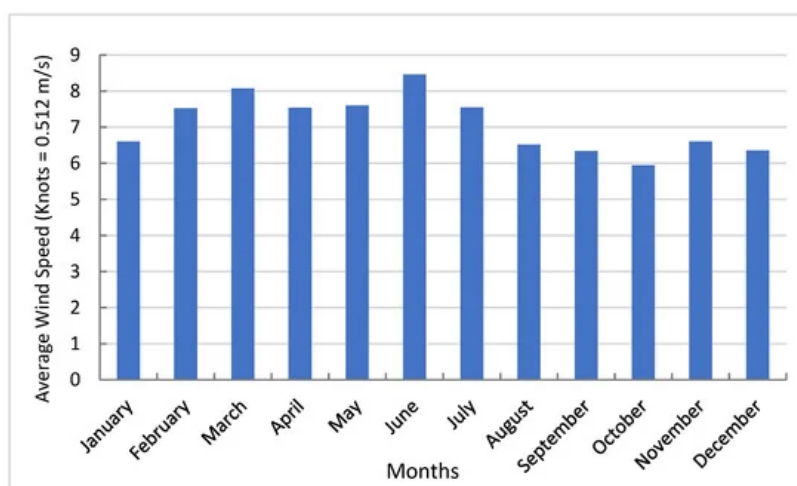
**Figure 6.** Average Rainfall Precipitation in Qatar over a period of 10 years (2009–2019) [31][32][33].



**Figure 7.** Walter and Lieth climate diagram for Doha, Qatar over a period of 10 years (2009–2019). Temperature (°C) refers to average monthly mean temperature (red solid line) and precipitation (mm) refers to average monthly precipitation (blue solid line) [30][31][32][33][35].

While the country's precipitation is low, the evapotranspiration is very high, estimated to 39 mm year<sup>-1</sup> in 2014, meaning significant amounts of water are lost through the crops and the soil surface, making optimal water management more crucial [36].

During all seasons in Qatar, the wind is always present. Figure 8 shows a 10-year average monthly wind speed over an annual cycle; the minimum wind speed is 6 km per hour and occurs in October. Strong winds and sandstorms occur often and contribute to the country's surface high evaporation rates, negatively impacting plant growth and thus food production. The effects of climate change must also be considered, as they are evident now [37][38] and will increasingly affect agricultural production and thus food security. Several studies predict that in the Gulf region, annual temperature and rainfall patterns will change over the following decades [10][39][40][41]. Qatar's average annual temperature has already risen by 0.3 °C over the past 40 years and this average is expected to increase by 1.5–3 °C by 2050 and by 2.3–5.9 °C by 2100 [42][43]. The Middle East and North Africa (MENA) region is considered a climate change hot spot for predicted extreme events including heat and drought events [44]. For example, for a global mean increase of 2 °C, MENA is predicted to rise by 3 °C, and for a 4 °C global mean projections, MENA is predicted to rise by 8 °C. Although there is predicted to be no significant change in Qatar's rainfall pattern in the medium term (2040–2069), a significant change is predicted at the end of the century (2080–2099) with a notable increase in annual rainfall [45][46]. Thus, increasingly erratic, and extreme precipitation patterns together with increasing extreme summer temperatures are predicted. These effects will likely shorten the growing season together with increasing the incidence of crop failure, reducing the production of both crop and livestock agriculture.



## **2.2. Land Availability for Agriculture in Qatar**

Qatar is a small country with a surface area of approximately 11,628 km<sup>2</sup> including a set of small islands <sup>[30]</sup>. It is about the same size as Rhode Island in the United States, or Malta and Luxemburg in Europe, or Hong Kong and Macau in Asia. Due to the relative scarcity of land available for agriculture, efficiently utilizing available land is a critical issue for ensuring national food security. There are however several competing interests and other limitations regarding land availability that require examination and further restrict the land available for traditional soil-based agriculture, which is assessed in this section.

### **2.2.1. Soil**

The State of Qatar lies on arid soil, typically composed of a coarse texture, shallow soil, low water retention, and slow soil formation, and is therefore considered poor agricultural soil. The Atlas of Soils for the State of Qatar published by the Ministry of Municipal Affairs and Agriculture in 2005 <sup>[47]</sup> estimates that in Qatar, about 68,716 ha are suitable for arable cultivation and of this area a total of 23,903 hectares is already being used by farmers, leaving 44,813 hectares to potential farmland.

The most fertile and arable soils in the country are the locally known Rodah (depression) which are developed by limestone young colluvial deposits and they only account for 2.44% (27,620 ha) of the total country area. The Rodah soils are scattered in over 850 depressions along in Qatar with a size of a few to 60 ha and that is a limiting factor for large-scale soil farming <sup>[48]</sup>. Traditionally, agriculture has been most intensively practiced in the northern regions of Qatar where the soil and rain conditions are more conducive to crop production. Soils in Qatar's north natural depression tend to contain higher clay than that of soils located in central and southern Qatar, while soils with the highest sand content are in depressions in the south of the country <sup>[49]</sup>. Soils with larger clay content tend to be relatively more fertile as the clay improves the soils' organic content and structure <sup>[50]</sup>. That is also a reason why most of the farms in Qatar are located in the northern part of the country <sup>[51]</sup>.

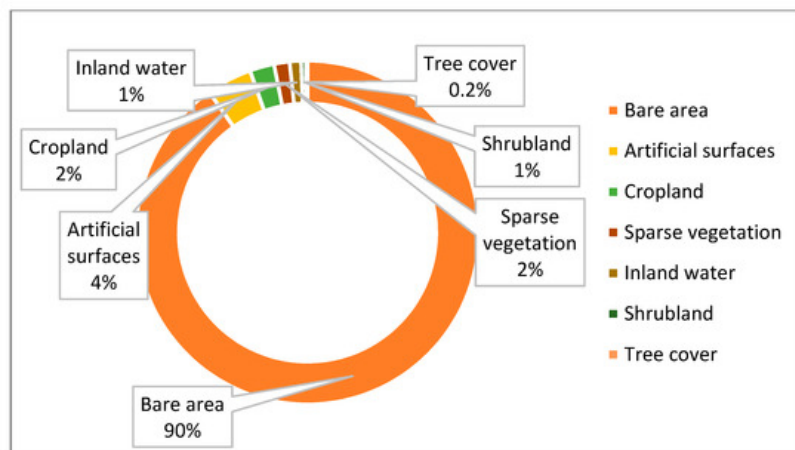
Likewise, these nutrient-rich depressions are also areas that support much of the native flora and fauna. Unfortunately, traditional irrigation (abstracted groundwater) has resulted in the salinization of soils in this area. Moreover, habitat loss due to increased agricultural production could also adversely affect already endangered native species that perform crucial ecosystem services. In recent years, the State of Qatar has made advances in protecting key habitats and species, recognizing sustainable development as a key pillar that underpins all the nation's development goals. However, the implication of Qatar's food security appears to compromise these important policy developments.

### **2.2.2. Land Use**

Land use in Qatar includes residential, commercial, and industrial, education and health, farming, sports, tourism and religion, transport and utilities, government and special use, and some areas are vacant and/or under construction <sup>[52]</sup>. The areas close to Doha, such as the adjoining Al Rayyan Municipality, Al Wakra, and Umm Slal have already been developed with multiple land uses leaving surrounding areas sparsely used in Qatar in 2015 <sup>[53]</sup>. More specifically, the areas including farms, nursery plant farms, poultry, and animal farms (camel, sheep, goats, cows) were about 25% out of the total land so far underuse in all Qatar in 2015 <sup>[51]</sup>.

According to the OECD's report on the land cover for 2018, Qatar had approximately 0.2% tree cover, 0.4% shrubland, 0.5% sparse vegetation, 2.4% cropland, 4.3% artificial surfaces, 90.3% bare area and 1.1% inland water of the total country area, as shown in [Figure 9](#) <sup>[54]</sup>. The bare area (90%) includes the land use categories mentioned above, including the urban area, which was recorded as 421.17 km<sup>2</sup> total in 2013 in the capital city of Doha <sup>[55]</sup>.





**Figure 9.** Land cover for Qatar in 2018 <sup>[54]</sup>.

Qatar is a highly urbanized country with 99.1% of its population being urban in 2018 <sup>[6]</sup> and the majority living in the capital city of Doha and the surrounding suburbs. Urbanization in Doha has been increasing in recent years, with statistics indicating open spaces and the surroundings to have reduced from 76.8% in 1997 to 25.3% in 2010 <sup>[56]</sup>. This space reduction is attributed to the growing demand for residential, commercial, and recreational purposes. At the same time, there was an increase of 288.7% for built-up and a greater increase of 426.4% for recreational areas, respectively for the same period, indicating a positive planning attitude towards improving living standards in Doha and the surrounding areas. Within this context, urban agriculture could be incorporated in the urban planning strategies, as it provides a viable alternative for ensuring food security in Qatar while reducing pressure on ecosystems and the financial resources necessary to support agriculture in the hyper-arid country. The use of the urban environment for agriculture provides multiple benefits besides increasing food security. These include improving aesthetics, shading in the urban environment and also supporting mental health while increasing leisure activities, connection with nature and promotion of outdoor physical activity <sup>[57][58]</sup>. In Qatar, this could take the form of hydroponic or aquaponics gardens <sup>[59]</sup> urban orchards, edible landscaping and rooftop gardens or community gardens <sup>[60]</sup>.

### 2.2.3. Habitat Loss

Qatar is a small country and land is scarce, thus any expansion of land-take for agriculture effectively results in habitat loss of the many native plant and animal species. Moreover, Qatar's terrestrial and coastal ecology is unique with a significant abundance of life-forms that have adapted to the harsh climate and although it is currently relatively undervalued, it should be preserved especially for future generations <sup>[61]</sup>. Many factors already adversely affect Qatar's native flora and fauna, like climate change, increasing land-take for urban development, and pollution, which together with the additional effects from a greatly expanded agriculture sector would produce considerable accumulative stress. Therefore, extensive agriculture practiced in Qatar's yet undeveloped hinterland would deplete this unique habitat's biodiversity and ecosystem services, endangering native flora and fauna. According to IUCN and the MME, there were 193 vulnerable and 20 endangered terrestrial and marine recorded species in Qatar in 2017 <sup>[62]</sup>.

The unique sabkha environment, so dominant in Qatar supports a yet unexplored repository of unique microbial communities. Recent studies also suggest that sand dunes in Qatar support rich microbial life with an abundance of genes encoding sporulation and dormancy making the microbiome well-adapted to the exceptionally hyper-arid Qatari desert <sup>[63]</sup>. This wealth of biological and genetic diversity could and should be explored for a variety of bioactive compounds that could be potentially exploited for important innovative environmental engineering solutions

Furthermore, Qatar is obligated to the international community as signatories of several international treaties, covenants, environmental agreements, and conventions, such as:

- the Convention on Biological Biodiversity;
- the UN Convention to Combat Desertification; and
- the International Plant Protection Convention.

All these agreements obligate the country to protect its ecology even as it endeavors to advance its economy. Such international conventions emphasize protection of the unique biological diversity of Qatar which can only be maintained by promoting the habitat protections of these sensitive ecosystems. The continued development of agriculture in the State of Qatar may put other natural resources at risk, particularly if it is based on traditional, land-based agricultural systems.



It is a dilemma with food security and ecological conservation and restoration seemingly pushing in mutually exclusive directions. However, one possible solution to the need to provide the nation with food security but conserve and restore its unique ecology is to greatly expand urban food production. This is potentially a very sustainable alternative that completely avoids habitat loss and resultant ecological damage, that supports ecosystem services, promotes sustainable development, and ensures an environment for long-term habitation and tourism development.

#### 2.2.4. Tourism Growth

The natural environment supports significant economic activity in the country. Tourism continues to develop in the State of Qatar, accounting for more than 5% of GDP [64]. From the year 2012–2016, there was a 44% growth in tourism as a segment of GDP, a 22% increase in tourism jobs, and a 45% increase in tourism investment [65]. Given the 2002 World Cup, Qatar may expect an even greater global tourism presence in the coming years [65]. In fact, tourism growth was greater than overall economic growth, one of five countries that saw such substantial growth in tourism [66]. The unique habitats and extreme desert environments with coastal shores are not only of biological value but also drive economic development, a diverse economy, and hold a substantial economic value. The current drive for locally-based agriculture to improve food security needs not to challenge habitat and species protections or risk natural environments that support tourism.

#### 2.3. Water Availability

The agricultural sector in Qatar utilizes 91% of all renewable freshwater resources in the state [40]. Aquifers supply 36% of the country's water production, mostly in agriculture. Rainfall re-charges aquifers with an estimated annual amount of 80 mm (Figure 6). Although the water resources in the country are limited, in the period 2006–2016 the total water quantity (net of loss) increased from 447.27 to 890.24 million m<sup>3</sup> per year. Qatar is highly dependent on seawater desalination for water production as desalination is the main source of total water production (61%), followed by groundwater abstraction (25%) in 2016. The greatest proportion of water uses, out of total produced water, were allocated for agricultural and domestic purposes, compared to the industry, commercial, and government sectors. The agricultural sector consumes the largest quantities of freshwater compared to the other sectors, coming up to 296.3 million m<sup>3</sup> total water used in 2016, as shown in Table 3. The main source of water in agriculture is the abstracted groundwater, followed by reused TSE. The abstracted groundwater must be desalinated before use in the hydroponic cultivation method, as it highly saline, which could negatively impact plant growth. The reasons for the high salinity concentrations of the groundwater are the stress caused by agriculture itself, urban development, and climate change [67]. The use of treated sewage effluent for agriculture and landscape irrigation purposes (5%), started in 2004, as shown in Figure 10, and increased to 30% in 2017 [68].

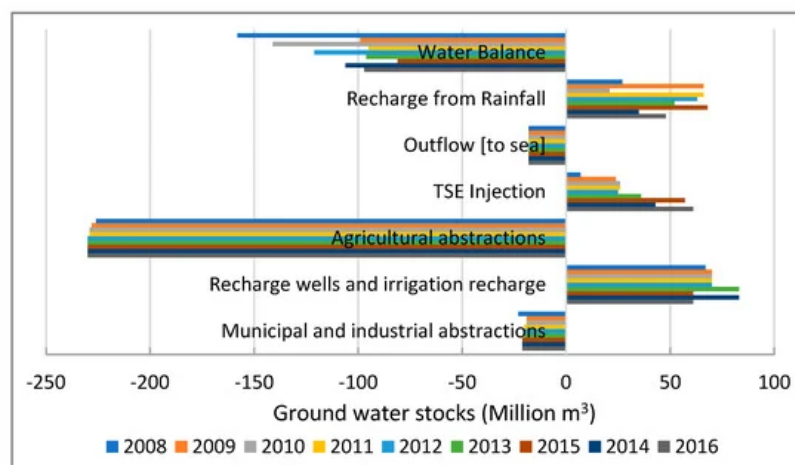


Figure 10. Qatar Water Balance (2008–2016) [69].

Table 3. Abstracted groundwater and Treated Sewage Effluent (TSE) (million m<sup>3</sup>) used in the agricultural sector (2010–2016) in Qatar [68].

Year	Agricultural Water Sources		
	Abstracted Groundwater (Million m <sup>3</sup> )	TSE (Million m <sup>3</sup> )	Total (Million m <sup>3</sup> )
2010	228.88	32.28	261.16
2011	229.47	41.98	271.45

Year	Agricultural Water Sources		
	Abstracted Groundwater (Million m <sup>3</sup> )	TSE (Million m <sup>3</sup> )	Total (Million m <sup>3</sup> )
2012	230.05	58.71	288.76
2013	230.55	55.23	285.23
2014	230.64	64.92	294.92
2015	230	61.7	291.7
2016	230	66.29	296.29

The use of TSE in irrigation is cheaper if compared to desalination [70]. It has been reported that reuse wastewater is priced at \$0.28/m<sup>3</sup>, which is only half of the desalinated water cost [71]. Another report claimed that savings close to three folds can be realized when highly treated wastewater is utilized instead of desalinated water [72]. The energy required to desalinate water is also much higher than treating wastewater [73]. Researchers have reported that the energy required to treat wastewater is in the region of 0.8–1.2 kWh/m<sup>3</sup>, while the energy required to desalinate seawater could be around 4 kWh/m<sup>3</sup> [74].

TSE use is a sustainable solution for agricultural irrigation as the aquifers are being depleted, the groundwater quality and quantity has been deteriorating because of over-pumping and seawater intrusion and additionally, the desalination methods are emitting high CO<sub>2e</sub> gases [75]. However, the use of TSE in agriculture is perceived negatively by farmers, as most of them view wastewater as unclean and unsafe [76]. Despite considerable investments in producing high-quality TSE using advanced treatment technologies in Qatar, there is hardly any demand due to various religious, social, and cultural factors that limit the use of treated wastewater in the country [77].

From the agronomic perspective, sustainable management practices to achieve sustainable groundwater use in Qatar include using water-efficient irrigation methods, replacing water-intensive crops with water-efficient crops, and enhancing awareness of water resources to the farmers. Moreover, the government could develop and apply certain water-use tariff structures to put a limit on irrational water use, and finally, enhance the rainfall infiltration to the aquifers [67].

Given current climate change scenarios that portend increasing temperatures and water scarcity, Qatar is uniquely placed to develop innovative technologies for a global agricultural market. As of December 2020, water is now being traded as a commodity on the New York Stock Exchange, stressing the increasing scarcity and value of these most important resources, and could make traditional, large-scale irrigation practices economically unfeasible [69]. Continued development of indoor and outdoor agriculture that is not land-based, but hydroponic-based, and suitable for incorporation into the urban environment, can better drive the development of agriculture in Qatar without risking recent developments in enhancing the natural environment.

## 2.4. Supply Chain

Qatar is the second-largest producer of ammonia, urea, and urea-formaldehyde among the Gulf countries. The fertilizer industry is a rapid-growing sector with a 9.4% average annual growth rate [78]. However, there are challenges in the supply chain for farmers and agricultural companies, as Qatar relies on imports for the necessary agricultural inputs like propagation material, plant protection, and some plant nutrition products.

Reliance on external supply comes with the risk of supply shocks. A supply shock is a phenomenon where the external supply is cut off abruptly due to adverse events occurring in the supply countries. Since the nation has no control of the markets of its suppliers, it is impossible to predict when such disruption is likely to occur. In many cases, Qatar's agricultural sector is hit by input supply shocks which are aggravated by the country's over-reliance on external supply.

Being a relatively small country compared to its trade partners, Qatar has low bargaining power when negotiating agreements for the supply of agricultural inputs. This causes over-pricing by its trade partners, which affects the final price of these inputs once they are in the country. Private farmers purchasing such supplies from the government after importation must bear the burden of these extra costs incurred during importation. Consequently, investment in the agricultural sector has become too expensive, hence deterring potential private investors.

Finally, the instability created to Qatar's external supply chain by the 2017 blockade by neighboring nations shocked the country. It is essential to understand that Qatar's main agricultural trade partners were neighboring nations, especially those in the UAE. The blockade reduced the country's import options significantly and created shortages in the supply of

agricultural inputs from nations such as Saudi Arabia, Egypt, the UAE, and Bahrain. All these factors greatly affected the nation's agricultural supply chain making it unstable, unpredictable, and unreliable. If not mitigated by both public and private investment and initiatives, the sector's growth could be irrevocably impaired.

### **3. Opportunities**

Qatar's emerging agriculture sector has the potential to significantly improve national food security. Several opportunities for the development of this sector (some very sustainable) include

- the development of export products and markets;
- the use of greenhouse farming with hydroponics and aquaponics;
- the use of TSE for irrigation;
- the development and practice of permaculture techniques, and
- the use of saline-resistant crops.

#### **3.1. Exports**

The winter season in Qatar is very mild, with abundant sunshine resulting in a peak growing season that produces high-quality agricultural products. Thus, Qatar's winter climatic conditions offer an opportunity not only to satisfy local demand but also for exporting fresh high-quality agricultural products to countries in the Northern Hemisphere where severe winter conditions could prevent this. According to the Planning and Statistics Authority, in 2019 Qatar exported and re-exported products like dates, cereals, eggs, milk, and milk products as well as fish <sup>[1]</sup>. However, exports are still low compare to the imported products, as shown in [Figure 2](#), with imports reaching the amount of 1,320,720 tonnes, whereas exports were only 14.157 tonnes in 2017, a ratio of 1 to 93 <sup>[5]</sup>.

#### **3.2. Greenhouse Production**

The traditional limitations to agriculture caused by the harsh summer climate and the limited extent of fertile soil could be rendered irrelevant with the adoption of soilless cultivation techniques, (e.g., cultivation in growth bags using soil substitutes such as cocopeat, rockwool, or perlite) and advanced greenhouse technologies. Greenhouse farming with soilless cultivation techniques such as hydroponics or aquaponics, could potentially greatly increase food production in Qatar. This would be strategically preferable to utilize non-productive or marginal land unsuitable for soil cultivation <sup>[79]</sup>.

It is imperative that the greenhouse design and technical equipment used should be suitable for the Qatari climate as standard methods and technologies used in other regions like Europe and the USA cannot be transferred to the Middle East due to the different climate control strategies and input availability <sup>[80]</sup>. According to researchers, to achieve an optimal thermal performance of greenhouses operating in hot and arid climates, the greenhouse should be oriented East to West and have an aspect ratio of 1:3, which will allow a lower temperature distribution along 80% of its length which leads to efficient cooling <sup>[81]</sup>.

Greenhouse cultivation can ensure that crop production extends over the whole year and requires fewer inputs than open-field production. Moreover, agricultural business' diversification is increased through the provision of a greater variety of cultivated crops <sup>[17]</sup>. The advances of smart greenhouse technology (e.g., water-saving irrigation techniques and optimal resource management of many inputs like pest control and nutriment) enable crop production with minimal or greatly reduced inputs of energy, water, and pesticides while maximizing crop yield <sup>[82]</sup>. Therefore, technological advancements in smart greenhouses enhancing productivity, water-saving irrigation techniques, and optimal resource management reducing the cost of production, offer an additional opportunity to expand domestic food production.

#### **3.3. Use of TSE for Irrigation**

The use of Treated Sewage Effluent (TSE) is an alternative water resource for irrigation in agriculture and landscaping, offering the opportunity for Qatar to produce food, without depleting the country's natural groundwater resources. Replacing desalinated potable water with TSE for irrigation also reduces cost, as TSE is cheaper than desalinated water and requires less energy to produce <sup>[70][73]</sup>. However, at present, traditional cultural beliefs and practices in the country have greatly restricted the use of TSE apart from irrigation for planting in urban landscaping and amenity areas. Even in parks and public green spaces, potable water is still predominantly used for irrigation.

It is unsustainable to rely on exclusively using potable water for Qatar's growing agriculture sector. Fortunately, Sharia Law permits the use of TSE if it is safe and even "views wastewater reuse as part of the optimization of existing resources and as being supplementary; hence, misusing it is considered a disobedience to God" [83]. A national strategic consultation that includes policymakers, agriculturists, scientists, and the public should review scientific data on the quality of treated wastewater and thus, reevaluate existing customs and their limitations.

Other sustainable water strategies use Qatari native plants as a method of phytoremediation of wastewater [84] and rainwater harvest.

### 3.4. Halophytes and Saline Crops

Agriculture in Qatar may also benefit from the cultivation and the development of non-traditional crops, such as halophytes and saline crops, which do not require fresh water and are tolerant to high salinity in water and soil. These crops have great potential to increase agricultural development and habitat restoration in areas affected by salinity [85]. Several researchers proposed sustainable halophyte farms using seawater for irrigation [86][87] or even fish waste that is nutrient-rich [88]. These would not only complement the hyper-saline ecosystem but would be economically valuable. Halophyte crop yields can equal yields of conventional crops grown using potable water, such as the forage crop alfalfa [88][89].

The critical factors in sustainable halophyte production are the choice of the appropriate halophyte species which should be economically and ecologically important as well as the adoption of optimal water management for irrigation [87]. Halophytes' salinity tolerance ranges from high to medium which subsequently allows seawater and/or brackish water to be used for agricultural irrigation while different species have diverse usages like food, fodder, fuels, medicines, building materials, fibers, and other utilitarian objects or even for soil and water remediation and for sequestering CO<sub>2</sub> [89][90]. Moreover, some halophytes can desalinate and fertilize the soils creating micro-habitats allowing the growth of other non-saline tolerant annual plants [88]. Researchers highlight the big potential for sustainable productivity of indigenous halophytic plant species such as the *Avicennia marina* and the *Dunaliella salina* on the landforms of saline sabkha along the southern and western Arabian Gulf [91].

Halophyte farms can also become a new biofuel source apart from food and feed sources, which can lead to new industries generating new jobs and income together with rational use of natural resources applicable for farms and consequently leading to sustainable living. Biofuel production from halophytes does not compete with traditional food crops for land and water, as it utilizes marginal lands and water sources while diversifying the use of halophytes. Moreover, the halophyte biofuel production system can offer multiple products like animal feed from the seed meal or ethanol production from straw [92].

According to a recent proposal by researchers an innovative, halophyte farm based on the land and the seacoast can integrate mangroves and seagrasses in its production units offering extra ecosystem benefits such as atmospheric carbon sequestration and reduced land-based marine pollution [86]. Mangroves, which can be found in large populations in Al Khor west of Qatar, can also be used for biofuel production, fodder, and other economically important products thus creating additional jobs and profit [93].

Qatar has also the opportunity to expand halophyte research and development by creating an innovative "World Halophyte Garden" providing genetic material to the researchers and the private sector for commercial use. As stated by researchers, the Arab Gulf States provide an ideal location for the creation of such a genetic pool due to their plentiful saline ecosystems, the wide number of undeveloped native halophyte species, and their limited freshwater availability [94].

Other researchers have investigated creating a 'saline agriculture' through the development of crops adapted to drought and salt using genetic engineering and traditional breeding tools [95]. Researchers in Florida found that inoculating snap peas with arbuscular mycorrhizal fungi increased yields at higher salinity levels [96], while researchers in Egypt found that inoculating tomato plants with the root endophytic fungus *Piriformospora indica* increased growth and yield under salt stress conditions [97].

### 3.5. Urban Farming

Urbanization in Qatar has been rapid, especially in Doha, where urban development approximately increased fourfold between 1987 to 2013 [55]. The use of the urban environment for agriculture provides multiple benefits besides increasing food security through increasing food accessibility and food quality [98]. Researchers [98] underline numerous benefits that it provides to economic, social, and environmental development. Some of the social benefits are the creation of self-sufficient (or increasing self-sufficiency) communities with access to fresher, healthier, local food.

Urban lifestyle is improved in terms of leisure activities, places of relaxation, connection with nature, social interactions, and promotion of outdoor physical activity <sup>[58]</sup>. In addition, local economic development is enhanced by creating new jobs and increasing household income. Furthermore, urban agriculture provides urban residents with ecosystem services, such as water and air purification protection of urban biodiversity, reduction of food miles, and cities' carbon footprint by recycling urban food waste <sup>[99]</sup>. Urban farming is currently also considered one of the solutions to climate change adaptation, as it can play a notable role in improving the urban climate and the heat island effect <sup>[100]</sup>. In Qatar, urban agriculture could take the form of hydroponic or aquaponics gardens <sup>[59]</sup>, urban orchards, edible landscaping, and rooftop gardens or community gardens <sup>[60]</sup>. The introduction of permaculture practices could combine biodiversity conservation with food security. A detailed proposal on transforming Qatar University into a productive permaculture campus in the desert provides great inspiration <sup>[101]</sup>. The concept of food forests has been successfully achieved in harsh climates such as in the desert of Wadi Rum (Jordan) and near the Dead Sea by Geoff Lawton, whereby water resources are conserved, waste is composted, and the food forest becomes self-regenerative.

### **3.6. Composting**

Compost can be used as a soil amendment in open field cultivation, as it improves soil physic-chemical properties and microbial biomass while enhancing the growth of plants even in saline soils <sup>[102]</sup>. It can also be used as a soil substitute in grow bags used in hydroponic cultivation. Food and green waste can be used for composting with multiple benefits. Food waste is the main waste component dumped at the landfill sites, where it converts into methane, carbon dioxide, and other greenhouse gasses by anaerobic digestion, contributing significantly to global warming. Additionally, when food waste is placed in landfills, all the energy stored is lost like the not collected methane, thus a potential energy source is lost. These are valuable bioenergy sources that could have been utilized either for power production or converted into value-added products <sup>[103]</sup>.

Qatar produces a considerable amount of food and green waste, and domestic waste production amounted to 1.2 kg per capita per day in 2015 <sup>[104]</sup>. Therefore, Qatar could and should use this valuable but currently neglected waste resource, turning it into compost for use for urban landscape and in the agricultural sector. This correspondingly reduces the amount of waste going to landfill as well as improving Qatar's environmental footprint, while satisfying high local demand for compost for gardening, and local horticultural business.

### **3.7. Organic Home Garden Initiatives**

While studies on home food production have not been conducted in Qatar, a study in Oman showed that home occupants were not encouraged due to harsh weather, excessive water bills, and the absence of horticultural knowledge as well as the prevalence of extensive hard pavements within most urban plots <sup>[57]</sup>. However, it is increasingly considered important to spread awareness and knowledge of home food production, its potential, and practical advice to Qatar's general population. Demonstration projects are therefore considered highly important in this respect. For example, a community initiative named "Gharsa" is working to educate women about organic home gardening. Correspondence with the founder Mariam Al Dosari on 17 January 2021, advised that "Gharsa" provides educational courses, high-quality seeds with good disease resistance, organic certified fertilizers and pesticides, and gardening tools. They have a strong social media presence and currently have over 100 actively participating home food gardens.

### **3.8. Government Support**

The Qatari government through the Ministry of Municipality and Environment has launched several initiatives to help and further encourage the development of the agricultural sector <sup>[13]</sup>. For instance, there has been a concerted effort to supply greenhouse owners all over the country with low-cost technology needed to increase production, reducing the capital investment required for start-up agricultural businesses but increases production efficiency thereby raising profits. However, these initiatives are still at an early stage and their net effect has yet to be measured. Nonetheless, the government has more opportunities for boosting growth especially by partnering with private agricultural tech companies. Such partnering should ensure that there is sufficient infrastructure development for the optimal operation of the farms, as well as ensuring that there is the intellectual capacity for training a specialized labor force to support the increasing technological sophistication of agriculture as in the case of hydroponic cultivation techniques. The idea is to ensure that the small space available for farming in Qatar is used intensively, productively, and profitably. The year 2019 saw the Qatar government offer project lands to private investors. These lands were offered at an extremely subsidized fee to encourage agricultural business investment. This again is a big opportunity for increasing agricultural production as agricultural space is increasingly becoming expensive.

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