



Modeling electricity consumption patterns during the COVID-19 pandemic across six socioeconomic sectors in the State of Qatar

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ABSTRACT

The propagation of the COVID-19 pandemic, and the associated measures taken by many countries to slow down the spread of the disease, has significantly affected all aspects of people's lives, including the global energy sector. This study aims to investigate the impact of the pandemic on the spatial patterns of electricity consumption in six socioeconomic sectors (residential (villa and flat), industrial, commercial, government, and productive farms) in the State of Qatar. The spatiotemporal patterns of electricity consumption have been assessed using various Geographic Information Systems (GIS) and spatial statistical modeling prior and during the pandemic. The results demonstrate variations in electricity consumption within and between the six sectors. The main changes in the electricity consumption within sectors during the pandemic year is during the lockdown phase. Spatially, some sectors are affected by the pandemic, and hence the pattern and the spatial and temporal distribution of electricity consumption has changed during the pandemic year compared to pre-pandemic years. The results also show that there were variations of spatial clustering of electricity consumption among these sectors. Most of the high-high clustering patterns are located in the mid-eastern and northeastern parts of Qatar. The highest variation in electricity consumption between sectors occurred in the productive farms due to its massive development during the pre-pandemic period and were not affected by the pandemic. There is a sharp decline in electricity consumption in both the industrial and commercial sectors during the pandemic year. Other sectors witnessed an increase in electricity consumption during the summer months, which was mainly due to travel restrictions imposed by many countries around the world. This analysis is vital for policymakers to detect the changes in electricity consumption patterns in the context of emergencies such as the pandemic.

1. Introduction

The outbreak of COVID-19 has emerged as a serious public health threat to the entire globe and every aspect of life has been profoundly affected [1]. Apart from the huge loss of life across the world, it has had a tremendous impact on economics, society, politics, technology, and health [2,3]. Different measures have been put in place to reduce the speed of the propagation of the COVID-19 pandemic and to flatten the curve of infected cases. Many social and production activities have been reversed or suspended, such as restrictions on movement locally or internationally, the closing of public institutions such as schools and universities, working from home to prohibit mass gatherings, and the closing of most businesses including services, commercial, and industrial sectors [1,4].

The COVID-19-induced lockdown not only had an immense impact on improvement of the environment, such as air quality [5–7] and water quality [8,9], but also had a significant impact on energy and electricity

consumption patterns across the world [10,11]. The pandemic has affected the energy sector—considered one of the imperatives for modern societies—by altering the supply and demand of energy, since most residents have remained in either passive or active home quarantine. Electricity consumption can be considered an important indicator of economic fluctuations and during the pandemic can be monitored to gauge the economic impact of the virus.

Recently, a number of studies have been performed on the impact of the pandemic on energy demand due to lockdown and restrictive measures on economic activities [12–14]. In China, for example, the domestic electricity consumption of residents in urban and rural areas has increased by 5.3% in the first quarter of 2020 because of the stay-at-home policy. Similarly, the electricity consumption in the agricultural sector has increased by 4%. Conversely, in the manufacturing and service industries it has declined by 3.1% and 19.8%, respectively [15,16]. In Italy, electricity consumption witnessed a decline up to 37% during the pandemic compared to the same period in 2019 [17]. In Ontario, Canada, a daily reduction in electricity consumption of 18%

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Nomenclature abbreviations

GIS	Geographic Information Systems
GDP	Gross domestic product
GCC	Gulf Cooperation Council
MW	Megawatt
GWH	Gigawatt hours
KAHRAMAA	Qatar General Electricity and Water Corporation
MME	Ministry of Municipality and Environment
villa	Residential villas
flat	Residential flat
com	Commercial
indu	Industrial
Pro	Production farms
govt	Government
SMEs	Small and medium-sized enterprises
IDW	Inverse Distance Weighting
CV	coefficient of variation
SD	Standard deviation
r	Pearson correlation

was observed during the weekends and a peak of -25% [18]. Energy consumption in Turkey witnessed reduction by 5%, 20%, and 22% in March, April, and May, respectively, compared to the same period of 2019 [19,20]. In Brazil, electricity consumption declined during the first trimester of 2020 in comparison with 2019 values, where different sectors witnessed this decline, including the industrial (0.4%), residential (0.3%), and commercial (2.2%) [21]. Weekly energy demand in countries that imposed full lockdown policies was reduced by 25%, while this percentage was 18% in countries that imposed partial lockdown policies. Worldwide, electricity demand in the service, commercial, and industrial sectors decreased because of lockdown policies. However, this reduction was partially offset by higher residential use [21]. Therefore, temporal electricity-related data can offer insights into the effect of the COVID-19 pandemic and associated mitigation policies.

Consumption of energy, water, and gas in the State of Qatar has increased exponentially after a rise in oil and gas production in the country and the region [22]. The increasing demand for electricity was driven by population growth and economic development and is affected by the weather, particularly during the summer season where the temperature exceeds $40\text{ }^{\circ}\text{C}$ [23]. Even though the State of Qatar is rich in fossil fuel energy resources, there is a strategic plan to move towards sustainability in energy use by decreasing dependence on, and consumption of, conventional energy resources and increasing the dependence on clean and renewable energy [24]. Prior to the pandemic, many studies have been performed to investigate the energy consumption patterns in Qatar [24–26]. For example [24], investigated domestic energy consumption behavior and public awareness of renewable energy in Qatar. They found that citizens are not willing to change their energy consumption behavior through economic means due to the country's energy subsidies, and that users' awareness and education of their environmental impact requires efficient energy usage and monitoring.

Considering the literature on electricity consumption prior or during the pandemic, few notable research gaps have been identified in studying the energy literature related to Qatar. First, most of the studies focused on policies related to energy consumption patterns [25]. Second, most of the studies considered specific sectors in order to examine electricity consumption patterns at city or country scale [24,27]. Lastly, to the best of our knowledge, there has been no study in Qatar to investigate the impact of the COVID-19 pandemic on electricity consumption patterns. Furthermore, the international studies focused on the impact of COVID-19 on energy supply and demand, electricity

consumption, and electricity cost. However, these studies did not perform spatial analysis of the impact of COVID-19 on electricity consumption in terms of considering different socioeconomic sectors. This gap is a major impediment to designing effectively tailored interventions for this important indicator of the economy.

Therefore, considering this research gap, this study aims to investigate the spatiotemporal impact of COVID-19 pandemic on electricity consumption across six socioeconomic sectors. These sectors are residential (villas and flats), government, commercial, industrial, and productive farms, which are considered as indicators of social well-being and economic development. The residential sector was affected by the stay-at-home policy during the lockdown phase and this forced many employees to work from home and students to learn from home. The electricity consumption in the government sector during the pandemic might indicate the increased institutional work to slow down the spread of the disease. The rest of the sectors are used to investigate the impact of the pandemic on the economic activities in the State of Qatar. The novelty of this study is that it investigate the electricity consumption in the context of COVID 19 in a different approach than prior studies. This paper contributes to the body of knowledge in different ways. First, to the best of our knowledge, this study is the first of its kind to investigate the spatiotemporal impact of COVID-19 pandemic on electricity consumption across different socioeconomic sectors. Therefore, this study will fill this gap by examining the changes of electricity consumption pattern under the context of the pandemic and visualise the hot spots and the cold spots of electricity consumption over space, time, and sector levels. Second, the study considers different temporal levels in investigating the electricity consumption under the context of the pandemic. The electricity consumption was assessed on monthly and annual levels as well as through different stages of the development of the disease and its associate measures. To fulfill the objectives of this study, a few research questions were formulated:

- (1) Is there any impact of COVID-19 pandemic mitigation measures on electricity consumption patterns in Qatar?
- (2) Are there any substantial changes in electricity consumption patterns in comparison to the period prior to the pandemic?
- (3) Are there any inter-sector variations of electricity consumption patterns in Qatar due to the pandemic?

The structure of the article is as follows. Section 2 describes the fundamental information of the main characteristics of the study area. Section 3 highlights the country's electricity market. Section 4 explain the data, variables, and spatial and statistical methods used to analyze the data. Section 5 presents the main results of the spatial and statistical analysis, the implications for better understanding electricity consumption in the six socioeconomic sectors are discussed. Section 6 discuss the main results. At the end, section 7 presents the conclusion and the policy implications of the study.

2. Study area

Qatar is located in the far eastern part of the Arabian Peninsula, with a geographical area of 11437 square kilometers (Fig. 1). The mean annual rainfall is about 80 mm and relative humidity ranges from 59% to 95% [28]. The summer season is characterized by high temperatures and high relative humidity. Most of the rainfall occurs during the months of November to March (particularly in the winter season).

The State of Qatar adopted an ambitious 2030 development vision that has led to massive urban development, rapid population growth, large-scale investment projects, rising government expenditure, significant economic prosperity, and, consequently, the significant growth rate in real Gross domestic product (GDP). Between 2004 and 2016, Qatar witnessed an average growth rate of real GDP and of population at 15% and 10% per year, respectively. Fossil fuels (liquefied gas and oil) are the keystones of the country's economy and account for more than

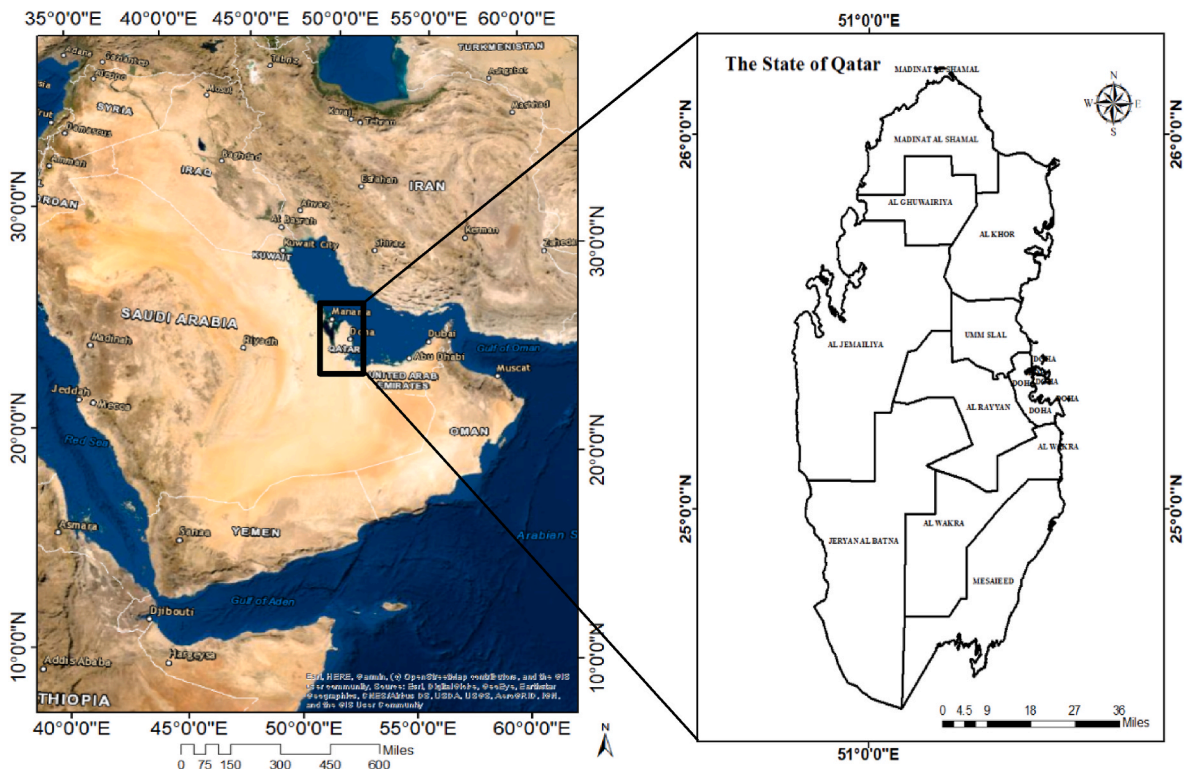


Fig. 1. Location map of the study area (Qatar).

80% of total government revenue [29]. The government has significantly promoted the industrial sector (both heavy and light industries). The major industries are steel and iron, fertilizers, petrochemical industries, and cement industries. The agricultural sector has significantly improved within the last few years (Qatar has about 280 sq. km). Qatar is almost self-sufficient for vegetables (about 70% during summer and 40% during winter). After the discovery of vast oil and gas reserves in Qatar, population growth accelerated from the 1970s, as these natural resources attracted a large number of migrant workers from overseas. Currently, the population of Qatar is 2.7 million, as shown in Fig. 2, and it is projected to reach 3.8 million by 2050 if the current growth rate is maintained [30], and where more than 90% of the total population lives in Doha (the capital and administrative center of Qatar) located on the eastern coast of Qatar [31].

However, the country has implemented several policies targeting a reduction in its share of the non-hydrocarbon sector in the GDP. The State of Qatar is spending more than US\$200 billion on infrastructure

projects, not only in preparing for the FIFA World Cup in 2022, but also as part of the country's long-term development plan, which is known as Qatar Vision 2030 [10,32]. This vision focuses on development within the four main pillars: economic, social, human, and environmental. Most of this funding is being invested in developing the country's infrastructure, including the building of a new airport and port, new rail and metro lines, and a state-of-the-art road network. The transformation of Qatar into a modern country is also a part of Qatar Vision 2030, which has the long-term goal of creating a sustainable, state-of-the-art country, raising the standard of living, and achieving increased economic growth by using the country's human and natural resources [33,34]. The infrastructure investment includes mega-transport projects, coupled with the expansion of the tourism sector and real estate new-builds, to diversify the economy. These factors have resulted in a sharp and unanticipated rise in the immigration of workers.

In an attempt to stop or slow down the spread of the disease, the Qatari government imposed different policies that had huge economic repercussions in the country. The government started a nationwide lockdown on March 9, 2020, including the closure of all non-essential services; the closure of schools, restaurants, and retail outlets; the imposing of self-quarantine and stay-at-home policies; restrictions in local mobility and international flights; and the closure of non-essential firms and industries. The imposed restrictions had direct consequences both on people's lives, by reducing the number of infected cases and mortality rates, and on economic activities, particularly in industrial and commercial production and services. These mitigation policies have been unequivocally reflected in electricity consumption.

However, the Qatari government announced a four-phase plan to lift the country's COVID-19 lockdown restrictions after the rate of incidence reduced substantially. The first phase started on June 15, 2020 and included the easing of some restrictions, such as allowing the limited opening of mosques, permitting offices to resume operations with a maximum capacity of 20% of employees and with the implementation of all precautionary requirements, the partial opening of some shops (the area of the shop must be no less than 300 m²) and where the capacity of

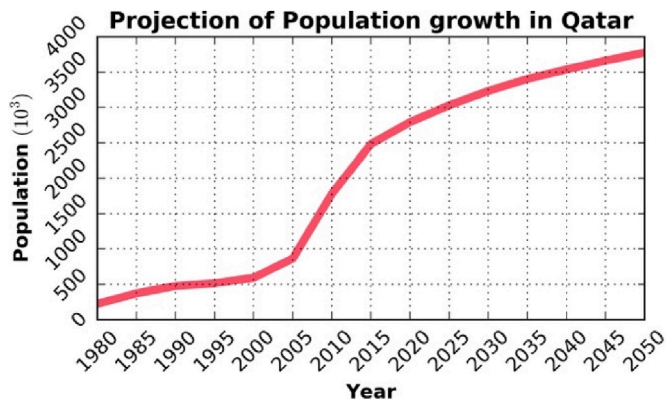


Fig. 2. Population growth in the State of Qatar. Source [30].

shopping centers should not exceed 30%, and some health facilities were able to resume services at 40% of capacity. The second phase started on July 1, 2020 and included allowing the gathering of less than ten people, opening shopping centers for limited hours per day, private health clinics were able to function at 60% capacity, the reopening of parks and beaches, the opening of restaurants, museums, and libraries with limited capacity, and offices were allowed to operate at 50% capacity, among others. The third phase started August 1, 2020 and included fully opening shopping centers, private health clinics were able to operate at 80% capacity, the reopening of facilities and services, such as nurseries, childcare, low-risk inbound flights, driving schools could fully operate, and offices were permitted to operate at 80% capacity, among others. The final phase started on September 1, 2020 and included allowing businesses to operate with full capacity, full opening of shopping centers, restaurants, museums, libraries, and wholesale markets, and private health care could operate at full capacity, among others.

3. Qatar's electricity market

3.1. Qatar's electricity market

Qatar is the second highest electricity consumer among the Gulf Cooperation Council (GCC) nations, which include, in addition to Qatar, the countries of Saudi Arabia, United Arab Emirates, Kuwait, Bahrain, and the Sultanate of Oman [42,44,52]. In Qatar, the electricity market tries to fulfill the needs of various sectors of the Qatari economy and hence can be considered as a demand-oriented market. This market is expanding rapidly due to population growth and economic development, particularly in heavy industries. The value of electricity demand in 2016, for example, reached a value of 7435 MW, with an increase of 2.3% compared to the 2015 value, and the electricity transmitted was 39,667 GWh [35]. The largest demand in 2016 was from the industrial sector with a value reaching 1560 MW. To meet this demand, both public and private sectors are responsible for generating electricity. However, the private power generation companies must still operate under the supervision of the government. The annual installed electricity power generation is able to meet the country's electricity demand (see *Figures, 3–5*). However, it might face different challenges if the population growth and economic development rates remained high. Furthermore, the government provides free electricity and water for its citizens and subsidizes prices for expatriates, which elevate the pressure on these two important resources. The maximum proportion of electricity in Qatar is consumed due to cooling systems in buildings [36]. The number of industries, commercial sectors, and productive farms have increased due to economic and population growth. The production of electricity in Qatar has increased by 3.7 times between 1990 and 2010 [37].

Population growth and economic development have led to a rapid increase in annual electricity generation and consumption as well as Qatar's peak electricity demand (see *Figs. 3 – 5*). Other driving forces of this unprecedented growth of annual electricity generation include the highly subsidized electricity tariffs, intensive demand for cooling during the hot summer, and the ambitions for a higher standard of living. Electricity generation increased by 1000% between the years 1985 and 2017, from 3964 GWh to 43843 GWh. Between 2006 and 2016, the average yearly growth of the electricity generation rate was 9.9%, as shown in *Fig. 3*. This rate increased by 27.4% in 2020 compared to year 2016, as shown in *Figs. 3 and 4*. In general, the average electricity production in Qatar is 3600 GWh from January 2014 to December 2020. Qatar Annual Installed Capacity (MW) has increased steadily since 2005, as shown in *Fig. 5*. However, the average growth rate of electricity consumption was 16.9% from 2008 to 2016. Currently, energy consumption per capita in the country is among the highest in the world and growing fast at a rate of 2.6% compared with the growth in income per capita (1%) [38]. Therefore, there is a gap between electricity demand and electricity supply. This forced the authorities to invest in multi-billion-dollar projects aiming for capacity expansion for a new generation, transmissions, and distribution network assets [39]. However, the revenue losses in oil and gas imports since 2014, particularly in 2020, have created a pressing need to utilize the existing assets and energy reserves more efficiently. Therefore, many energy efficiency measures have been implemented, such as promoting energy star appliances. Furthermore, additional savings in cooling load was achieved by increasing the proportion of district cooling [37,40]. Although these measures have boosted energy-saving, meeting peak electricity demand remains a significant issue. For example, in summer 2017, residents experienced several power outages because the system utilization had exceeded 90% of its capacity.

KAHRAMAA provides free electricity for Qatari citizens and subsidized electricity for expats. This is considered a significant issue for electricity consumption and conservation in the country. Free or subsidized electricity does not induce energy conservation by Qatari residents. This energy policy has a negative influence on both electricity consumption and energy efficiency [35]. KAHRAMAA finances the free and subsidized electricity through the State of Qatar budget. Therefore, the electricity market in the country is demand oriented. This policy and the absence of motivation for electricity conservation led to high costs charged to the public budget. However, the positive trends in population growth and rapid economic prosperity encouraged the authorities to sustain the increase in the electricity supply generation [10]. However, the increase in electricity generation does not mean that it will be sufficient to respond to the increase in electricity supply and may result in an electricity shortage. To this end, power and energy policy in Qatar is a strategic challenge engaged with numerous sources of uncertainty in the

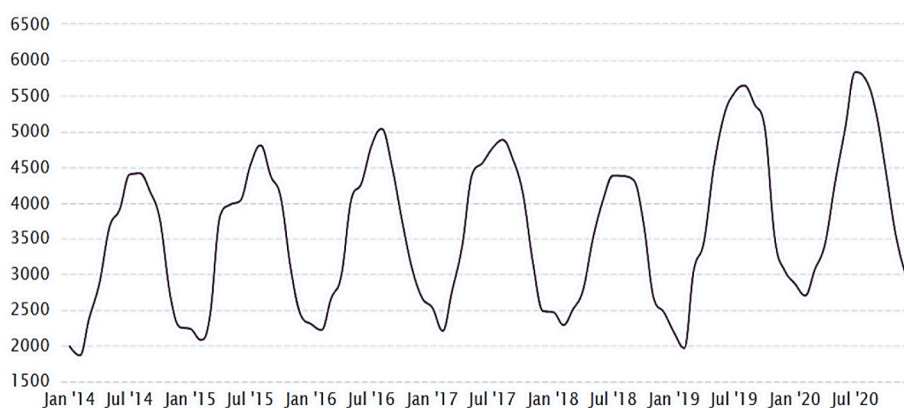


Fig. 3. Monthly electricity generation between 2014 and 2020 (GWh)
(Source: <https://www.ceicdata.com/datapage/en/indicator/qatar/electricity-production>).

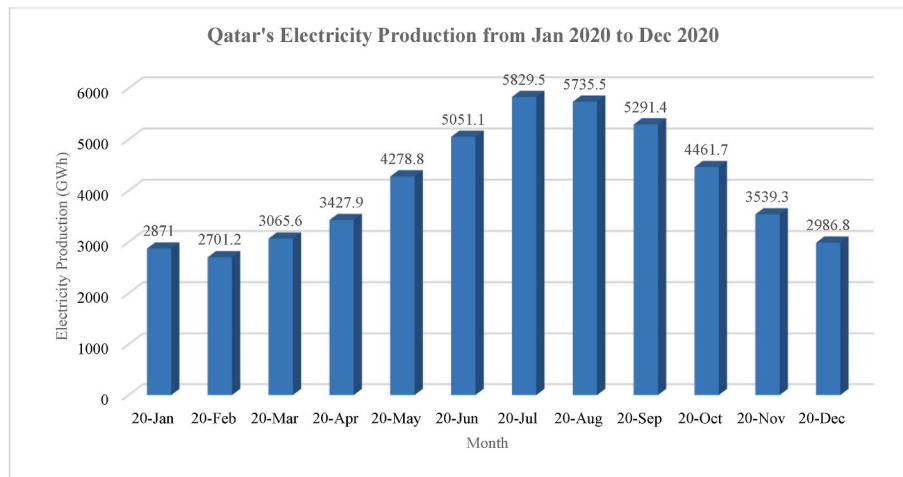


Fig. 4. Qatar's electricity production from Jan 2020 to Dec 2020 (Source: <https://www.ceicdata.com/datapage/en/indicator/qatar/electricity-production>).

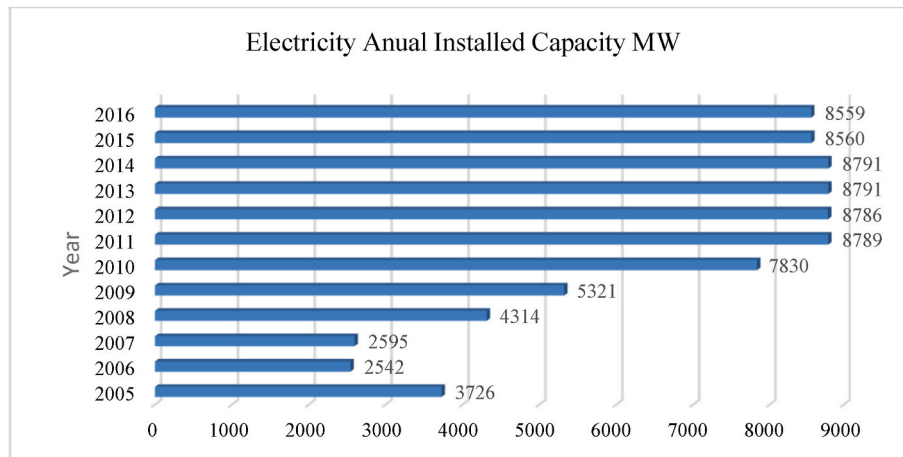


Fig. 5. Qatar annual installed capacity in MW (Source: <https://www.ceicdata.com/datapage/en/qatar/electricity-and-water-statistics/electricity-annual-installed-capacity>).

projection of the demand, and with sets of goals in sustainability and economic growth. This requires policymakers to devise the best set of infrastructure development plans to decide where and when to make investments on advanced technologies via grid expansion planning frameworks.

4. Datasets and methods

4.1. Dataset description

The electricity consumption data used in this study was provided kindly by KAHRAMAA (the Qatar General Electricity and Water Corporation) for the period starting on 1 January 2017 and ending on 31 December 2020 for different socioeconomic sectors. Data were obtained monthly and were provided at a very detailed spatial scale (i.e., meter level) and is measured in KWh for six main sectors: residential villas (villa), residential flat (flat), commercial (com), industrial (indu), production farms (pro), and government (govt). It is worth noting that the monthly electricity consumption data were subjected to rigorous quality control checks to remove meters with missing and zero values in any individual month within the whole study period. Additionally, the block shapefile map was provided by the Ministry of Municipality and Environment (MME). A geodatabase was developed within the GIS environment, and ArcMap 10.7 was utilised to link the electricity

consumption rates to the blocks' boundaries shapefile of the Qatari block geographic units. The electricity consumption readings are spatially joined with the blocks that are located in it to analyze the water and electricity consumption on the finer scale possible.

The energy consumption pattern in Qatar in the six sectors is shown for the last four years in Fig. 6. The figure shows that residential villas and commercial (includes banks, services institutes, SMEs) are extremely relevant in terms of electricity consumption, with relatively stable increased rates over the years prior to the pandemic. The industrial sector is third in terms of electricity consumption. However, Fig. 6 shows that electricity consumption by this sector has fluctuated over the years. The government sector (i.e., ministries, public schools and offices, hospitals, and universities) ranked fourth in terms of electricity consumption, followed by residential flat. The productive farms is the least sector in terms of yearly fraction of total electricity consumption, since this sector is newly developed and is limited in area due to the country's climate and a lack of arable land. These patterns are consistent with the population growth, industrialization, and economic development in the country.

Between the years 2007 and 2010, the number of industries increased from 482 to 611 and the consumption of electricity in the industrial sector increased by about 85% between 1999 and 2011. Conversely, electricity consumption in the residential sector decreased by about 12%. The consumption of electricity in the commercial and

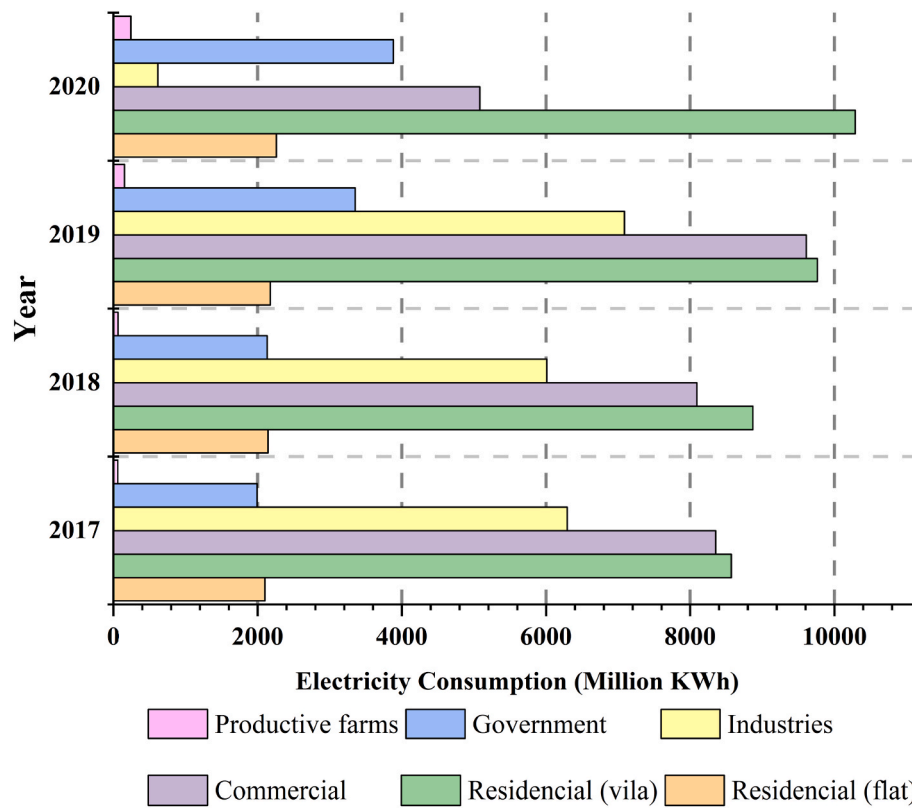


Fig. 6. Energy consumption pattern in Qatar since last 4 years (2017–2020).

government sectors increased by about 295% and 441%, respectively. The price of electricity in U.S. dollars per kWh for these sectors, which includes all components of the electricity bill, such as the cost of power, distribution, and taxes, are shown in Table 1. Fig. 6 shows that there were substantial increases of electricity consumption by sector prior to the pandemic. However, in 2020, there were substantial decreases of energy consumption in different sectors due to lockdown and the closing down of productive activities. In particular, the level of electricity consumption significantly decreased in the industrial and commercial sectors due to their closure.

4.2. Methods

4.2.1. Spatial pattern of electricity demand

We used GIS techniques to investigate the spatial distribution of energy consumption among six different land use sectors. GIS provides different tools to determine the different spatial statistics of any geographical phenomenon. This is a key step to understand the impact of the COVID-19 pandemic on the electricity consumption of different socioeconomic sectors and the geographical impact on electricity consumption due to the imposing of lockdown policies for slowing down the spread of the pandemic in Qatar.

To define the spatial patterns of electricity consumption among different socioeconomic sectors, we employed the Inverse Distance Weighting (IDW) and Kriging for spatial pattern analysis [41–43]. IDW

is a deterministic method that incorporates information on the geographical position for multivariate interpolation with a known scattered set of points [44,45]. This method is characterized in that all the points on the earth's surface, on the basis of distance, are considered to be interdependent [46]. IDW assigns more weight to closer points to estimate the variables of interest. In this study, GIS tools with the IDW method have been used to examine the spatial pattern analysis of electricity consumption for six sectors for the years of 2017, 2018, 2019, and 2020, respectively. Equation (1) has been applied for the spatial modeling of electricity consumption demands in Qatar.

$$Z_p = \frac{\sum_{i=1}^n \frac{z_i}{d_{ip}}}{\sum_{i=1}^n \frac{1}{d_{ip}}} \tag{1}$$

Where, Z_p refers to value of unknown point, Z_i is the value observed at the point of i ; i represents the nearest neighborhood of interpolated point produced; p is equal to inverse distance weight respectively; n is the number of points used in the interpolation procedure for estimating the elevation of point P .

4.2.2. Identification of spatial clustering of energy demand

To define the spatial patterns of electricity consumption across the six socioeconomic sectors, we employed the local Moran's I test, which is a well-established geospatial statistics analysis. This statistical tool is well known in the GIS literature as a strong tool for understanding the

Table 1

Electricity prices per kw per sector (US Dollars) as for February 2021 (Source: Kahramaa - <https://www.km.qa/CustomerService/Pages/Tariff.aspx>).

kw	Residencial (Villa)	Residencial (Flat)	Commercial	Industrial	Productive farms	Government sector
1–2000	0.03	0.03	0.035	0.036	0.02	0.087
2001–4000	0.035	0.035	0.035	0.036	0.02	0.087
4001–10,000	0.05	0.05	0.047	0.036	0.02	0.087
10,001–15,000	0.05	0.05	0.06	0.036	0.02	0.087
15,001 and more	0.07	0.07	0.06	0.036	0.02	0.087

spatial patterns of any geographical phenomenon [47–49]. Moran’s *I* is a measure of spatial autocorrelation of data, allowing us to define spatial clustering of electricity consumption across different socioeconomic sectors and its varying spatial densities. Spatial data are described as random or independent if no patterns for the configuration of these data can be identified; and conversely defined as highly correlated if likely values are spatially close to each other [50,51]. In this study, Local Moran’s *I* has also been applied for better understanding whether the electricity consumption patterns are clustered, dispersed, or random during pandemic and non-pandemic years. Equation (2) and equation

(3) has been used for spatial patterns of electricity consumption demands.

$$I_i = \frac{(x_i - \bar{x})}{s_i^2} \sum_{j=1, j \neq i}^n w_{ij}(x_j - \bar{x}) \tag{2}$$

$$s_i^2 = \frac{\sum_{j=1, j \neq i}^n (x_j - \bar{X})^2}{n - 1} \tag{3}$$

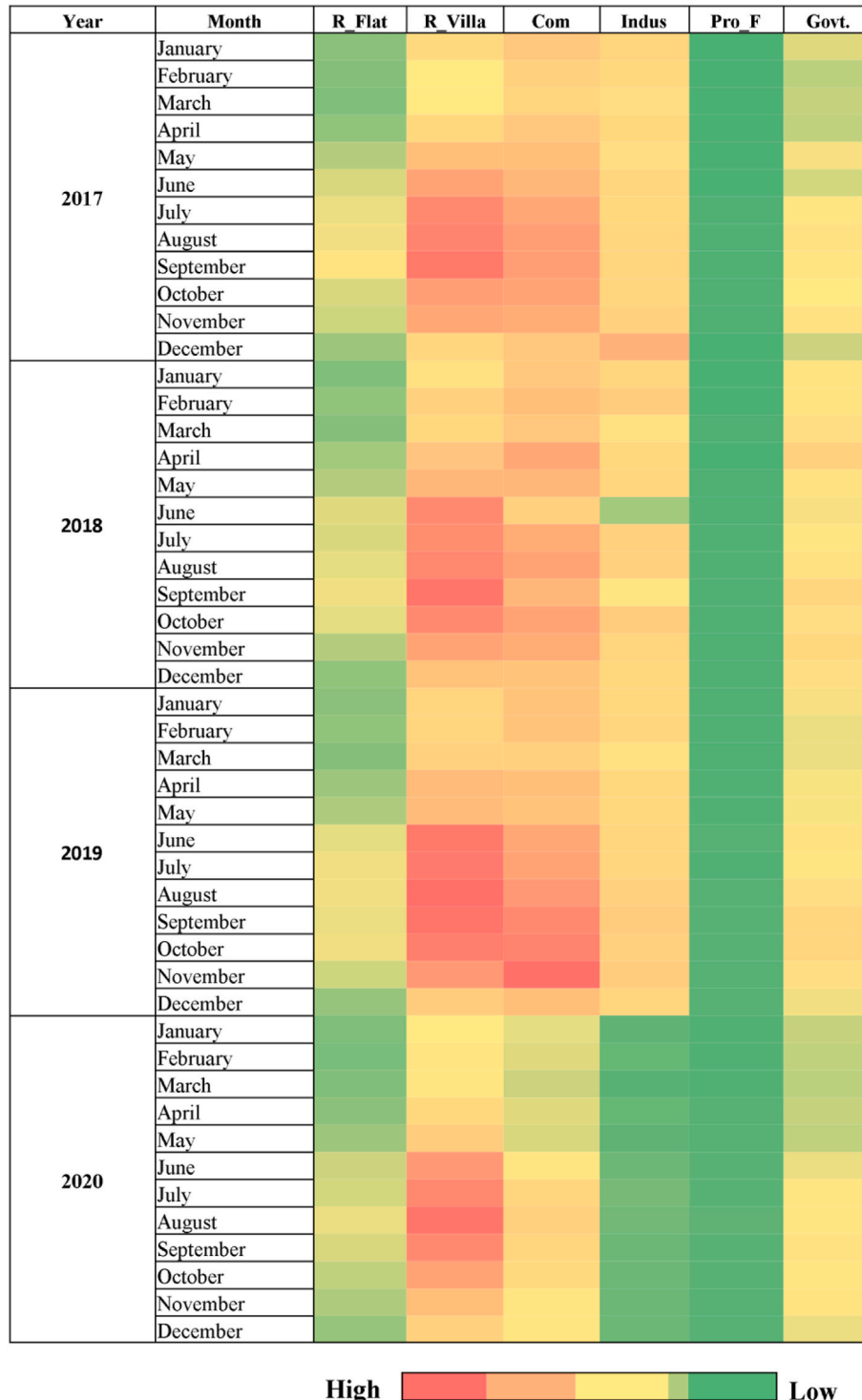


Fig. 7. Heat map showing energy consumption pattern in Qatar in six major sectors since 2017 to 2020.

Where, S_{ij} is the aggregation of all spatial weights, n is the total number of consumer for each sector, x_i and x_j represents the electricity consumption level of i^{th} and j^{th} country; \bar{x} is the mean value of the electricity consumption and w_{ij} is the spatial weight of j and i , respectively.

4.2.3. Statistical analysis

The coefficient of variation (CV) has been used to understand the relative variation of electricity consumption demand in different sectors. The CV is a statistical measure of relative variability and dispersion of data points around the mean. It represents the ratio of the standard deviation to the mean. The CV is a useful statistical measure for comparing the degree of variation from one data series to another. There is a direct relationship between the CV and the dispersion around the mean. The result of the CV is often expressed as a percentage. Furthermore, one-way ANOVA and Post Hoc Tukey HSD analysis was performed to understand the significant variations of electricity consumption patterns in different sectors. In addition, Pearson correlation (r) analysis has been performed to examine the relationship between different electricity consumption sectors.

5. Results

The energy heat map shown in Fig. 7 is normalized by sector to display the electricity usage patterns over time prior and during the pandemic for each individual sector on a monthly basis. The map shows that the commercial and the residential (villas) are the major electricity consumption in the country, particularly during the summer season, prior to the pandemic. This demonstrates the relationship between electricity demand and consumption in different sectors in the country. The heat map shows that there was a sharp decline of electricity demand and consumption in the industrial and commercial sectors during the pandemic. This denotes the substantial impact of the lockdown due to the pandemic on the electricity demand and consumption in these sectors.

Prior to the pandemic, the annual average electricity consumption was 4823 million KWh (between 2017 and 2019) with the highest annual electricity consumption in 2019 (5357 million KWh) followed by 2017 (4562 million KWh), and 4552 million KWh in 2018. In terms of the sectors for the same period, the residential (villas) consumed more electricity than any other sector with an annual average (814 million KWh), followed by commercial (800 million KWh), industry (590 million KWh), government (279 million KWh), residential (flat) sector (181 million KWh), and productive farms (13 million KWh), respectively. On average, the electricity consumption increased by 14% between 2017 and 2019 due to the increase in electricity consumption in all sectors. However, productive farms witnessed the highest increase in electricity consumption, followed by government, commercial, residential (Vila), industrial, and residential (flat) sectors. Table 2 shows the annual variation of electricity consumption between the years 2017 and 2019. The entries in the table, and reflected in Fig. 8, show consistence growth in the residential (villa and flat), government, and productive farms sectors between 2017 and 2019. On the other hand, the industrial and commercial sectors encountered decline in electricity consumption in 2018 compared to 2017 but increased in 2019. The most notable increase is in the productive farms sector as the country tried to achieve

Table 2
Pattern of Electricity consumption growth in Qatar between 2017 and 2019.

Sector	2017–2018	2018–2019	2017–2019
Residential (Flat)	2.03%	1.46%	3.51%
Residential (Vila)	3.51%	10.06%	13.93%
Commercial	−3.12%	18.75%	15.04%
Industries	−4.50%	17.93%	12.62%
Government	7.05%	57.19%	68.27%
Productive farms	5.64%	136.28%	149.61%

food Self-sufficiency after the neighbouring countries imposed blockade on Qatar and stopped exporting the food to the country. This increase in electricity consumption denotes the impact of population growth and economic development on the electricity sector in the country.

During the pandemic, electricity consumption by the commercial and industrial sectors was substantially affected by the lockdown policy, as shown in Fig. 9. The figure also shows that the electricity consumption in the government sector increased during the pandemic, while it fluctuated in both residential sectors based on the months of the year. In general, there was a substantial reduction in electricity consumption, and hence on electricity demand, during the year 2020 in both commercial and industrial sectors. The results showed that the highest annual average electricity consumption in 2020 was 857.35 million KWh from residential (Villa), followed by commercial (423.34 million KWh), government (323.6 million KWh), residential (Flat) (188.14 million KWh), industrial (51.3 million KWh), and Productive Farms (20.20 million KWh) sectors, respectively. However, the industrial and commercial sectors are hardly affected by the lockdown in the State of Qatar. Table 3 shows that electricity consumption in the industrial sector has declined by around 9.5-fold compared to the annual average in the years prior to the pandemic. The commercial sector witnessed reduction in electricity consumption during the pandemic by an average of 70% compared with prior to the pandemic. On the other hand, the electricity consumption in the other sectors has increased during the pandemic compared to previous years, with a noticeable increase in the productive farms and government sectors.

Disaggregating the electricity consumption on a monthly basis (Fig. 9), we notice differences in electricity consumption in these sectors. In terms of the residential sectors (villas and flats), during the first few months of the lockdown (March–May), electricity consumption is within the range of the same period as in previous years. However, electricity consumption increased in the summer months (June–August) compared to the same period prior to the pandemic. The commercial and industrial sectors witnessed a decline in the amount of electricity consumption during the whole year during the pandemic. The higher reduction in electricity consumption occurred during the first few months of the lockdown (March–May). The productive farms sector was not affected by the lockdown policy, as the electricity consumption has increased steadily during all months in the pandemic year. Finally, electricity consumption during the lockdown period witnessed a slight reduction in the government sector compared to the years prior to the pandemic but increased in the summer period.

5.1. Spatial variation of energy consumption prior and during the pandemic

The results demonstrate variations in electricity consumption across the six sectors and this implies in the spatial distribution of these sectors in the country. Figs. 10 and 11 show the spatial distribution of electricity consumption across the six sectors in Qatar prior and during the pandemic, respectively. A comparison of electricity consumption profiles between these sectors clearly shows that some sectors are spatially affected by the pandemic, and hence the pattern and the spatial distribution of electricity consumption has changed in some of these sectors.

In terms of the residential sector, Fig. 10 shows that the residential (flat) is mainly concentrated in Doha city with high electricity consumption prior to the pandemic. This spatial pattern did not change during the pandemic, as Fig. 11 shows. The highest residential (villa) electricity consumption is scattered outside Doha city boundaries and shows variation in energy consumption prior to the pandemic. This spatial pattern did not change during the pandemic. However, as Fig. 11 shows, electricity consumption has increased during the pandemic year in some parts of the country, particularly in the north-eastern area.

Regarding the commercial sector, the figures clearly show that the spatial distribution of the electricity consumption of this sector was severely affected by the pandemic. The commercial services and

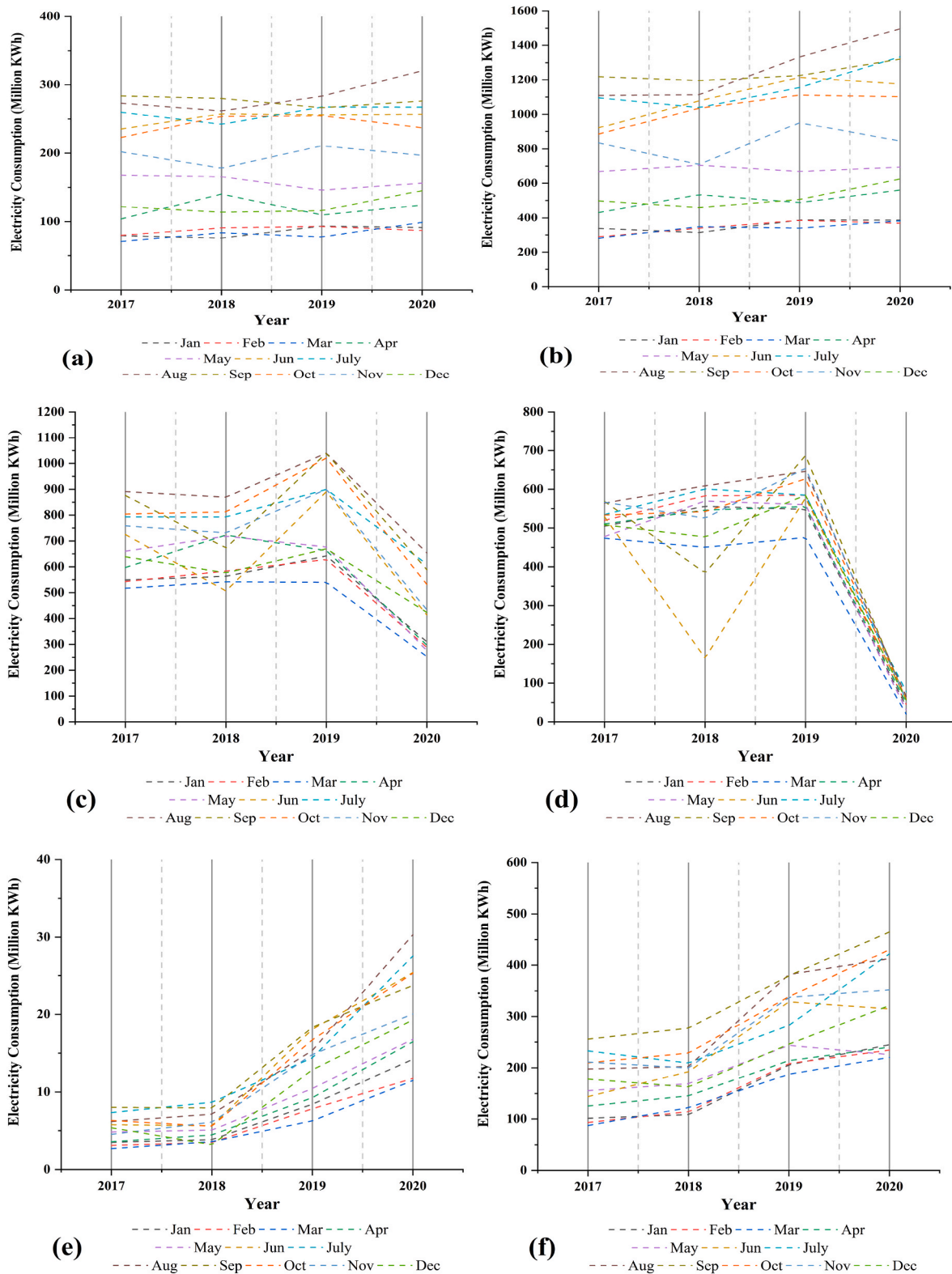


Fig. 8. Annual variation of electricity consumption form six sectors (a) Residential- Flat (b) Residential- Villa (c) Commercial sector (d) Industries (e) Productive Farms and (f) Government sector.

activities were distributed in many areas across the country prior to the pandemic (Fig. 10). However, after imposing the lockdown policy, and the gradual restriction on activities to mitigate the spread of the virus, many commercial activities were asked to close, which led to a considerable reduction in electricity consumption. The commercial

services during the pandemic were concentrated in the northern parts of the country, as shown in Fig. 11.

The reduction in the spatial distribution of electricity consumption is more noticeable in the industrial sector. The industrial areas are concentrated in the northeast and southeast of the country. Fig. 11



Fig. 9. Monthly variation of electricity consumption form six sectors (a) Residential- Flat (b) Residential- Villa (c) Commercial sector (d) Industries (e) Productive Farms and (f) Government sector.

Table 3
Changes of percentage of electricity consumption pattern during the pandemic compared to prior to the pandemic.

Sectors	2019–2020	2018–2020	2017–2020	Average
Residential (Flat)	7%	5%	4%	5.33%
Residential (Villa)	17%	14%	5%	12%
Commercial	−64%	−59%	−89%	−70.67%
Industries	−922%	−876%	−1051%	−946.67%
Productive farms	75%	73%	37%	61.67%
Government	49%	45%	14%	36%

shows a high decline in electricity consumption in the industrial area in the northeast of the country, and a less but noticeable reduction in the southeast industrial area in the country compared to the period prior to the pandemic. This is mainly a direct consequence of lockdown policies, in which many factories and manufacturing activities were closed as a mean for curbing the spread of the disease. Finally, the electricity consumption of the productive farms was not affected by the pandemic as they are spatially distributed outside the main cities, and was not included within the geographical coverage of the lockdown. In addition, the number of workers in this sector is usually small compared to other sectors, and the precaution measure, such as physical distancing, can be

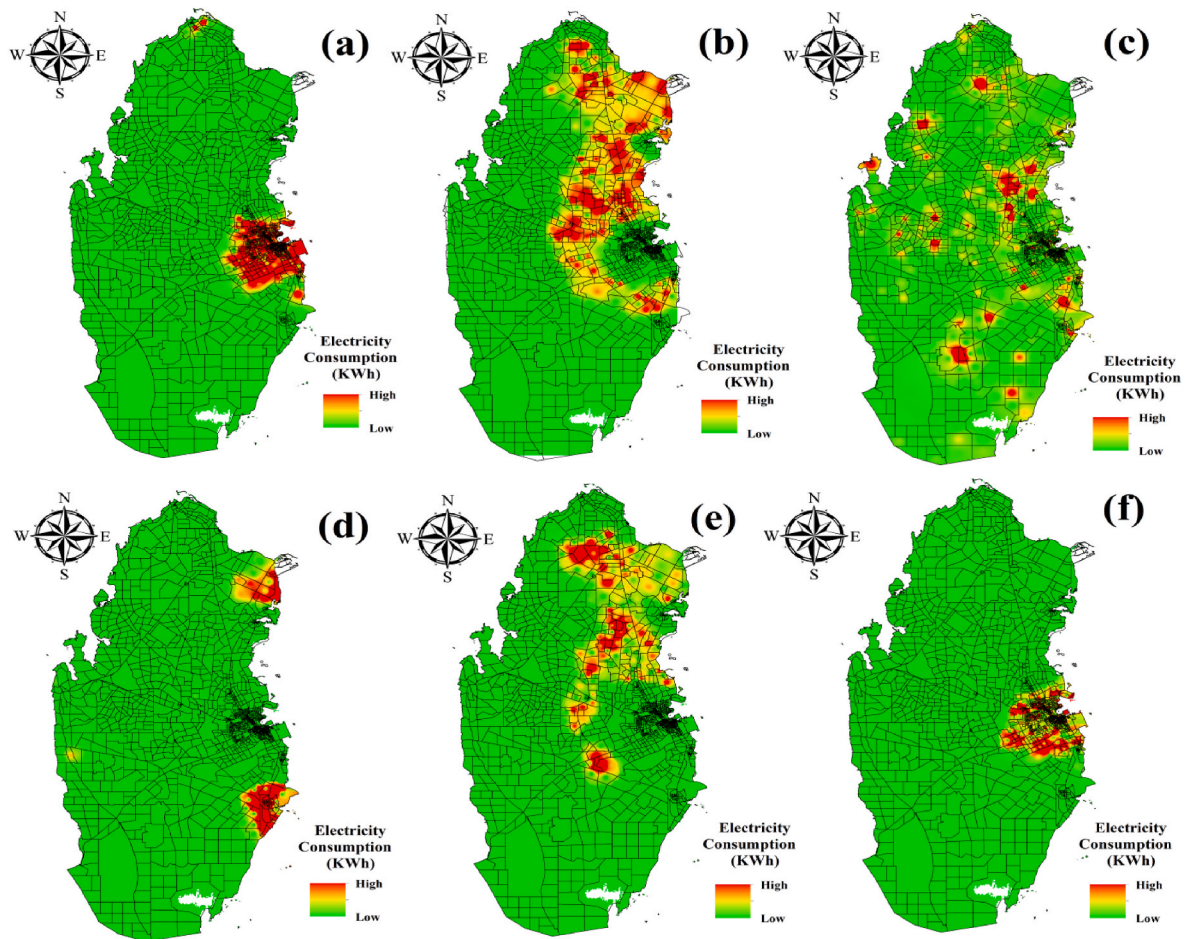


Fig. 10. Spatial pattern of energy consumption (KWh) in 2017 (Non-Pandemic year) (a) Residential- Flat (b) Residential- Villa (c) Commercial sector (d) Industries (e) Productive Farms and (f) Government sector.

applied easily in this sector.

The statistical analysis has been performed for better understanding the electricity consumption pattern in Qatar during the COVID-19 pandemic year. The results of the CV show differences between the different sectors, as shown in Table 4. The highest variation occurred in the productive farms sector due to its massive development during the pre-pandemic period. Furthermore, the results clearly show that the industrial and commercial sectors are affected by the pandemic, as the variation is higher than the other sectors.

Table 5 shows the correlation between different electricity consumption sectors. The results show a positive correlation between different electricity consumption sectors with strong positive correlation between residential (villa) and residential (flat) ($r = 0.982$), residential (villa) and commercial ($r = 0.982$), residential (flat) and government ($r = 0.945$), residential (flat) and productive farms ($r = 0.982$), commercial and productive farms ($r = 0.952$), respectively, as shown in Table 5 and reflected in Fig. 12. Furthermore, the one-way ANOVA and Post Hoc Tukey HSD test shows that there was significant variations of electricity consumption patterns in different sectors (the significant level was tested at 0.05). The p value was <0.0001 , which clearly denotes the fact that there were significant variations of energy consumption in different sectors during pandemic and non-pandemic periods.

The spatial clustering of electricity consumption of the six sectors during the pandemic year (2020) and the non-pandemic year (2019) are shown in Figs. 13 and 14, respectively, during the same time based on Moran's I test. From the figures, it was observed that there were variations of spatial clustering of electricity consumption among different sectors. For example, most of the high-high clustering patterns are

located in the mid-eastern and north-eastern parts of Qatar. These areas are mostly dominated by residential sectors (both Villa and Flat), productive farms, industries, and commercial areas, respectively. The significant level of the clustering maps was also produced at 0.05, 0.01, and 0.001 level. As per the result, it was observed that most of the clustering of electricity consumption were significant at 0.01 and 0.001 levels of significance. Western and south-eastern parts of Qatar are uninhabited and results showed that these areas are not significant in terms of electricity consumption.

6. Discussion

This study aimed to investigate the impact of the COVID-19 pandemic on electricity consumption in six different socioeconomic sectors in the State of Qatar. The key findings from this research were that electricity consumption in these sectors was affected differently due to the lockdown policies adopted by the country, and that electricity consumption among these sectors vary geographically. The electricity consumption dropped significantly in the industrial and the commercial sectors with confinement measures but increased in the other sectors. Although the strict implementation of the lockdown policy was between the months of March and June, the industrial and commercial sectors were unable to recover as lockdown policies were gradually softened.

The residential (villas and flats) sectors witnessed a slight increase in electricity consumption during the first few months (March–May) of 2020, due to lockdown policies, compared to the same period prior to the pandemic (between 2017 and 2019). The most noticeable increase in electricity consumption in this sector was during the summer months

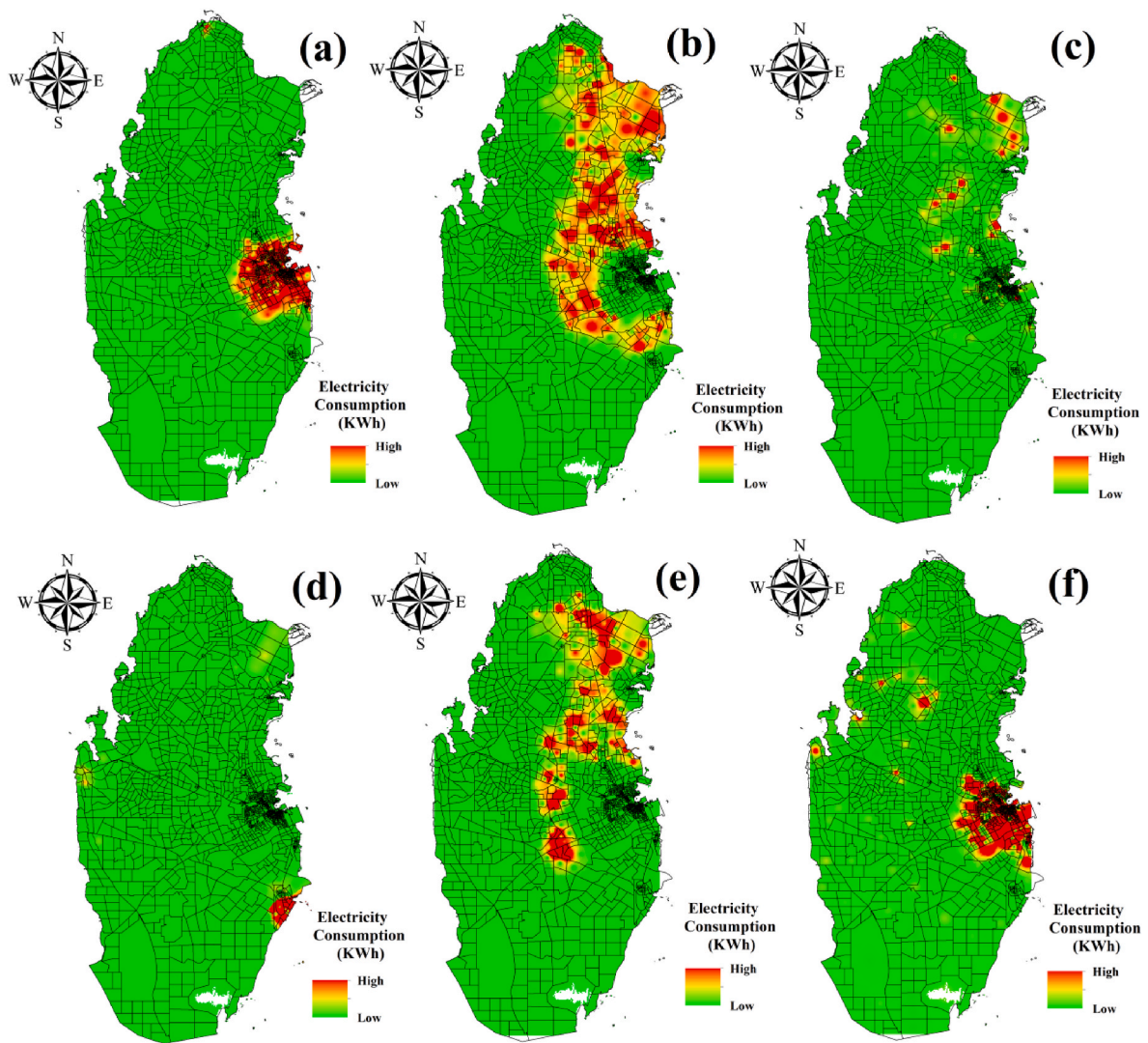


Fig. 11. Spatial pattern of energy consumption (KWh) in 2020 (Pandemic year) (a) Residential- Flat (b) Residential- Villa (c) Commercial sector (d) Industries (e) Productive Farms and (f) Government sector.

Table 4
CV with SD and mean energy consumption since last ten years.

Statistics	Sector					
	Residential (flat)	Residential (Vila)	Commercial	Industries	Government	Productive farms
Mean	2170.01	9372.49	8869.70	5743.50	3776.44	58.40
SD	400.96	2253.16	2538.98	2201.61	959.35	81.34
CV (%)	18.48	24.04	28.63	38.33	25.40	139.27

Table 5
Correlation between different energy consuming sectors.

Sectors	Residential (flat)	Residential (vila)	Commercial	Industries	Government	Productive farms
Residential (flat)	1.000					
Residential (vila)	0.982**	1.000				
Commercial	0.982**	0.932**	1.000			
Industries	0.691*	0.600	0.600	1.000		
Government	0.945**	0.955**	0.955**	0.555	1.000	
Productive farms	0.982**	0.961**	0.952**	0.600	0.955**	1.000

**Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

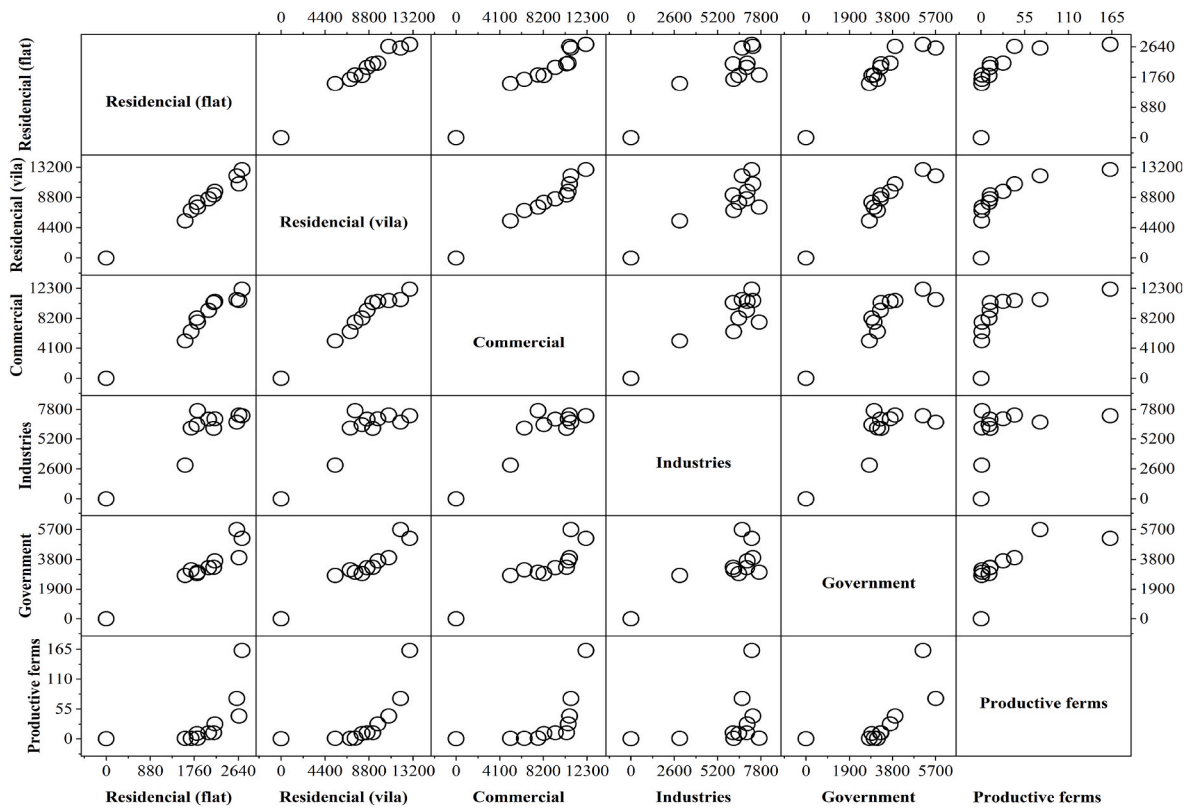


Fig. 12. Scatter plot showing relationship between sectors of energy consumption.

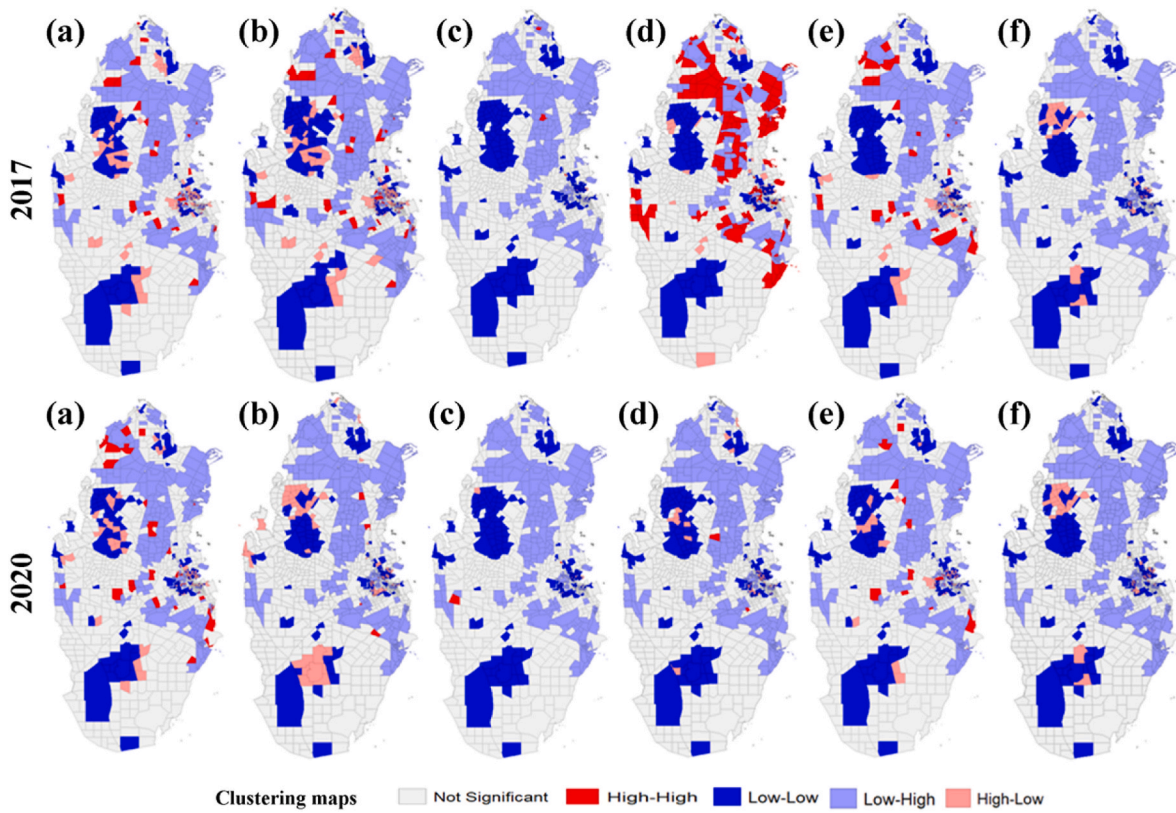


Fig. 13. Spatial clustering of energy demand during non pandemic (2017) and pandemic year (2020) (a) Residential- Flat (b) Residential- Villa (c) Commercial sector (d) Industries (e) Productive Farms and (f) Government sector.

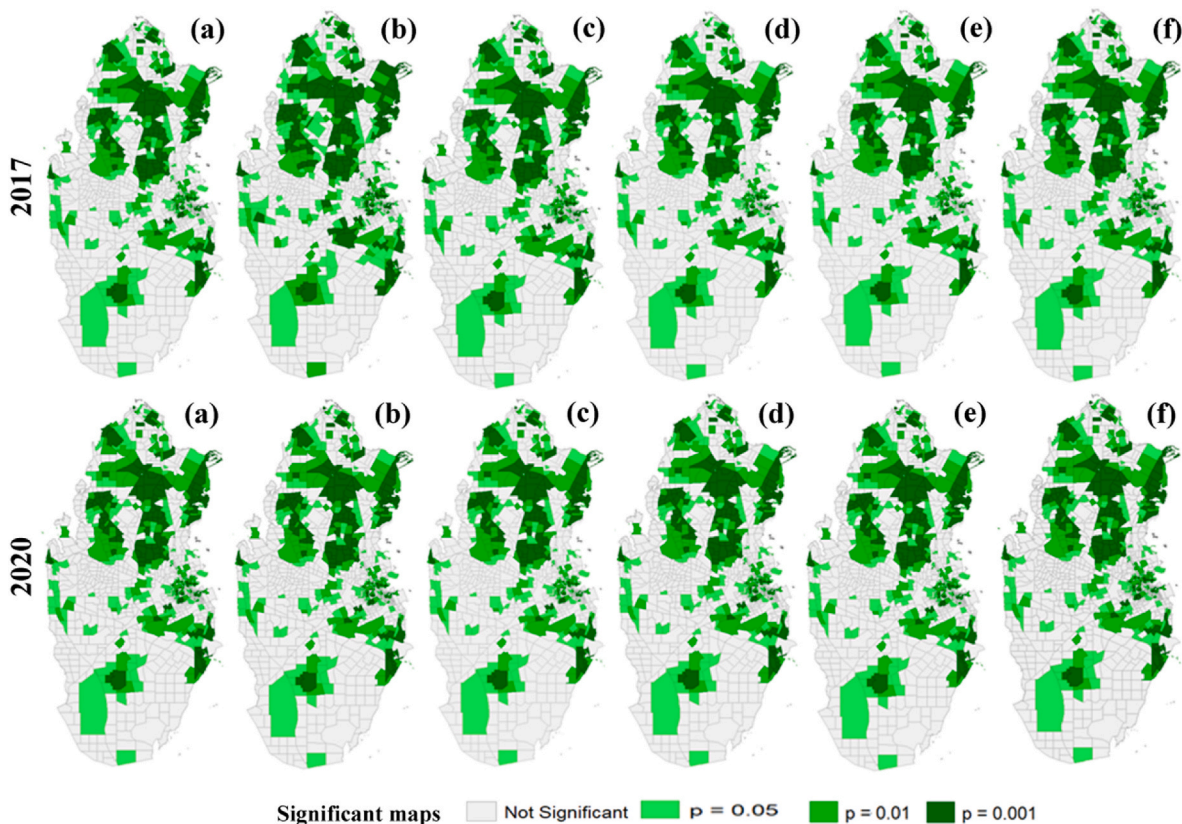


Fig. 14. Significant maps of energy demand from six sectors during non pandemic (2019) and pandemic year (2020) (a) Residential- Flat (b) Residential- Villa (c) Commercial sector (d) Industries (e) Productive Farms and (f) Government sector.

(June–August) compared to the same period prior to the pandemic. This trend occurred for varied reasons. First, during the first months of the lockdown, residents were asked to stay at home, and hence people have spent more time at home. However, the slight increase in electricity consumption is because KAHRAMAA provides free water and electricity for citizens (Qataris) and subsidizes tariffs for non-citizens (expatriates). Prior to the pandemic, this policy did not incentivize residents to practice electricity conservation habits, and hence had a negative impact by increasing the electricity consumption of many households. The stay-at-home policy and the absence of incentives for electricity conservation led to the higher consumption of electricity at the household level in the residential sector. Second, the noticeable increase of electricity consumption during the summer months compared to the period prior to the pandemic is due to the stringency of restrictions on traveling outside the country. Many Qataris usually spend the summer months outside the country due to the high temperatures and humidity. Likewise, expatriates living in Qatar travel home to spend their vacations with their families, thereby escaping the country's heat. During the summer of 2020, the majority of expats preferred to stay in the country because of the restrictions imposed on travel by many countries around the world, including Qatar and their native countries, and due to the uncertainty of whether or not they would be able to return to Qatar and keep their jobs. Residents' decisions to avoid traveling in the summer resulted in the increase of electricity consumption, particularly through the use of air conditioning, which is the country's main source of electricity consumption. Third, many of the expat workers left the country because of the shutdown of many services, commercial, and industrial activities, particularly after the first few months of the lockdown. This resulted in an elevation of electricity consumption in the residential sector at the beginning of the lockdown period, but did not affect electricity consumption during the summer.

The commercial sector witnessed a sharp decline in electricity

consumption during the pandemic due to the lockdown policy. All non-essential services were closed, including retail outlets, restaurants, malls, small businesses, companies, banks, and so on. When the lockdown was eased, the commercial sector could not recover fully because the closure of commercial services resulted in the permanent closure of many companies, shops, and other businesses, which played a significant role in reducing the electricity consumption during the pandemic. Prior to the pandemic year, the commercial sector benefited from the tariff subsidy. As such, this policy has had a negative impact on both electricity consumption and energy efficiency, since the probability of reducing electricity costs due to energy efficiency improvements is likely to be smaller than the costs sustained for efficiency improvements. The data in this study reflects the electricity consumption for around 46,000 entities classified as commercial, and hence the reduction of around 40% of energy consumption during the pandemic year compared to the pre-pandemic period is strong evidence on the impact of the COVID-19 pandemic on the Qatari economy.

The most affected sector by the pandemic and the lockdown policies is the industrial sector. Prior to the pandemic, the government significantly promoted the industrial sector (both heavy and light industries). The major industries are steel and iron, fertilizers, petrochemical industries, and cement industries. The industrial sector witnessed significant development prior to the pandemic, particularly after the blockade imposed on Qatar by Saudi Arabia, United Arab Emirates, Bahrain, and Egypt. The first spread of the disease was in the industrial area in Doha city. Authorities closed this area for a few months from March 2020, which resulted in a decrease of electricity consumption in this area. Furthermore, due to restrictions on the movement of goods caused by the pandemic, and because the Qatari market is small and that Qatar depends on the export of these heavy industrial products, the production of these commodities was reduced significantly, resulting in a reduction of electricity consumption by this sector. Furthermore, the

countermeasures adopted by many countries to curb the spread of the disease has resulted in severe shocks to the energy sector. Oil and gas prices witnessed a significant decline due to the decline in global demand for these resources, as well as the less flexible extraction of these resources. Qatar is one of the main producers of gas and oil globally and depends on the revenues from selling these resources to develop its economy. This drop has also affected the industrial sector in the country and, in turn, affected electricity consumption.

The findings of the study also show that electricity consumption in the government sector has increased despite the changes in the spatial distribution of this consumption. Prior to lockdown, the electricity consumption increased in this sector due to its expansion. This sector witnessed a reduction in electricity consumption during the months of April and May 2020 compared to the same period prior to the pandemic, and which was mainly due to restrictions imposed to slow down the spread of the disease. However, in the summer months, electricity consumption increased due to restrictions imposed on mobility and traveling outside the country, and hence many employees did not have the chance to take their vacation and travel outside the country. Many governmental institutions outside Doha city were closed to reduce public gatherings, and hence the spatial distribution of electricity consumption was reflected on the map for the pandemic year.

The productive farms sector has expanded during the last four years in Qatar, mainly due to the blockade in 2017. The country used to depend on importing food from other countries, particularly Saudi Arabia and the United Arab Emirates. However, following the blockade, the country invested in this sector and has since continued to expand it. This resulted in an increase of electricity consumption prior to the pandemic and this trend continued during the pandemic. This sector is isolated and geographically distant from areas of high population concentration. As such, with the precautionary measures put in place, workers can safely perform their work. Furthermore, this sector is essential in satisfying the local market needs for fruit and vegetables, and therefore cannot be shut down.

Mapping the electricity consumption by sector over space and time shows where, when, and why the electricity consumption has changed. In terms of geographical distribution, the maps show that electricity consumption has notable local properties with significant spatiotemporal agglomeration and clustering. These maps enable policymakers to identify spatial areas with high electricity consumption with a higher certainty. Furthermore, mapping the statistical significant cluster of electricity consumption's high values can provide spatially explicit information and can be considered as a spatial guideline for policy-makers to manage the electricity demand and consumption at the time of risk and to identify the factors that lead to high electricity consumption in specific areas. Furthermore, these maps enables authorities to scale up intervention pathways to assess the sectorial demand's dynamic due to forcing various mitigation and restriction measures to reduce the risk of the spread of the disease.

Thus, the outcomes of this study align with the outcomes of other studies in other countries across the globe. During the pandemic year, many countries encountered a reduction in electricity consumption, as shown in Table 6. This illustrates not only the impact of the pandemic on the electricity sector, but it reflects the impact of the pandemic on the world's economy and development as the electricity sector plays a key role in sustaining economic growth and development.

7. Conclusion and policy implications

This study aimed at examining the impact of the outbreak of the COVID-19 pandemic on electricity consumption patterns and the spatial distribution of this consumption in Qatar in different socioeconomic sectors. GIS techniques and various spatial statistical analyses were used to assess the impact of the COVID-19 pandemic, and the associated policies and measures imposed by the State of Qatar, on electricity consumption. There is a need to assess the spatial impact of lockdown

Table 6

The impact of COVID-19 on electricity consumption pattern in different countries in the world.

Study country	Sources	Major findings
Spain	[52]	Electricity consumption declined by about 3% in March, and 24% in April (2020) in comparison to previous year during same time.
Singapore	[53]	Electricity consumption significantly decreases during lockdown periods.
France	[54,55]	During pandemic periods, 380 TWh electricity generation will be affected.
Germany	[56,57]	There was substantial reduction of electricity consumption but consumption of renewable Electricity increased by about 41% during COVID-19.
India	[58,59]	There was huge loss of revenue (about 7.2 billion US dollar) due substantial reduction of electricity demand.
Italy	[52]	During the month of March and onwards, electricity consumption decreased by 10.1%. The consumption of renewable was significantly increased.
United State	[60]	During COVID-19 periods, electricity consumption to residential sector increased by 20% and decreased to industrial sector (by about 4.2%).
United Kingdom	[52]	Power consumption declined by about 10% after March in 2020.
Australia	[61]	Electricity consumption particularly in industrial and commercial sectors decreased by 1% and 7% respectively.
Kuwait	[62]	Power consumption decreased by about 17.6% due to COVID-19 in 2020.
Ukrain and Hungary	[63]	Electricity consumption significantly decreased during lockdown periods.

and stay-at-home policies on the spatial consumption of electricity in order to identify the most affected places and sectors.

The findings of this study showed that the industrial and commercial sectors were the most affected by the pandemic. There was a substantial reduction in electricity consumption in these sectors, which indicates that the economy of the country has been negatively affected by the pandemic and the associated measures taken to slow down the spread of the disease in the country. Conversely, the production farms sector was not affected by the spread of the disease. This sector witnessed significant development during the past few years driven by the blockade that was imposed on the country in 2017. On the other side, the electricity consumption in the residential (villas and flats) and the government sectors witnessed a substantial increase during the summer months only during the pandemic year.

The spatial and temporal analysis of electricity consumption across different socioeconomic sectors is important to the authorities to promote their response in planning for electricity demand, production, and supply. This analysis is vital for policymakers to detect the changes in electricity consumption patterns in the context of emergencies such as the pandemic. Increasing or decreasing the electricity demand and consumption in the six sectors require planning for sustainable management of resources at the time of risk to avoid weakening the fiscal situation and the country's economic development. This creates a situation where policymakers should adopt alternative fiscal and non-fiscal tools (such as using renewable energy) in areas witnessing high demand of electricity. The maps generated in this study show the development and the dynamic changes in hot spot and cold spot areas through time, which gives the authorities the opportunity to assess the transformation of power supply from using fossil energy to low carbon green energy. Furthermore, authorities should consider and encourage electricity service policies that aims in reducing the electricity consumption in residential sector in time of risk. Furthermore, the findings suggest that authorities develop policies that encourage the trade in and the use of the utilization of high-energy-efficiency equipment in the residential sector to make the social well-being and economic development mode healthier, dynamic, and resilience. The propagation of the disease

promote teleworking (home office schemes) practices that might become a normal pattern in the near future and hence the authorities should develop policies to promote energy to achieve sustainable management of electricity resources and achieve more environmental friendly behavior.

Although the government of the State of Qatar announced supportive packages to support and protect its economy from the negative impacts and against the harmful damage of the pandemic, the reduction in the electricity consumption in both the industrial and commercial sectors is a strong indicator of the negative impact of the pandemic on the Qatari economy. Easing the lockdown measures was not enough for these two sectors to recover and hence the authorities needs to take more steps to achieve economic recovery. Furthermore, the authorities must work on changing the residents' behavior toward electricity consumption either by awareness campaigns or by increasing the electricity prices.

Credit author statement

Ammar Abulibdeh: Conceptualization, Methodology, Data Curation, Formal analysis, Writing - Original Draft, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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