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Powering Qatar's agricultural growth: Examining the link between electricity prices and development

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This study analyzes the impact of electricity prices on the development of the agriculture sector in Qatar, using annual data from 2003 to 2019. Its findings contribute to addressing a gap in current literature and offer valuable perspectives on the sector's obstacles and potential prospects. An extended Cobb-Douglas production function was employed as a theoretical framework, in conjunction with several econometric techniques, including Fully Modified Least Squares, Dynamic Ordinary Least Square, Canonical Cointegration Regression, and Gets, to analyze the persistent relationship between electricity prices, and the gross value added of the agriculture sector. Our research found that electricity prices exert a positive effect on agricultural development. Although the magnitude of the impact was small over the long term, it remained statistically significant. Specifically, the elasticity of the electricity prices ranged between 0.097–0.11, whereas the elasticity of another examined variable, labor productivity, was also positive and ranged between 0.67–0.74. These empirical findings support the ongoing government policy to reform energy prices, increase vegetable production using modernized hydroponic systems, and reduce groundwater use for irrigation, among other policies to sustain food production. Clearly, if these policy options are managed properly, the agriculture sector can play a significant role in diversifying the economy, maintaining environmental conditions and improving food sustainability.

KEYWORDS

agriculture, Qatar, productivity, econometrics, subsidy, electricity, nexus

Introduction

Qatar's arid climate, marked by high temperatures and low precipitation, poses a formidable obstacle to the growth of its agriculture sector, which requires considerable support to thrive. In 2019, the sector consumed 316.1 million m3 of water, a 27% surge from 2009 (PSA, 2019), and demand is expected to climb further as population growth and economic development intensify competition among users and sectors (PSA, 2019). Despite these challenges, developing the sector remains crucial for compelling reasons (Appendix A).

The agriculture sector, like any other sector of the economy, relies on several factors to survive, including, labor, land, capital stock, favorable climatic conditions, and technology choices, among others. However, the harsh climatic conditions (acute lack of rain/surface water, elevated temperature, desert climate) of Qatar have made it difficult to develop the sector without government support. The Qatari government has been providing several direct and indirect support to boost the development of the agriculture sector, along with consultation and marketing incentives for farmers including, subsidized rates for both water and electricity, subsidized rates for agricultural input components, such as water, energy, seeds, pesticides, fertilizers, equipment, technologies, and access to markets and retailers. Most subsidies are provided either explicitly of implicitly through low prices. Shannak, (2022) mentions that government support and incentives have a vital role in shaping the agriculture sector and determining its structure and existence.

In the arid climatic region, electricity subsidies are crucial support as electricity in modern agriculture is a key component at different production stages. Electricity is consumed to pull out the water from the groundwater well or to desalinate the water and later distribute it in the field. It is also needed for the manufacture of agricultural inputs, such as fertilizers and pesticides as well as to package and transport crops. Electricity subsidies in the Qatari's agriculture sector are expressed in modest electricity prices. For instance, between 2002 and 2015, the electricity price was on average 0.07 QAR/KWH, but for instance, 0.19 QAR/KWH in the United States, was taken as a benchmark price. This difference between international benchmark price and local electricity price indicates dedicated support for the Qatari agriculture sector development.

However, these high electricity subsidies might lead to inefficient use of the resource (see (Shannak, 2022), IMF, 2004, 2013, *inter alia*). Furthermore, some scholars conclude in their studies that electricity subsidies can have several negative effects on the economy and society (WB, 2001; Birner et al., 2007; Strand, 2010; Badiani, 2012, (Shannak, 2022). There are various negative effects, including: 1). Costly: Subsidizing electricity can be expensive, especially in developing countries where government resources are limited. This can divert funds away from other important social programs, such as healthcare and education. 2) Unreliable and unpredictable: Subsidized electricity prices can encourage overconsumption and discourage conservation, leading to power shortages and blackouts. This can make electricity supply unreliable and unpredictable, which can harm businesses and individuals who rely on it. 3) Environmental degradation: Subsidized electricity prices can encourage the use of fossil fuels, leading to increased greenhouse gas emissions and environmental degradation. 4) Deprived service: In some cases, subsidies can lead to unequal access to electricity, with the rich benefiting more than the poor. This can further widen income disparities and perpetuate poverty. Overall, electricity subsidies can have unintended consequences and may not be an effective or sustainable way of promoting access to electricity. Instead, alternative approaches, such as targeted subsidies, increased investment in renewable energy, and energy efficiency programs, may be more effective in achieving this goal while minimizing the negative impacts.

Accordingly, the goal of this study is to examine the complex and multi-faceted role of electricity prices in the development of the Qatari agriculture sector. This is an addition to the role of other traditional driver, such as labor productivity in shaping agriculture development. The study applied cointegration modeling to the Qatari data in an enriched production function framework for the period 2003–2019.

To the authors' knowledge, this is the first study to explore the role of electricity prices for the Qatar agriculture sector by numerically estimating its effects in the long run. The goal is to establish modeling framework to understand the direct and indirect effects of electricity prices on the development of the agriculture sector. This modelling framework contributes to developing sustainable Water Energy Food (WEF) strategies for Qatar in respect of agriculture sector policy guidelines synthesis and related Sustainable Development Goals, through understanding the relation between electricity prices and agricultural output per capital, which is directly driven by the development of agriculture sector. Additionally, the numerical model developed in the study could be a helpful key in prioritizing the critical parameters that may play a big role in WEF supply and demand management, and how to be used as an essential policy in the agricultural sector. It also supports Qatari policymakers with a smooth transition to higher electricity prices, to ensure that the agriculture sector can continue to grow and thrive, while also addressing the broader energy and environmental challenges facing the country. The findings of this study could assess policymakers in facilitating this transition by developing guidelines and recommendations that support the sector in absorbing the changes related to higher electricity prices.

Policymakers are likely to find the results of this study interesting for multiple reasons. First, numerical assessments of electricity pricing, and labor productivity are essentials to the development of the agriculture sector. Policymakers cannot develop effective policies and measures to support the development of the agriculture sector without having accurate and up-to-date information on the numerical effects of each driver. Having this information can help policymakers to: 1) Identify the most critical drivers of agriculture development, and prioritize their efforts accordingly. 2) Assess the impact of changes in the drivers, such as changes in electricity prices, on the agriculture sector, and develop strategies to mitigate any negative effects. 3) Evaluate the effectiveness of existing policies and measures, and make adjustments as needed to promote sustainable and equitable agriculture development. 4) Develop targeted and effective policies and measures to support the agriculture sector, based on a comprehensive understanding of the drivers and their interplay.

Second, strategic planning requires reasonable projection and simulation that only can be prepared using numerical measures and long run models. Third, one of the strategic objectives of QV2030 is to diversify the national economy. This in turn, makes it imperative to understand the numerical contribution of the agriculture sector in the development of the entire national economy.

In summary, this study analyzes the impact of electricity prices on the development of the agriculture sector in Qatar, it helps to fill a gap in the literature and provides valuable insights into the challenges and opportunities facing the sector. This type of research can help policymakers and stakeholders to make informed decisions and develop effective strategies to support the growth and development of the agriculture sector in Qatar. The findings of this study can also inform the development of similar studies in other countries and regions, helping to advance our understanding of the drivers of agriculture development more broadly. By providing evidence-based insights into the factors that shape agriculture development, this type of research can help to promote more sustainable and equitable agriculture practices and support the growth of the sector around the world. Investigating this topic is crucial and timely because countries with similar climate conditions, such as Saudi Arabia, are currently reforming their energy subsidies and exploring the impact on agricultural growth (i.e., Hasanov and Shannak, 2020).

Literature review

In this review, the research that has evaluated the impact of electricity incentives, and land availability on agricultural development in Qatar will be reviewed. However, to our knowledge, there are few studies for Qatar. Accordingly, the review of other Qatar-related countries, such as the Gulf Cooperation Council (GCC) countries, which are relevant to our research objective will be assessed. Moreover, the role of incentives in agricultural development will be discussed generally and specifically for Qatar. Thus, the review will go through varied factors that generally impact agriculture development in GCC and Qatar. Additionally, the econometric analysis applied used to estimate the interaction between several factors that may affect agriculture development, will be discussed.

In the GCC, agriculture is often water-intensive, and it is common for water to be used for irrigation and other agricultural purposes. However, the region faces significant challenges in terms of water scarcity, which can limit the growth and development of the agriculture sector. Thus, some researchers related water availability and resources to agricultural development. Mohammed and Darwish (Mohammed and Darwish, 2017) analyzed the relationship between virtual water and domestic food-water security in Qatar. They highlighted that the total virtual water between 1998 and 2015 averaged 1,360 Mm3y−1. Blue and green water account for 31% and 69% of virtual water imports, respectively. Additionally, an average of 70% of the total water requirement is from virtual water imports. Moreover, agricultural Qatar's dependence on virtual water increased to 90% in 2015 (Ministry of development planning and statistics, (2017). Finally, they also studied the virtual water policy implications on Qatar's food security. According to The Ministry of development planning and statistics, (2017), the total amount of water used in agriculture was around 295 million m3, in 2014. At the same time, the total amount of treated wastewater used in agriculture reached 65 million m3, representing 22% of the total water used. Although many studies discussed the statistics records of the water resources and availability in Qatar, none of these conducted any numerical estimation of the water impact on agriculture.

(Christopher and García Téllez, 2016) calculated the productivity of water and electricity for water extraction in 47 countries worldwide, including Qatar. They showed that the least energy-water productivity country in the sample was Qatar. Qatar was compared with other countries such as Canada for its agriculture and showed that for Qatar to achieve similar GDP as Canada, it must increase the water by 9.5 times and the energy by 94 times for agriculture. They related these findings to the arid climates that caused less benefit from the rainfall and more dependence on the extracted water for the agriculture sector. This indicates a high-cost opportunity for water and energy used in agriculture in GCC countries, particularly Qatar. They concluded that the best strategy is to import agricultural products that are highly water intensive and thus allow the state to save domestic water and reduce energy consumption in the sector.

Kamal et al. (2021) developed a revised and thorough qualitative model of the impact of water efficiency policies on water and electricity in Qatar. They developed data regression equations for the GDP, population, and rainfall to estimate the future water consumption of different sectors, including agriculture, until 2050. Moreover, they applied the system dynamics using stock and flow diagrams to determine the quantitative nature of the water system and its effects on electricity consumption and CO_2 emissions. They concluded that replacing groundwater with desalinated water can significantly increase energy use, whereas replacing groundwater with treated wastewater can considerably increase the water system's resilience. The developed model gave an understanding of the functions of agricultural inputs such as electricity and water. However, it does not assess the numerical effects of the energy/electricity on the sector.

Few studies investigated the econometric analysis of several factors related to the development of the agricultural sector in Qatar and other GCC countries. The interaction with several factors related to agriculture development was also investigated through circular economy concept. Ibrahim and Shirazi (Ibrahim and Shirazi, 2021) used the Circular Economy (CE) approach to understanding the interrelationships between water and energy and their effect on the environment. They found that the Qatari economy's energy perspective of CE (mobility and electricity sectors) and water perspective of CE (agriculture and water supply systems) provided an opportunity for exchanging, regeneration, virtualizing, sharing, optimizing, and closing loops to achieve CE growth. They concluded that the nexus between the electricity, mobility, agriculture, and water supply systems needs consideration for optimal policy outcomes for the CE in Qatar. Recently (Abulibdeh, 2022), examined the effects of economic growth, energy use, and the crop production index on different GHG emissions, using time series data between 1990 and 2019 for the State of Qatar. They analyzed the short and long-term impacts between these different variables using autoregressive distributed lag (ARDL) bounds testing. Moreover, the stationarity properties of the variables were tested using the Zivot–Andrew's test. They concluded that energy consumption, electricity consumption, and the crop production index have a significant and positive relationship with GHGs, while economic growth has a negative and significant relationship in the long term with these gases. The vector error correction model (VECM) Granger and Toda-Yamamoto causality tests were applied to analyze the relationship between the variables. Their results suggested a different causality relationship between the different variables. Several critical policy implications are derived from the findings of this research to sustain environmental quality in the state of Qatar. Their study conducted a different econometric analysis to study the effect of several factors, including agriculture, on the economic growth in Qatar.

Hasanov and Shannak, 2020 assessed the impact of electricity subsidies on agriculture development in Saudi Arabia, one of the GCC members, during the pre-reform period. They carried out the analysis to find how large the magnitude of the electricity insensitive was and if the removal of them would be a relevant measure to be taken. They applied different econometric analyses, including Dickey-Fuller type unit root tests (URTs), the cointegration test, and the long-run estimation. They also highlighted the positive impact of the incentives in both the short and long term on agricultural development. They found that the investment in technological progress and the capital stock might result in more sustained development, compared to the electricity incentives by the government in the agricultural sector. Additionally, they found that increasing the CO2 emission from fossil fuel consumption increased the temperature and adversely impacted the development of the agriculture sector. Finally, their empirical findings suggested that some mitigation actions must be taken for the sector and support the implementation of the ongoing policy of gradual reduction of the electricity incentives.

Similarly, Al-Faris (Al-faris, 2002) used Cointegration techniques, including Augmented Dickey-Fuller (ADF) and Phillips–Perron unit root tests, to determine the electricity demand in the GCC countries in the period between 1970 and 1997. Their study examined the properties of the time series of the price of electricity, GDP, electricity consumption, and price of substitute (LPG). To achieve effective income and price policies, there is a need to involve an element of shock; the changes must be significant. Nevertheless, in the long run, the elasticities of price and income are larger in magnitude. Moreover, cross-price effects (of competing fuels) are small, which may support the argument that the possibility of energy switching, particularly in the residential sector, is still limited.

Alrwis et al. (2021) analyzed the relationship between (water resource and security) and agricultural income and GDP from 1995 to 2017, using the standard econometric analysis to estimate the proposed regression model. Water resources and security are critical components of agricultural production, as water is necessary for crop growth and the maintenance of livestock. Their results illustrated the relationship between the water resources and the estimated crop area and *vice versa*. They found that the change in the water availability by 10% resulted in a 5.1% change in the crop area. At the same time, a 10% change in the estimated crop area resulted in a 1.5% and 2.9% change in the agriculture output and GDP, respectively. They concluded that lacking water resources will negatively impact agricultural output and GDP. Thus, they recommended a policy for water resources conservation. The study introduced a framework in the context of economic accounting for different crops persisting in the crop composition.

Nouman et al., 2021 investigated the influence of the green revolution on food security in Pakistan by examining yearly time series data spanning from 1975 to 2017. The study employed Johansen co-integration and F-bounds tests, and the findings indicated a positive and noteworthy effect of the green revolution on food security in Pakistan. The autoregressive distributed lag model revealed that agricultural machinery, agricultural credit, fertilizer use, high-quality seeds, fuel consumption, and an increase in the area under cereal crops are the key factors of the green revolution that enhance food security in Pakistan.

Ullah et al., 2018 utilized Johansen and autoregressive distributed lag (ARDL), to examine the long-term association between agricultural gross domestic product (GDP) and fruit production in Pakistan from 1961 to 2015. The research focused on three fruits, namely, mango, apple, and peach. The results indicated the presence of a long-term co-integration between agricultural GDP and fruit production. Additionally, the Bound test of the ARDL model confirmed the existence of a long-term relationship between agricultural GDP and fruit production. The short-term form of the ARDL model coefficient demonstrated that all three fruits had a positive impact on agricultural GDP.

In addition to affecting agricultural income and GDP directly, water resources and security can also have indirect impacts on the economy. For example, when water resources are scarce or unreliable, it may become more expensive to produce food, which can lead to higher food prices and increased inflation. This can have broader economic implications, as higher food prices can reduce consumer spending, slow economic growth, and increase poverty levels.

Therefore, it is important for policymakers to focus on improving water resources and security in order to support sustainable agriculture and economic growth. This may involve measures to improve water management, increase the efficiency of water use, and promote the development of new water technologies, among others. By taking these steps, policymakers can help to ensure that water resources are used sustainably, and that the benefits of water resources are shared widely and equitably.

Clearly, to the best of our knowledge, no studies employed cointegration analysis to investigate the impact of water resources and energy subsidies, along with other drivers on the agriculture sector in Qatar. The current study investigates the drivers of Qatar's agricultural gross value added by analyzing the impact of electricity price, labor-capital formation as potential drivers of agriculture development in Qatar by applying econometric analysis (cointegration) using different methods.

Theoretical framework

The objective of this study is to examine the driving factors behind agricultural development in Qatar, one of which is electricity prices. Therefore, it may be appropriate to use a bivariate framework to analyze this factor. However, econometric analysis has shown that relying solely on a bivariate framework may result in biased outcomes due to the omitted variable problem, a topic that has been extensively studied in the literature. For example (Lütkepohl, 1982), addressed this issue and explained that it could lead to a wide range of spurious findings and non-causality in the Granger-causality analysis. Similarly, Triacca (1998), Odhiambo (2009), and CAPORALE et al. (2004) have shown that a bivariate framework that overlooks significant variables in the analysis may also result in theoretically inaccurate coefficient signs and sizes, as well as incorrect causality direction.

Consequently, in this study, we followed the methodology applied by Hasanov and Shannak, 2020, where they employed an extended Cobb-Douglas production function (CDPF) (Cobb and Douglas, 1928).

The CDPF can be expressed as follows:

$$Y = AL^{B}K^{\propto}e^{y}\varepsilon \quad (1)$$

where,

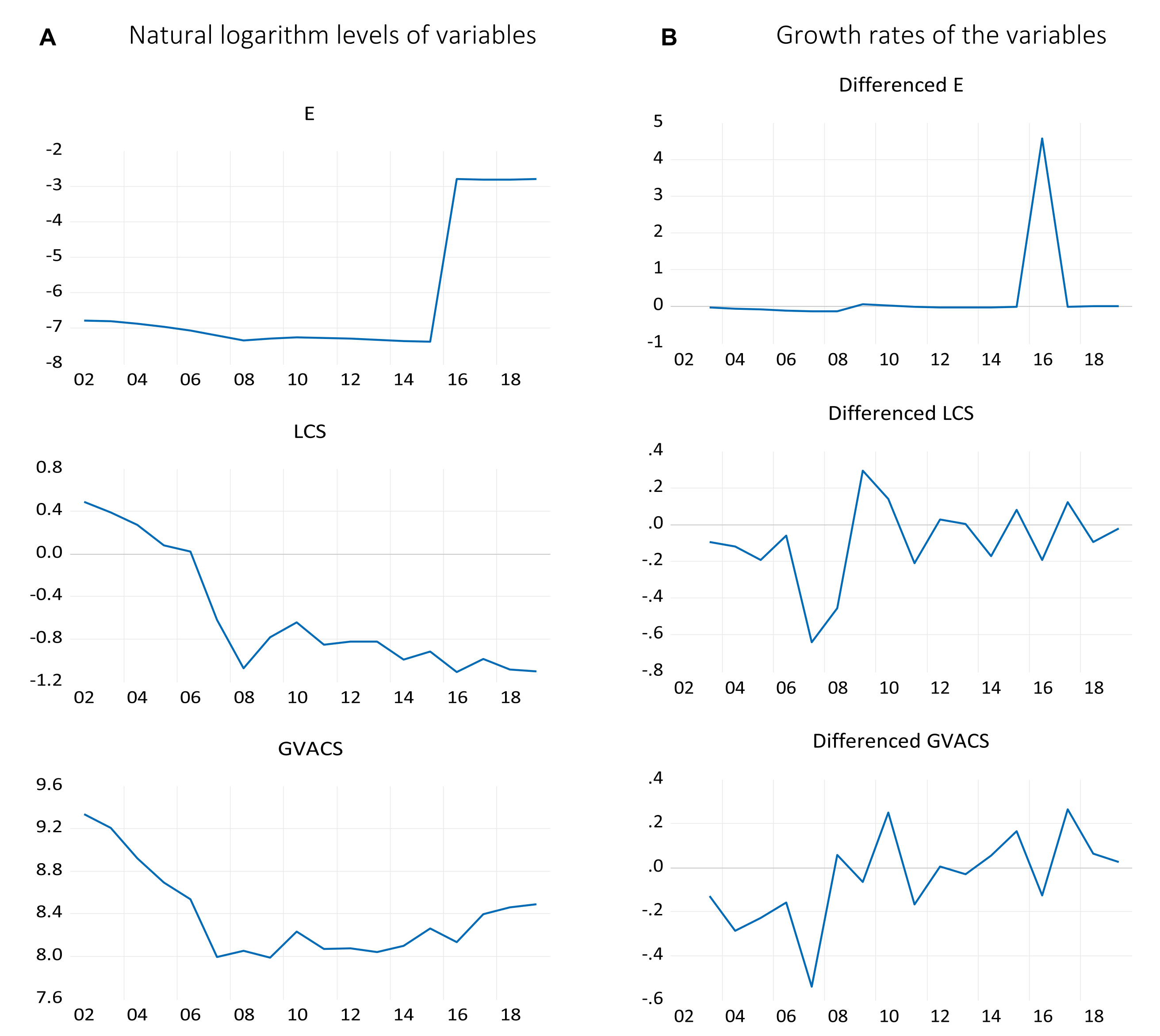

FIGURE 1
Time profile of the variables.

Y = total production (the real value of all goods produced in a year).

L = labor input.

K = capital input (a measure of all machinery, equipment, and buildings; the value of capital input divided by the price of capital).

e = natural number, i.e., the base of the natural logarithm.

A, α, β, and γ are coefficients to be estimated.

Also, α and β are the output elasticities of capital and labor, respectively.

The CDPF was utilized in this study in a manner that emphasizes productivity over outputs. Having said that, Gross Value Added of the agriculture sector, which represents the total output of the sector was divided by capital stock. Gross Value Added (GVA) per capital stock is a measure of productivity that indicates the economic value generated by each unit of physical capital, such as machinery, equipment, and buildings. Similarly, labor was also divided by capital stock to reflect productivity. Labor per capital stock is a measure that compares the amount of labor input to the amount of physical capital available for production in an economy. This measure is useful in evaluating the efficiency of an economy's use of physical capital and labor. A higher ratio of labor per capital stock indicates that there is more labor input available for each unit of physical capital, which may suggest that the economy is labor-intensive. Conversely, a lower ratio of labor per capital stock suggests that the economy is capital-intensive and relies more on technology and machinery for production.

Moreover, this study incorporated electricity prices, in addition to labor per capital, under the assumption of the constant return to scale hypothesis. To summarize, the CDPF is a relevant theoretical framework for our analysis to strengthen econometric estimations. The function is expressed in the natural logarithm form for the purpose of econometric estimations, and takes the following form:

TABLE 1 Descriptive Statistics of the studied variables (natural logarithm format).

	e	*gvacs*	*lcs*
Mean	−7.48	8.39	−0.59
Median	−8.43	8.25	−0.82
Maximum	−4.09	9.34	0.49
Minimum	−8.67	7.99	−1.11
Std. Dev	1.87	0.41	0.56
Skewness	1.30	1.08	0.89
Kurtosis	2.74	3.07	2.18
Jarque-Bera	5.12	3.50	2.86
Probability	0.08	0.17	0.24
Sum	−134.71	150.98	−10.57
Sum Sq. Dev	59.60	2.92	5.35

$$y^{*} = \propto_{0} + \propto_{1} L^{*} + \propto_{2} e + \varepsilon \quad (2)$$

Where, y* and L* are natural logarithm expressions of gross value added per capital, which is productivity, and labor per capital in agriculture; e is the natural logarithm of agriculture electricity prices; ε is the error term; and $\propto$ is the elasticity to be estimated.

Among others, the following studies have employed the CDPE framework in their agricultural-related analysis, such as: (Hasanov and Shannak, 2020), Yunhua (2005), (Liu and Wang, 2005), Faridi and Murtaza (2013) (Faridi and Murtaza, 2013), and Evenson and Mwabu (2001) (Evenson and Mwabu, 2001). Biddle (2011) (Biddle, 2011) reviewed agriculture studies that have applied the CDPF framework in their studies.

Data and methodology

Data

The annual time-series data were employed for agriculture gross value added per capital stock (*gvacs*), electricity price in agriculture (*e*), and labor per capital stock in agriculture (*lcs*) for the period 2003–2019. Figure 1 below illustrates the natural logarithm levels of the variables, and their first differences against time in years. Moreover, Table 1 provides descriptive statistics of the studied variables.

The studied variables have an immense impact on the agriculture production cycle. For instance, electricity prices play a significant role in the cost of production in the agriculture sector. High electricity prices can increase the cost of pumping water for irrigation and operating other agriculture-related machinery, making it more difficult for farmers to turn a profit. On the other hand, lower electricity prices can increase the competitiveness of the agriculture sector, making it more attractive to investors and allowing farmers to expand their operations. It is worth noting that during the study period, electricity prices in Qatar remained fixed at (0.07 QR/KWh) equivalents to 0.019 US $/KWh until 2016 when a significant jump in prices occurred (7 QR/KWh) equivalents to 1.92 US $/KWh, which explains the sudden increase in electricity prices observed in Table 1 below.

Moreover, labor per capital stock refers to the amount of labor input available for production relative to the amount of physical capital available. In the agricultural sector, this typically includes the number of agricultural workers or hours worked in relation to the amount of land and equipment available. An increase in labor per capital stock can lead to an increase in agricultural output and productivity, as more labor input is available to cultivate and harvest crops. However, this relationship also depends on the quality and efficiency of the labor input, as well as the availability of other inputs such as water, fertilizer, and seeds. Consequently, investigating these factors should help address related challenges and promote a supportive environment for agriculture can help to drive growth and development in the sector.

Panel A: Natural logarithm levels of variables Panel B: Growth rates of the variables

Agriculture gross value added (GVA). This refers to goods produced in the agricultural and forestry sector in Qatar, measured in constant 2010 U.S. dollars. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. The values were retrieved from World Development Indicators, 2021. Agriculture gross fixed capital formation. It represents the total value of a producer's acquisitions, such as livestock, machinery and equipment, plantation crops. The data was obtained from the Food and Agriculture Organization of the United Nations (Food and Agriculture Organization of the United Nations, 2021) (FAOSTAT, 2021) for the period 1970–2020, measured in million U.S. dollars (US$) at 2010 prices.

Agriculture Labor corresponds to employment in agriculture, forestry, and fishing. The data was obtained from the Food and Agriculture Organization of the United Nations (Food and Agriculture Organization of the United Nations, 2021) (FAOSTAT, 2021) for the period 1991–2019, measured in person and based on ILO modelled estimates.

Agricultural electricity tariff, the average electricity rate across the segments for agriculture use were used. The data was obtained from KAHRAMAA 2022 for the period 2002-2022 and deflated by Qatar Consumer price index (2010 = 100) and converted it into U.S dollars (US $) using a bilateral exchange rate of US$ against QAR. Exchange rate and CPI data were collected from World Development Indicators, 2021.

Methodology

First, the used variables tested for unit-root properties, by applying the typical procedures for time series data. Second, in case all used variables are integrated of the same order, one can proceed to test for the long-run cointegration relationship. Once the cointegration relationship is confirmed, the long-run relationship can be estimated. The Dickey-Fuller (ADF) (Dickey and Fuller,

TABLE 2 ADF and PP test results for Unit Root.

	Unit root test Table (PP)				Unit root test Table (ADF)			
	At Level				At Level			
		gvacs	*lcs*	*e*		*gvacs*	*lcs*	*e*
With Constant	t-Statistic	−2.71	−3.03	−0.5257	t-Statistic	−2.74	−1.8529	−0.52
	Prob	0.09*	0.05*	0.86 n0	Prob	0.08*	0.34 n0	0.86 n0
With Constant and Trend	t-Statistic	−1.38	−1.27	−1.5214	t-Statistic	−1.38	−1.63	−1.5262
	Prob	0.82 n0	0.85 n0	0.78 n0	Prob	0.82 n0	0.73 n0	0.77 n0
Without Constant and Trend	t-Statistic	−0.99	0.03	−0.9675	t-Statistic	−1.15	0.03	−0.9617
	Prob	0.27 n0	0.68 n0	0.28 n0	Prob	0.21 no	0.68 n0	0.28 n0
	At First Difference				At First Difference			
		d(*gvacs*)	d(*lcs*)	d(*e*)		d(*gvacs*)	d(*lcs*)	d(*e*)
With Constant	t-Statistic	−3.44	−3.52	−3.9444	t-Statistic	−3.39	−3.54	−3.9446
	Prob	0.02**	0.02**	0.009**	Prob	0.02**	0.02**	0.009***
With Constant and Trend	t-Statistic	−5.49	−6.01	−4.8559	t-Statistic	−5.48	−3.79	−4.17
	Prob	0.002***	0.001***	0.007***	Prob	0.002***	0.04**	0.02**
Without Constant and Trend	t-Statistic	−3.40	−3.15	−3.8831	t-Statistic	−3.37	−3.17	−3.88
	Prob	0.002***	0.003***	0.000***	Prob	0.002***	0.003***	0.000***

Notes: (*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant. * MacKinnon (1996) one-sided *p*-values. **Source:** Authors.

1979) and Phillips-Perron (PP) (Phillips and Perron, 1988) URTs are utilized for testing stationarity features of the variables. The null hypothesis of this test states non-stationary of all variables.

To test the cointegration relationship between a dependent variable (*gvacs*) and independent variables (l*cs,* and *e*), the Johansen Cointegration Test is used (Johansen, 1988); (Johamen and Jtiselius, 1990); (Johansen, 2006); (Andrews, 2015) and also verified using the Park Added Variables test. The null hypothesis for Johansen Cointegration Test is the non-existence of the cointegration relationship. The null hypothesis for the Park Added Variables test that series are cointegrated. Since both unit root tests and utilized cointegration tests are widely used in similar studies, they are not detailed here. Interested readers are referred to the above-mentioned literature.

The long-run relationships estimations were tested using different techniques to ensure robust results. The fully modified ordinary least squares (FMOLS) (Phillips and Hansen 1990; Hansen 1992a, 1992b), Dynamic OLS (DOLS) (Stock and Watson, 1993) and canonical cointegration regression (CCR) (Park 1992), and The general to-specific modeling approach (HendryDavid et al., 1984); Campos et al., 2005, *inter alia*) methods, were employed for the long-run estimations for robustness.

Empirical estimation results

Following the time series modeling methodology, the unit root properties of variables have been examined using the ADF test (Dickey and Fuller, 1979) and PP test, the results are presented in Table 2.

The results of the ADF and PP tests clearly indicate that the null hypothesis of a unit root cannot be rejected for the level of the variables. However, the null hypothesis is strongly rejected when testing for the first difference between them.

As Table 2 demonstrates, all the variables are integrated of the first order, hence, as a conclusion, all variables are I (1), and their first differences are stationary. Therefore, the cointegration relationship can be tested.

The Johansen Cointegration Test was used for this exercise, and the results are reported in Table 3. The null hypothesis was rejected that there is no "none"" cointegration relationship between studied variables.

As can be seen in Table 3, Table 4 the used tests conclude the existence of a cointegration relationship among the studied variables. For the next step, the long-run estimations were analyzed. Table 5 detailed estimation results from the FMOLS, DOLS, and CCR techniques.

As a robustness check the Gets approach in dynamic form was also utilized to estimate the long run relationship between the studied variables.

Tables 5 and 6 show that all utilized estimation techniques provide close results. All the variables were found to have relevant signs and are statistically significant.

Discussion and policy implications

Herein, the empirical findings are discussed. Based on the unit root test results, documented in Table 2 show that, l*cs, e,* and *gvacs* are non-stationary variables, meaning that their mean, variance,

TABLE 3 Unrestricted Cointegration Rank Test, using Trace and Max-eigenvalue tests.

Unrestricted cointegration rank test (Trace)					Unrestricted cointegration rank test (Maximum eigenvalue)					
Hypothesized		Trace	0.05		Hypothesized		Max-Eigen	0.05		
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**	No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**	
None *	0.75	37.50	29.79	0.005	None *		0.75	22.64	21.13	0.030
At most 1	0.60	14.85	15.49	0.06	At most 1 *		0.60	14.81	14.26	0.040
At most 2	0.002	0.038	3.84	0.84	At most 2		0.002	0.038	3.84	0.84

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level, Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level, * denotes rejection of the hypothesis at the 0.05 level, **MacKinnon et al. (1999) *p*-values, *denotes rejection of the hypothesis at the 0.05 level, ** MacKinnon et al. (1999) *p*-values. **Source:** Authors.
Furthermore, the Park Added Variables cointegration test was also performed as a robustness check. The test indicates that the null hypothesis of cointegration can not be rejected, since the probability value of chi-square statistic test is larger than 5 percent level of significance (0.0.094 > 0.05).

TABLE 4 Cointegration test results(Cointegration Test—Park Added Variables).

	Value	df	Probability
Chi-square	2.80	1	0.094

and covariance (at least one of them) change over time, while their first differences are stationary.

Tables 3 and 4 show that the variables of interest are cointegrated, meaning that there is a long-run relationship between them. Hence, it is helpful to estimate numerical values for this relationship and apply it as a basis for policy suggestions.

The impact of *lcs,* and *e* on *gvacs* was estimated by employing four different estimation techniques, Gets, FMOLS, DOLS and CCR, as a robustness check. The results show that there is a theoretically expected and statistically significant relationship between agricultural *gvacs* and studied drivers. It is worth mentioning at this point that the numerical values, i.e., elasticities, from the different estimators are very close to each other, indicating that the results of the analysis are not sensitive to the choice of estimator, and are likely to be robust and reliable.

According to the estimation results, a 1% increase in l*cs* is associated with a 0.67%–0.74% increase in *gvacs* in the long run. *lcs* was calculated by dividing the total number of workers by the amount of capital stock available, hence, we measure the labor input that is available for each unit of capital. This measure can be useful in understanding the efficiency and productivity of an economy or sector, as well as the potential for growth and expansion. The relationship between an increase in labor *per capita* stock and a corresponding rise in gross value added *per capita* stock in the agriculture sector in Qatar can be explained by the following: First, improved efficiency: once we have more labor available to work with the existing capital stock in the agriculture sector, it can lead to an increase in productivity and efficiency. The workers can specialize in different tasks and work more efficiently, leading to an overall increase in output per unit of capital. For instance, additional workers can perform tasks such as planting, harvesting, and maintaining crops more efficiently and effectively, which can result in higher yields and quality of produce. Additionally, with more workers available, it may be possible to cultivate a larger area of land, further increasing overall agricultural output. Second, economies of scale: increasing the number of labor force in the agriculture sector, farms may be able to take advantage of economies

TABLE 5 Long-run estimation results using FMOLS and CCR.

	FMOLS	DOLS	CCR
Variable	Coefficient (Std. Error)	Coefficient (Std. Error)	Coefficient (Std. Error)
lcs	0.70(0.07)***	0.73(0,06)***	0.74(0.06)***
E	0.11(0.02)***	0.11(0.02)***	0.11(0.02)***
C	9.70(0.15)***	9.72(0.15)***	9.72(0.16)***
R-squared	0.81	0.95	0.81
Adjusted R-squared	0.79	0.88	0.78
S.E. of regression	0.16	0.10	0.16
Long-run variance	0.01	0.00	0.01

Notes: The dependent variable is gvacs; Coef. and Std. Er. are coefficient and standard error; Standard errors are in parentheses; *, ** and *** indicate significance levels at 10%, 5%, and 1%.**Source:** Authors.

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TABLE 6 Estimation results of the Gets approach in dynamic form.

Variable	*e*	*lcs*	Constant
Coefficient	0.097	0.67	9.49
p-value	0.000	0.000	0.000
Test	AR 1–2 test	ARCH 1-1 test	Hetero test
test statistics	0.253	0.392	0.086
p-value	0.78	0.54	0.98
R-squared	Adjusted R-squared		
0.83	0.80		

Notes: Dependent variable is GVA; AR, autocorrelation test (Godfrey 1978); ARCH, autoregressive conditional heteroscedasticity test (Engle 1982); Normality test = Doornik and Hansen (1994) normality test; Hetero test = heteroscedasticity test (White 1980); RESET23 = Regression Specification Test (Ramsey 1969). **Source:** Authors.

of scale, which refer to the cost advantages that farms can achieve by increasing their scale of production. This can lead to lower costs per unit of output, which in turn can increase gross value added per capital stock. It is evident within the Qatari context that the labor force has undergone a 63% increase from 2002 to 2019 (FAOSTAT, 2021). Third, technological progress, it is expected that by increasing the number of labor *per capita* that could lead to an increased investment in technological progress. This can lead to the adoption of new technologies that can increase efficiency and productivity, leading to an overall increase in output per unit of capital. In summary, an increase in labor per capital stock can lead to an increase in gross value added per capital stock by increasing efficiency, taking advantage of economies of scale, and promoting technological progress.

The found numerical values for the labor *per capita* elasticity of agricultural *gvacs* are in harmony with the nature of the agriculture sector in Qatar. As previously mentioned, the development of the agriculture sector in harsh climates and desert environments can require significant capital investment. To attract investors and increase outputs, governments have offered various incentives such as access to modern technologies, production inputs, technical support, and more. Moreover, as the related literature suggests (see, for example, (Shannak, 2022), (Hasanov and Shannak, 2020), *inter alia*), capital investment includes technological progress policies such as advancing technology use to increase productivity, which are more relevant policy measures for developing countries. For example, vertical farming, the use of Internet of things (IoT) to automate agriculture practices, autonomous tractors, among others are technological options that could contribute to increase productivity and overall *gvacs*.

The findings suggest that a 1% increase in *e* is associated with an increase of 0.097%–0.11% in *gvacs* in the long run. Evidently, the long-run elasticities are modest but most importantly they are statistically significant. The explanation for this finding is that the sectoral long-run growth impacts of the electricity prices are small, however they are needed. The following explanation would support this finding. Increasing electricity prices for the agriculture sector in Qatar is likely to lead to an increase in gross value added per capital stock for the sector in the following ways:

First, encouraging efficiency: When electricity prices increase, farmers may be motivated to use energy more efficiently. They may adopt energy-saving practices such as using more efficient irrigation systems or adopting more energy-efficient equipment. This can lead to a decrease in energy consumption and lower costs, which can ultimately increase gross value added per capital stock.

Second, promoting technological innovation: Higher electricity prices may encourage farmers to invest in new technologies that are more energy-efficient. For example, they may invest in solar panels or other renewable energy sources to offset the cost of electricity. This can lead to increased productivity and higher output per unit of capital, which can lead to an increase in gross value added per capital stock. Third, enhancing quality of products: Higher electricity prices may force farmers to shift towards higher value crops that require less energy, or to adopt more sophisticated cultivation methods to optimize energy usage, which can lead to a better quality of agricultural products. This can increase the value of output per unit of capital, thereby increasing gross value added per capital stock.

Increasing electricity prices for the agriculture sector in Qatar could lead to an increase in gross value added per capital stock by encouraging efficiency, promoting technological innovation, and enhancing the quality of agricultural products. However, it is important to note that any policy aimed at increasing electricity prices for the agriculture sector should be designed and implemented carefully, to avoid any adverse impact on farmers or consumers. Recently, the government re-structured electricity prices across different sectors including the agriculture one in its efforts to sustain natural resources and reduce waste.

Additionally, increasing electricity prices would reduce the amounts of subsidies given, which would help the national economy, as well as the agriculture sector, to have a smooth transition with the least possible disruption and allow time for the agriculture sectors to absorb latest changes related to an electricity price increase, and be efficient. Eliminating electricity subsidies by setting higher electricty prices will spare extra resources to the government, which can be distributed for different projects in line with the goals of the QNV2030.

The obtained elasticity estimates are consistent with the nature of Qatari's agriculture sector. A high population growth rate, along with harsh climatic conditions, such as very high daytime temperatures, intense solar radiation, abrupt temperature drops at night, and very low precipitation, can pose significant challenges for the agricultural sector. These conditions can lead to reduced crop yields, increased water usage, and higher costs for cooling and irrigation.

Under these circumstances, the agricultural sector may be less attractive to investors, and farmers may struggle to sustain their operations without government support. In such cases, the government may provide incentives, such as modest electricity prices, to help offset some of the costs associated with operating in harsh climatic conditions.

It is important to note that government support for the agricultural sector in regions with harsh climatic conditions is just one aspect of a broader set of measures needed to address the challenges faced by farmers in these areas. Other measures that are relevant include investment in drought-resistant crops, gradual removal of electricity subsidies, improved water management practices, and enhanced infrastructure, may also be necessary to ensure the sustainability and competitiveness of the sector.

Labor per capital was found in this study key to drive agriculture *gvacs,* which may suggest that the sector is labor-intensive. Thus, appropriate policy measures to increase this factor and investments in agriculture and to stimulate food are needed. Herein, We suggest that the government could provide training and education programs to ensure that individuals working in the agriculture sector have the necessary skills and knowledge. This approach would not only increase the quantity of workers in the sector but also improve the quality of the workforce. Moreover, the government can implement immigration policies that attract skilled and experienced workers from other countries to work in the agriculture sector. Other related measures include financial incentives such as tax breaks, subsidies, and grants can be provided to encourage investment in the agriculture sector and increase employment opportunities. By implementing these policies, the government can increase the labor force in agriculture in Qatar and promote the growth of the sector.

As arable lands in Qatar are limited as well as water resources, policy measures that prioritize the use and distribute of these resources are essential. To illustrate, it is important to evaluate the local crops not just based on their economic value, but also on their water and land usage. This is because these factors have an impact on the energy demands and electricity prices associated with crop production. Importing crops that are water and land intensive allow the country to balance their increasing water and arable land demand while exporting less water-intensive and rationalize land use. This is very well articulated in the National Food strategy; it calls to efficiently cultivate crops and establish hydroponics greenhouse systems along with other technologies that save on water. Additionally, the strategy indicates that it is particularly important to switch groundwater used for fodder production by Treated Sewage Effluents.

There are various supplementary policy alternatives available to enhance the total output and value in the agriculture sector, such as implementing standards and regulations, providing production-related services, conducting research and development, and establishing an economic accounting system. This accounting system is designed to evaluate the utilization of natural resources in food production, enabling the tracking of their usage, optimizing distribution, and reducing wastage and mismanagement.

The present approach of the government is to enhance the production of vegetables by adopting a state-of-the-art hydroponics greenhouse cluster. This move is aimed at reducing water, energy, and land consumption while simultaneously elevating the overall productivity of greenhouse-grown vegetables like tomatoes, peppers, cucumbers, squash, and lettuce. Furthermore, the government has urged the reduction of groundwater usage and a shift towards treated sewage effluents. The combined effect of these initiatives is expected to fortify the nation's food security strategy.

The policy options suggested in this study could help to meet food security objectives and increase the agriculture output and Gross Domestic Product, respectively. The study concluded that the government's current strategy to reform energy prices and gradually adjust mitigation measures to sustain natural resources and prevent waste is relevant and timely. Clearly, if these policy options are managed properly, the agriculture sector can play a significant role in diversifying the economy, maintaining environmental conditions and improving food sustainability.

Finally, one of the limitations of our analysis is the absence of comparable economic data, such as electricity price elasticity, and productivity, which has been identified as relevant in other studies (Galt et al., 2017). Additionally, the analysis is limited to the agriculture sector of Qatar, which may restrict the applicability of the results due to the relatively small size of this industry in the state. This limitation of our study highlights the importance of investigating agriculture development in diverse countries in arid climatic regions. Furthermore, it is crucial for future studies to incorporate additional variables such as water prices, land and technology. This would enable a more comprehensive analysis and help to provide a better understanding of the factors that influence the agriculture sector in arid climatic regions.

Conclusion

The impact of labor productivity and electricity prices on the development of Qatar's agriculture sector has been analyzed using various estimation methods to ensure reliable results and robust policy recommendations. The empirical analysis reveals that the studied variables have long-term effects on the development of the agriculture sector in Qatar. The results obtained through different estimation methods are consistent with each other, indicating the robustness and reliability of the analysis.

Based on the empirical analysis, policymakers may want to consider gradually increasing electricity prices in the agricultural sector, while implementing appropriate mitigation measures. These findings align with Qatar's current policy of ensuring fair energy prices for both producers and consumers. Despite the impact of electricity prices on demand and production, farmers and operators have not significantly reacted to the increasing prices. This could be due to the sector's low electricity intensity or the current prices being economically viable. This study found that labor productivity plays a crucial role in driving agriculture growth, suggesting that the sector is labor-intensive. Therefore, appropriate policy measures and investments in the agriculture sector are needed to increase labor productivity and stimulate food production.

Since 2016, the Qatari government has been implementing a policy of gradually phasing out energy incentives by increasing domestic energy prices to align with market prices, while also implementing mitigation measures. This policy aims to facilitate the transition away from fossil fuels and provide sectors of the economy with sufficient time to adapt to the new environment. Moreover, increasing energy prices in the agriculture sector would incentivize farmers and operators to invest in energy-efficient and modern equipment, leading to higher total outputs and values. Efficient utilization of water, electricity, land, and capital can all contribute significantly to the agricultural output multipliers.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SS: Conceptualization, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing—original draft, review and editing. RS: Literature review MA-K, Writing—review and editing AA: Project administration.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix A

Compelling reasons for developing the agriculture sector.

First, food security is a crucial dimension for any economy. A strong agricultural sector can help ensure a stable food supply for a growing population, reducing the risk of hunger and malnutrition. This point is of particular importance in Qatar, amid the 2017-21 Gulf Cooperation Council (GCC) diplomatic crisis, as the country had to rethink its sustainable development goals while meeting local demand. In 2018, the Food Security Department of the Ministry of Municipality and Environment announced a new plan to curb the heavy reliance on importing several commodities, especially food items. This plan outlined four essential targets, including i) increasing local production, ii) maintaining larger amounts of strategic food in local storage to meet its need for up to 6 months, iii) holding on to international trade, and IV) implementing wider local market studies (Qatar National Food Security Strategy, 2020). This strategic plan which is expected to end in 2023 has accelerated initiatives and programs and increased food production by four folds since 2017, introduced new measures for sustaining a reliable local strategic reserve, maintained sufficient supply, and diversified sources of food imports.

Second, the development of the sector would, to some extent, help manage land areas in arid climates by promoting sustainable agriculture practices that conserve water and soil, and increase land productivity. This is essential for achieving the sustainability targets related to poverty reduction, food security, and environmental sustainability. For instance, the development of the sector can promote the use of greenhouses and vertical farming, which can help to reduce water use and increase crop yields. Greenhouses can help to create a controlled environment that can be optimized for plant growth, while vertical farming can help to increase crop yields per unit of land.

Third, the agriculture sector presents an opportunity to diminish emissions since plants act as natural carbon sinks. Advancing the sector would augment vegetation coverage and enhance carbon sequestration in the soil through photosynthesis. Additionally, well-executed agricultural practices can safeguard the environment, conserve resources, and alleviate the consequences of climate change.

Fourth, agriculture is frequently a primary stimulator of economic growth, particularly in developing nations, as it generates employment opportunities, income, and raw materials for other industries. Furthermore, promoting the agricultural sector aligns with Qatar's economic diversification strategy, which can help address negative impacts associated with oil dependency, including the so-called 'Dutch disease' (Yavas and Tuncalp, 1983; Shannak, 2021). The Dutch disease refers to a phenomenon where a country's dependence on a single natural resource, such as oil, can lead to a decline in other industries and the overall economy. This situation can arise because the inflow of foreign currency from the natural resource sector can cause the local currency to depreciate, resulting in other exports becoming more expensive and less competitive. Investing in agricultural development can mitigate this effect by diversifying the economy and reducing reliance on oil. By investing in the agricultural sector, a nation can establish new sources of income and employment, which can boost economic growth and stability. Furthermore, by enhancing food production, the country can decrease its dependence on imported food, thereby reducing its reliance on foreign currency. Overall, developing the agriculture sector can have far-reaching benefits for both individuals and communities, as well as the broader economy and the environment, which all in all, are essential factors of Qatar National Vision (2030), a strategic roadmap for the country.