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Impacts of COVID-19 on Kuwait's electric power grid

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ABSTRACT

In response to a request from Kuwait's Ministry of Electricity and Water, a resource adequacy model was developed to assess Kuwait's ability to supply sufficient energy to meet the load demand during the COVID-19 pandemic. Power system operators and utilities use this type of model to ascertain their ability to meet demand, most notably peak demand. The model includes active power loss as well as the loss of resource capacity under medium and large contingencies. As resource adequacy models do not take into account security constraints such as transmission limits and voltage, they cannot be used for operations. However, due to their simplicity, they are appropriate for studying a wide range of scenarios for formulating policy decisions. Resource adequacy analysis can provide valuable insights into the performance of a system under urgent conditions such as the one posed by COVID-19 and similar unforeseen disruptions. This model utilizes an analysis of historical load data to forecast the 2020 peak load and develop a number of scenarios to test the capacity margin of Kuwait's power system. The scenarios vary based upon load growth (2–25 %) and whether there is an outage or unavailable generation (no outage, 720 MW outage, 1440 MW, and 2400 MW outage).

1. Introduction

Kuwait spared no effort in its extensive preparations to aggressively contain the COVID-19 pandemic and prevent the spread of infections. Kuwait imposed a stay-at-home order, curfews and eventually, a full lockdown. The extraordinary comprehensiveness of the government's response has led to some concern as to whether Kuwait could sustain supplying its electricity needs during pandemic conditions, especially during the summer when extraordinary demands are placed on the electricity grid due to high temperatures alone.

While certain countries are experiencing a decline in electricity demand due to halting of manufacturing and economic activities because of government-imposed lockdowns, Kuwait may experience the opposite since its industrial sector does not compare to other countries. In many other nations with larger industrial consumers, during the pandemic electric energy demand dropped due to the imposed lockdowns, preventing the continuation of their operation. While the International Energy Agency (IEA) and British Petroleum (BP) Energy Outlooks (IEA, 2019) both (BP Energy Economics, 2020) forecast rising electricity in 2020, the IEA reported a steep decline in electricity demand due to lockdown measures (BP Energy Economics, 2020). Generation from coal, oil, gas, and nuclear all declined, with only electricity from renewables increasing. Forecasts from the IEA (BP Energy Economics, 2020) estimated that demand could fall to 10 % in certain regions and demand could decline as much as 20 % in regions with full lockdown measures. However, the IEA reported that residential electricity increased as result of the lockdown measures (BP Energy Economics, 2020).

However, in Kuwait, the most significant demand for electricity needs is not made by the industrial sector; instead, it is correlated with space cooling requirements – especially in the summer months. Complicating any analysis, Kuwait's government has coordinated a massive repatriation effort to protect its citizens from COVID-19, thus making it difficult to ascertain the residential demand for space cooling. Nevertheless, it is recognized that the extent of the demand for residential space cooling may put additional stress on the power grid. According to the Kuwait Energy Outlook (KEO), residential electricity demand could grow to 34.4 TW h in 2035 (Maylshev et al., 2019), an increase from 27.2 TWH in 2015, largely driven by the need for space cooling and the high rate of subsidization (94 % as of 2020 (Al-Abdullah et al., 2020)). Kuwait spent approximately 6 billion US dollars in 2017 on energy subsidies, most of which were allocated to electricity (Taylor,

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2020). Thus, Kuwait may not have experienced a load drop during the pandemic but may have even faced a load increase. Therefore, this analysis seeks to assess the ability of the Ministry of Electricity and Water (MEW) to meet electricity demand under these extraordinary circumstances and investigate whether the MEW can meet Kuwait's electricity needs. The Kuwait Institute for Scientific Research (KISR) has partnered with the MEW to develop a resource adequacy (RA) model. This type of model assists system operators by assessing if the supply (generation) is able to meet the demand (consumption plus losses). The model is used to evaluate numerous scenarios, including extreme load growth and generation outages. However, due to a lack of adequate data, the outage was applied across the entire time horizon for each scenario and thus ramping events are not considered as well. Due to urgency, this model was developed with the data that was immediately available, in order to provide insights into the stakeholders in a timely fashion.

In the past two decades, Kuwait has increased its capacity from 9.2 GW in 2000 to 19.5 GW in 2019 (Ministry of Electricity & Water, 2019a, b). Based on the analysis offered in this paper, Kuwait's power system has the adequate capacity margin needed for reliable delivery of power under most probable scenarios. Only under extreme circumstances (25 % load growth and the outage of 2400 MW of capacity) will the country face mild capacity shortages. Depending upon developments and operations, Kuwait may even be able to sell electricity to neighboring GCC countries.

Previous studies of Kuwait mainly investigated the development of supply and sustainability. In 2012, Kuwait set a goal of meeting 15 % of electricity from renewables by 2030 (Al-Abdullah et al., 2020). In (Alsayegh and Fairouz, 2011), Kuwait's power system was modeled with increased renewable energy generation and potential effects on the grid. The work from (Alsayegh et al., 2018) was further extended in (Alsayegh et al., 2018) where a sustainable energy strategy was proposed for all sectors in Kuwait. Another study (Mohammadi et al., 2019), developed a day-ahead unit commitment model specifically with Kuwait in mind for the coordinated scheduling of water desalination in the power system. The authors of (Wood and Alsayegh, 2012), developed an electricity and water demand model for Kuwait. Results show that electric power demand is highly correlated with Kuwaiti population and GDP, water consumption and Kuwaiti population, non-Kuwaiti population and GDP, and GDP and oil income, electricity and water demand and future mega projects. Their model was developed to simulate demand for the period of 2010–2030 based on high, base, and low oil prices. The authors of (Wood and Alsayegh, 2012) extended their work in (Wood and Alsayegh, 2021). Simulations in (Wood and Alsayegh, 2021), again were for three scenarios of oil prices (high, base, and low) and additionally two government policies that affect economic diversification and energy conservation. The authors found that government intervention, the second policy, can significantly reduce electric power demand.

In this paper, the authors forecast the electricity demand in Kuwait for the duration of the 2020 COVID-19 pandemic under five load growth scenarios. Utilizing these scenarios, a model has been developed to demonstrate whether Kuwait's generation capacity is adequate to meet the demands of the crisis. This was done by first describing the framework of the model and its underline assumptions. Then, the impacts of COVID-19 on Kuwait's load curve are discussed. Finally, results are presented along with outcomes and recommendations. The purpose of this study is to add to the literature by providing insights into Kuwait's electric power system and determining its resiliency under the duress of the COVID-19 crisis. Although there have been extensive investigations into resource adequacy models, especially for electric energy markets, there are few studies specifically on Kuwait and fewer specifically on the requirements of the COVID-19 crisis, which is unique in the history of the world. This paper provides context on how the demands of diverting substantial resources to combating the pandemic could affect Kuwait's electric power system.

2. Literature review

Resource adequacy models have been utilized by Independent System Operators (ISOs) and Regional Transmission Operators (RTOs) in the United States. The Pennsylvania-New Jersey-Maryland (PJM) Interconnection utilizes a similar framework in their planning initiatives. As part of the resource adequacy process, PJM develops an annual load forecast and reserve requirements whose results are utilized in PJM's Capacity Exchange (Pennsylvania-New Jersey-Maryland (PJM) Interconnection, 2019; PJM Resource Adequacy Planning Department, 2019). The New York ISO (NYISO) performs a review of RA for its territory, with a period of study from 2019 to 2023 in the latest annual report (New York Independent System Operator, 2019). Likewise, in 2004, the California Public Utility Commission (CPUC) formulated a resource adequacy policy in California to ensure the reliability of electric service. This policy established RA obligations for all Load Serving Entities in the jurisdiction of CPUC, including investor-owned utilities, energy service providers, and community choice aggregators (California Public Utility Comission, 2021). The policy guides resource procurement and promotes infrastructure investment. In (Siddiqi, 2007), the author describes the history of resource adequacy in the jurisdiction of the Electric Reliability Council of Texas (ERCOT), which runs an "energy-only" market. It is noteworthy that according to (Siddiqi, 2007), "ERCOT stakeholders viewed any mandated capacity market as a regulatory intervention and a subsidy that is likely to lead to greater reliance on regulatory processes to ensure resource adequacy."

RA models have been proposed to examine flexible resource requirements for power systems with high penetration of renewables (Tanabe et al., 2017). In (Aghaie, 2016), the authors analyze the impact of the high penetration of renewables in the German market and propose a model to deal with uncertainty due to renewables. Kwon et al. (2020) proposed an energy generation framework with a high degree of variable renewable energy resources that included different market designs to achieve resource adequacy resulting in a competitive market. Their formulation considered markets for capacity, energy and reserve products, leading to a more efficient analysis of generation, expansion, and revenue sufficiency in competitive markets. Included in their analysis is a case study of the ERCOT system with a comparison of the results, which demonstrated the effectiveness of their model and the importance of assessing strategic behavior in a competitive market framework.

RA has been extensively studied for electricity market design. Hogan (2005) argued that the trend toward greater regulation designed to ensure resource adequacy can be avoided by using transparent scarcity pricing, thus providing better incentives for operations and investment. Improving the market design would not eliminate the need for all regulatory intervention but would permit market-based solutions that would not disrupt the market. In a study of Australia's electricity market, Simshauser (2019) traced market imbalances to policy decisions made a decade earlier. He cited lack of reserve notices, blackouts, a black system event and record level forward prices as events that occurred as a result. He recommended transparency regarding exit decisions, policy stability, and limits on gas exports. Earlier, in 2010, Simshauser (2010) had warned that energy-only markets are likely to experience a resource adequacy problem regarding the opening of new generation. He noted that in competitive energy-only markets, generation companies struggle to be profitable, given reliability constraints and caps on market prices. After Australia's government withdrew direct investment, the industry met the challenge of resource adequacy by having utilities with investment-grade credit ratings set retail prices to "beat" a long-run marginal cost floor. Bushnell (2005) of the University of California - Berkeley, focused his attention on the competing views about what policy goals for resource adequacy in electricity markets were to be achieved and the means of achieving them. He examined motivations for policies and how the policies either address or conflict with these goals.

It should be noted that resource adequacy models do not take into

Table 1
Portion of the generation data provided and used for the resource adequacy model.

Unit-ID	Unit Type	Max Net Available Power	Min. Net Available Power	Commissioning	Decommissioning
DEPS-U1	Steam Turbine	130	37	1977	2022
DEPS-U2	Steam Turbine	130	37	1977	2022
DEPS-U3	Steam Turbine	130	37	1978	2022
DEPS-U4	Steam Turbine	130	37	1978	2022
DEPS-U5	Steam Turbine	130	37	1978	2022
DEPS-U6	Steam Turbine	130	37	1979	2022
DEPS-U7	Steam Turbine	130	37	1979	2022
DEGT-1	Gas Turbine	15	10	1979	2022
DEGT-2	Gas Turbine	15	10	1979	2022
DEGT-3	Gas Turbine	15	10	1979	2022
DEGT-4	Gas Turbine	15	10	1979	2022
DEGT-5	Gas Turbine	15	10	1979	2022
DEGT-6	Gas Turbine	15	10	1979	2022
DWGT-1	Gas Turbine	28.0	18	2008	2040
DWGT-2	Gas Turbine	28.0	18	2008	2040
DWGT-3	Gas Turbine	28.0	18	2008	2040
DWGT-4	Gas Turbine	28.0	18	2009	2040
DWGT-5	Gas Turbine	28.0	18	2009	2040
DWPS-U1	Steam Turbine	280	110	1982	2040
DWPS-U2	Steam Turbine	280	110	1982	2040
…	…	…	…	…	…

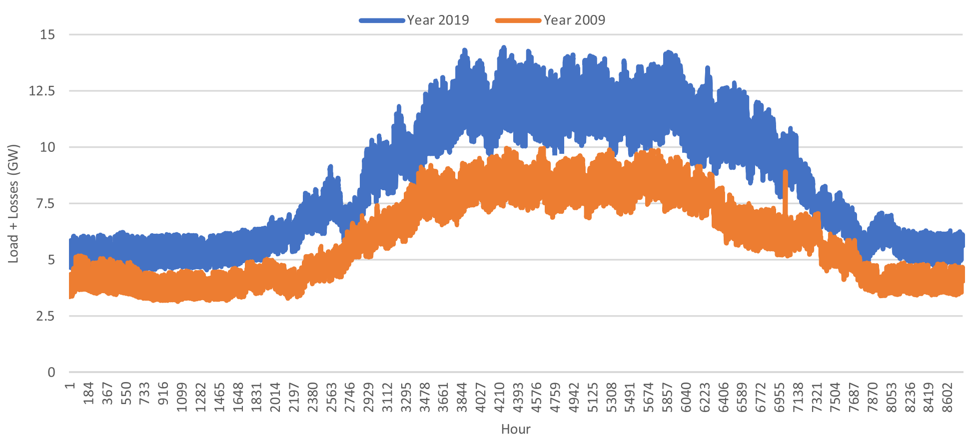

Fig. 1. Historical hourly load data 2009 and 2019.

account security constraints, most notably transmission. Models that incorporate transmission and other security constraints are known as operational models. Therefore, the work presented in this paper cannot determine the security of the power system under contingency events such as the loss of transmission, other equipment failures, or even voltage issues. It would be beneficial to have an operational model to help investigate these extraordinary circumstances; however, operational models take more than a year to develop. Perhaps in the coming months, this type of model can be developed for the MEW, but it would require much more data. It should be noted that operational models still have limitations. These models are limited to the transmission system and to ensure computational tractability, they do not model nodal voltages or the distribution system. Every model includes trade-offs. While models can help stakeholders gain insights into the system and the phenomenon being studied, attention should be paid to the limitations of the model, as they will always exist.

The literature on RA and the proposed models is extensive but mainly focused on electricity markets, their design, and the periods of study are

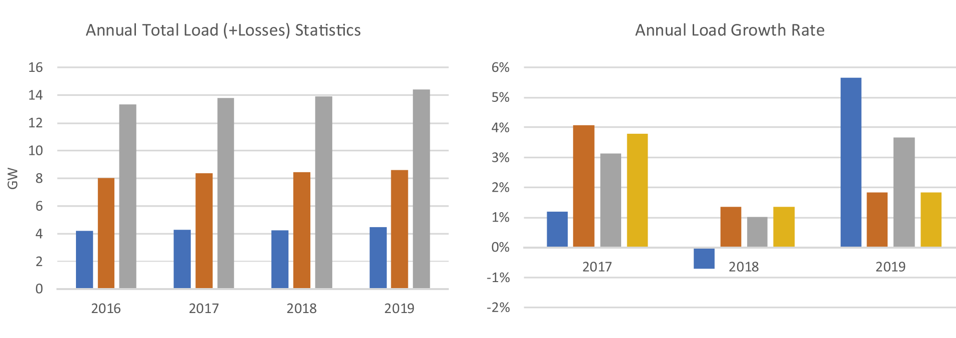

Fig. 2. Left—annual minimum, average, and peak load in MW for 2016-2019. Right: minimum, average, peak, and annual energy consumption growth rate for 2017-2019.

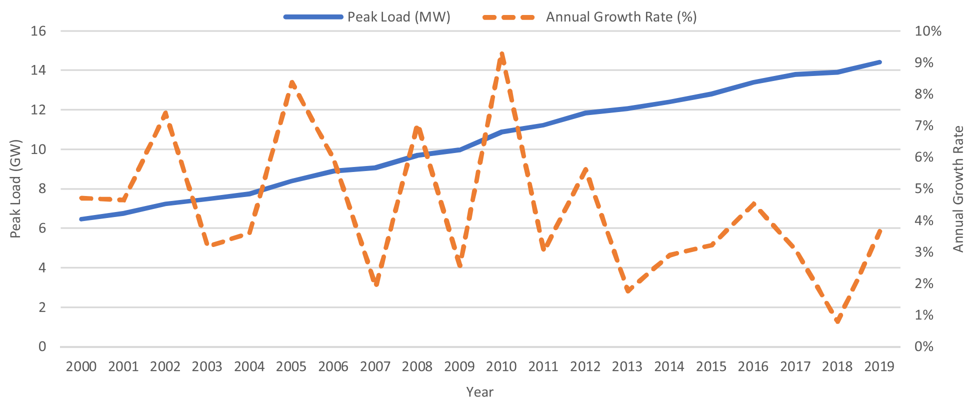

Fig. 3. Annual peak load + losses (blue) and annualized peak growth rate 2000–2019 (orange) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

long-term (years). In Kuwait, the MEW is the state-operator of the electric power system. There is no formalized electricity market and there are only two independent power plants (IPPs) – Az-Zour North Power Station and Al-Shagaya Renewable Energy Park. Furthermore, renewable energy capacity in Kuwait is only approximately 70 MW, of which 50 MW is concentrated solar thermal power with ten-hour molten salt storage. Thus, uncertainty due to renewables is minimal. The RA model in this paper focuses on the short-term unique circumstances of the year 2020 under COVID-19 and its associated lockdown to prevent further infections.

This study was requested because the government and in particular the MEW was concerned that it would not be able to meet demand under these circumstances. For this study, which was conducted in May 2020, the resource adequacy model takes into account the available supply (generation) and historical load. For the generation, the resource adequacy model incorporates data previously provided by the MEW, which can be seen in Table 1 below. As reported in the MEW electricity statistical yearbook 2019 (Ministry of Electricity & Water, 2019a, b) dataset, the installed capacity is 19580 MW. *The analysis presented here, however, is based on safe available capacity of* 17250 *MW and an additional 'unsafe' capacity of 590 MW.* As for the historical load, data was provided from 2009 to 2019. Fig. 1 plots the hourly load curve for 2009 and 2019. More details are presented in the subsequent section on Load Statistics and 2020 Projections.

3. Load statistics and 2020 projections

This is a study of the hourly load for 2019. In order to project the 2020 load from 2019, we should first look into the historical load growth rate. Fig. 2 shows general statistics for the load over the past four years. The figure suggests that the load in Kuwait has faced a mild growth rate of 1% to just below 4% over the past few years. While minimum and average load provide important insight for system operation, this paper is particularly concerned about worst-case conditions that occur during the peak hours. Fig. 3 shows the annual peak load and growth rate since 2000. The figure suggests that the growth rate has been lower over the recent past and under normal conditions, the load growth should be less than 5 % for 2020 compared to 2019.

To analyze the performance of the system under a wide range of possibilities, the following five load growth scenarios are modeled:

Mild load growth (2 %): This scenario reflects a mild load growth of 2 %, similar to 2014–2015, and 2018.

Medium load growth (4 %): This scenario reflects a medium load growth rate of 4 %, similar to 2015 and 2016.

High load growth (10 %): This is a high load growth rate scenario, similar to 2010. While we do not expect such a high growth rate, the scenario will provide insight into the performance of the network assuming this year will resemble the highest growth rate of the last 20 years.

Extreme load growth (15 %): This load growth rate is unprecedented in the historical data and models an extreme case.

Disastrous load growth (25 %): This last scenario represents an absolute worst-case scenario, where we assume that COVID-19 mitigation policies for some reason may lead to an extremely high load growth rate. As this scenario is extreme and outside reasonable expectations, the analysis is presented in an appendix.

These five scenarios are depicted in Fig. 4 to offer insights on the aggressiveness or conservativeness of the scenarios. The figure suggests that a growth rate of between 2% and 4% will be the most likely growth rate for 2020 under normal conditions. Some analysis on the impact of COVID-19 and deviation from "normal" conditions are offered in the next section.

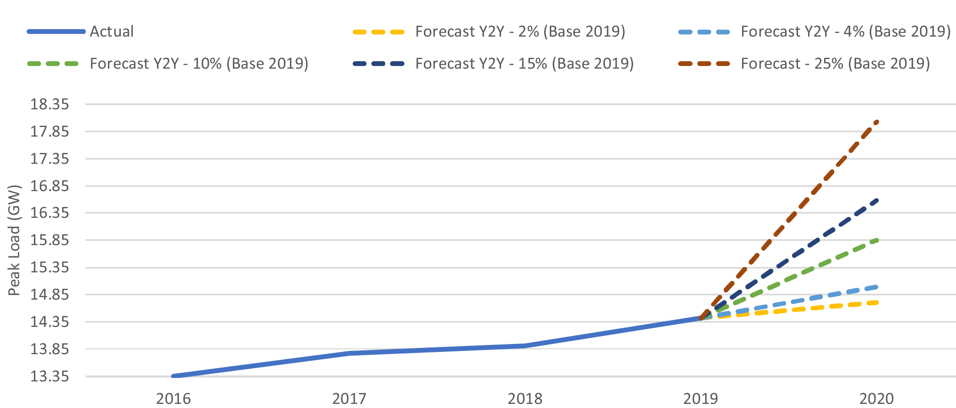

Fig. 4. Different load growth rates applied to 2019 peak load.

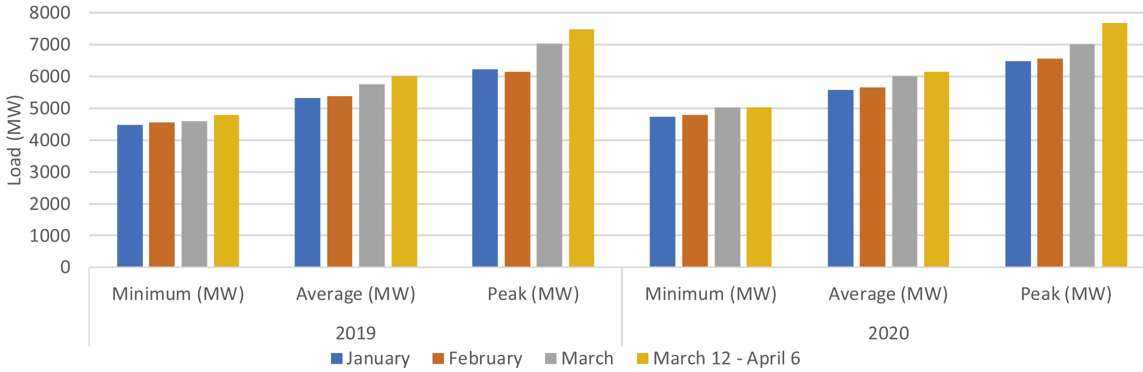

Fig. 5. Minimum, average, and peak load comparison between 2019 and 2020 for January, February, and March.

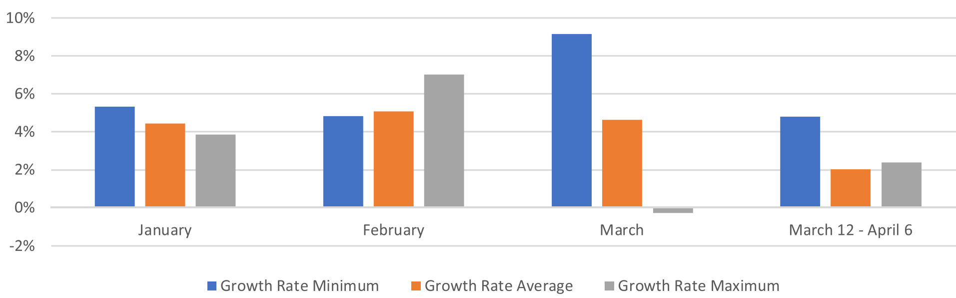

Fig. 6. Minimum, average, and maximum load growth rate for 2020 compared to 2019.

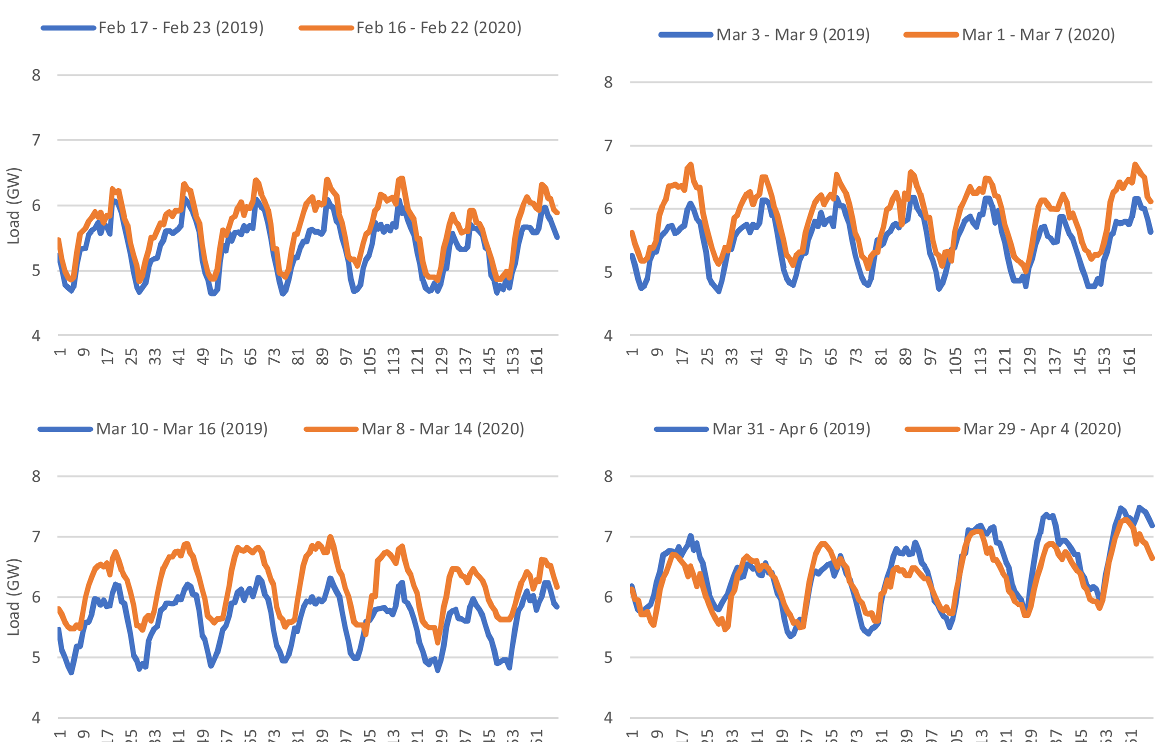

Fig. 7. Hourly load curves comparing representative weeks from 2019 to 2020. Top-left: February. Top-right: early March. Bottom-left: mid-March (March 12, 2020 government-imposed stay-at-home policies started). Bottom-right: end of March to April (March 22, 2020 government imposes partial curfew).

3.1. Impact of COVID-19 on the load curve

The Ministry of Electricity and Water provided us with hourly load data until April 6, 2020, allowing us to examine the impact of stay-at-home policies on electricity consumption thus far. Fig. 5 shows the minimum, average, and peak load in MW for the month of January, February, and March in both 2019 and 2020. Additionally, the figure compares March 12-April 6, a period that was declared as national holidays to fight the COVID-19 pandemic. The data shows that the load grows as the temperature increases from January to March. The data

Table 2
Worst-case scenario assumptions.

Parameter	Value
Projected 2020 Population	4,902,982 people
Added population (COVID-19 related travel policies)	100,000 people
Per capita peak load consumption	3.1 kW (highest over the last 20 years)
Population growth over the projected level	6.3 % (highest over the last 20 years)
Total peak load	16.4 GW
Total peak load (with 10 % increase in per capita consumption due to COVID-19 related policies)	18 GW

Table 3
Scenarios simulated in the resource adequacy model.

Scenario	Growth Rate from 2019 (%)	Outage (MW)
Baseline	2 %	0
Scenario 2	2 %	920
Scenario 3	2 %	1440
Scenario 4	4 %	0
Scenario 5	4 %	920
Scenario 6	4 %	1440
Scenario 7	10 %	0
Scenario 8	10 %	920
Scenario 9	10 %	1440
Scenario 10	15 %	0
Scenario 11	15 %	920
Scenario 12	15 %	1440
Scenario 13	2 %	2400
Scenario 14	4 %	2400
Scenario 15	10 %	2400
Scenario 16	15 %	2400
Scenario 17	25 %	0
Scenario 18	25 %	920
Scenario 19	25 %	1440
Scenario 20	25 %	2400

also shows that the 2020 load is slightly higher than 2019, which is to be expected, assuming a natural load growth rate. Fig. 6 depicts a clearer picture by showing the load growth rate for 2020 compared to 2019. January and February show a peak growth rate of 4 % and 6 % respectively. However, for March we observe a negative peak growth rate, which resulted from the implementation of the stay-at-home order in mid-March. This lowered the load because the demand caused by extreme summer temperatures does not manifest until late April. The March 12-April 6 growth rate, which relates entirely to the time that stay-at-home policy was enacted, shows a lower growth rate compared to the previous months.

To offer more perspective on the impact of COVID-19, in Fig. 7, hourly load curves for representative weeks in 2019–2020 are compared. Note that each load curve starts at 12 AM on Sunday and ends at 11 PM on Saturday. The figures suggest that the 2020 normal load (prior to March 12) grew compared to 2019. However, starting from March 12, 2020, the load starts to behave differently. The change of behavior is clearly visible in the last plot comparing the week of March 29-April 4, 2020 to the week of March 31-April 6, 2019. Note that the dates are shifted by two days between 2019 and 2020 to match the weekdays.

Thus far, it seems that COVID-19 has repressed the growth and even reduced the load. However, this finding is shortsighted and cannot necessarily be generalized for the summer months. To make sure the analysis here covers the absolute worst-case scenarios, we estimate the highest possible peak using the assumptions summarized in Table 2.

It should be noted that the scenarios included in Table 2 are rather pessimistic. They are developed for the sole purpose of evaluating the power system performance if every parameter moves in the direction of putting more stress on the system. The peaks under these two extreme-case scenarios are similar to the 15 % and 25 % growth rate cases that we have included in our analysis. Thus, we believe the results presented in the next section will offer insights on system performance even for worst-case scenarios, as shown in Table 2. A full description of all the analyzed scenarios is given below in Table 3.

4. Results and discussion

All scenario simulation results can be categorized into five main growth rates compared to 2019 under three capacity outage conditions (no outage, 920 MW, 1440 MW, and 2400 MW). Table 4 shows the simulation results for the 20 scenarios. The model is set to acquire 8% of the capacity as the reserve margin under each scenario. The table presents the generation capacity available (both safe and unsafe) in the system, as well as peak load and capacity margin for all the scenarios. Additionally, the table shows if the system needs to tap the unsafe capacity, due to high demand.

The baseline scenario, scenario 2, and scenario 3 simulation results show an energy demand of 76,970 GW h for 2020, assuming a growth rate of 2 %. A peak load of 14798 MW is anticipated. It is worth mentioning that the MEW has forecast a peak load of 14190 MW, and an expected electricity generation of 76,790 GW h for 2020 in the 2019 MEW electricity statistical book (Ministry of Electricity & Water, 2019a, b). Thus, the lowest growth rate considered in this analysis is very similar to the MEW's projections under "normal" conditions. Although scenarios 2 and 3 included outages of 920 MW and 1,440 MW respectively, because of the low growth rate, no energy or reserve curtailment was necessary. According to the MEW electricity statistical book (Ministry of Electricity & Water, 2019a), Kuwait has maintained a capacity margin of above 20 % over the past 10 years, based upon installed capacity. For accuracy, capacity margins are reported based upon 'safe' capacity only. From the lowest growth scenarios, the 'safe' capacity margins fall below 20 %. For the baseline scenario, scenario 2, and scenario 3, the capacity margin with only 'safe' capacity is 14.7 %, 10 %, and 7 %, respectively.

Scenarios 4, 5, and 6 include a growth rate of 4 %, similar to the average increase in peak load growth rate in the 2019 electricity book (4.4 %) (Ministry of Electricity & Water, 2019a). The energy demand under these three scenarios grows to 78,479 GW h with a peak load of 14,997 MW. Even with the forced outage of 920 MW and 1,440 MW under scenarios 5 and 6, the generation fleet can withstand these generation contingencies, and maintain a 'safe' capacity margin of 8.2 % and 5.1 %, respectively.

Scenarios 7, 8, and 9 are simulated with a load growth rate of 10 %. At this rate, electricity demand is simulated above historical growth rates. The energy demand in scenarios 7, 8, and 9 is 83,007 GW h, with a peak load of 15,862 MW. The simulation of scenario 7, without a forced outage, results in a 'safe' capacity margin of 8 %. A forced outage rate of 920 MW in scenario 8 leads to a 'safe' capacity margin of 2.9 %, while a loss of 1,440 MW in scenario 9 results in a 'safe' capacity margin of −0.3 %. Thus, in scenario 9, the Kuwaiti power system needs production from 'unsafe' capacity. The energy required from 'unsafe' capacity is 60 MW h. No energy curtailment is observed because the 'unsafe' capacity was able to fulfill the load.

Scenarios 10, 11, and 12 represent a load growth of 15 %. The forecasted peak load in this section of scenarios is 16,583 MW with a total energy demand of 86,780 GW h. The 'safe' capacity margin under scenarios 10, 11, and 12 are 3.9 %, −1.5 %, and −4.9 %, while the 'safe + unsafe' capacity margin is 7 %, 2 %, and −1.1 %, respectively. Although there is no energy curtailment in scenario 11, the outage of 920 MW will require the MEW to rely on 'unsafe' capacity to produce 1.32 GWh of electricity. Scenario 12 has the worst forecasted outcome with 1,440 MW of generation outage. With the peak load of 16,583 MW, there is only 15,810 MW of safe capacity available. The 'safe' capacity margin under this scenario falls to −4.9 %, while the 'safe + unsafe' capacity margin is −1.1 %, representing 31.15 GWh of unsafe production. However, the production even from 'unsafe' capacity is insufficient

Table 4
Simulated outcomes of each scenario.

Scenario	Energy (GWh)	Safe Production (GWh)	Unsafe Production (GWh)	Curtailment (MWh)	Max Curtailed (MW)	Hours with Violation	Safe Capacity (MW)	Unsafe Capacity (MW)	Peak Load + Losses (MW)	Safe Capacity Margin (MW)	Safe Capacity Margin (%)	Safe + Unsafe Capacity Margin (MW)	Safe + Unsafe Capacity Margin (%)
Baseline	76,970	76,970	–	–	–	–	17250	590	14708	2542	14.7 %	3132	17.6 %
Scenario 2	76,970	76,970	–	–	–	–	16330	590	14708	1622	9.9 %	2212	13.1 %
Scenario 3	76,970	76,970	–	–	–	–	15810	590	14708	1102	7.0 %	1692	10.3 %
Scenario 4	78,479	78,479	–	–	–	–	17250	590	14997	2253	13.1 %	2843	15.9 %
Scenario 5	78,479	78,479	–	–	–	–	16330	590	14997	1333	8.2 %	1923	11.4 %
Scenario 6	78,479	78,479	–	–	–	–	15810	590	14997	813	5.1 %	1403	8.6 %
Scenario 7	83,007	83,007	–	–	–	–	17250	590	15862	1388	8.0 %	1978	11.1 %
Scenario 8	83,007	83,007	–	–	–	–	16330	590	15862	468	2.9 %	1058	6.3 %
Scenario 9	83,007	83,007	0.06	–	–	–	15810	590	15862	−52	−0.3%	538	3.3 %
Scenario 10	86,780	86,780	–	–	–	–	17250	590	16583	667	3.9 %	1257	7.0 %
Scenario 11	86,780	86,779	1.32	–	–	–	16330	590	16583	−253	−1.5%	337	2.0 %
Scenario 12	86,779	86,748	31.15	0.557	183	7	15810	590	16583	−773	−4.9%	−183	−1.1%
Scenario 13	76,970	76,970	–	–	–	–	14850	590	14708.4	141.6	1.0 %	731.6	4.7 %
Scenario 14	78,479	78,479	0.37	–	–	–	14850	590	14996.8	−146.8	−1.0%	443.2	2.9 %
Scenario 15	83,001	82,924	76.95	5.47	422	37	14850	590	15862	−1012	−6.8%	−422	−2.7%
Scenario 16	86,669	86,386	282.44	111.02	1,143	324	14850	590	16583	−1733	−11.7%	−1143	−7.4%
Scenario 17	94,326	94,299	26.09	0.51	185	7	17250	590	18025	−775	−4.5%	−185	−1.0%
Scenario 18	94,243	94,012	231.02	82.63	1,105	231	16330	590	18025	−1695	−10.4%	−1105	−6.5%
Scenario 19	94,049	93,637	412.43	277.01	1,625	506	15810	590	18025	−2215	−14.0%	−1625	−9.9%
Scenario 20	93,248	92,423	824.66	1,078.23	2,585	1,188	14850	590	18025	−3175	−21.4%	−2585	−16.7%

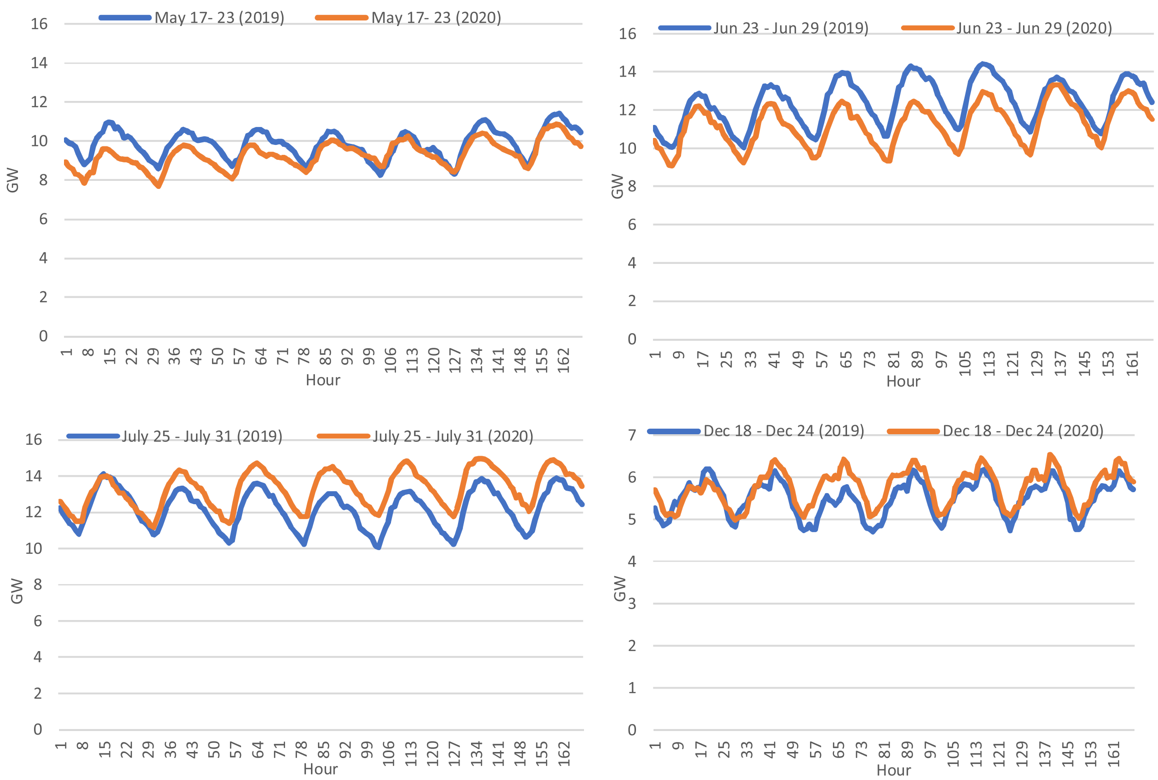

Fig. 8. Hourly load curves comparing representative weeks from 2019 to 2020. Top-left: May during full lock-down. Top-right: late June with full lockdown removed with still a partial curfew imposed and only 25 % of the workforce returning. Bottom-left: late July with no curfew and 50 % of the workforce returning. Bottom-right: December with no curfew and 50 % of the workforce returning.

to fulfill the load. Thus, the system will experience the energy curtailment of 557 MW h over 7 h of the year. The maximum load shedding observed in the results was 183 MW. Note that this curtailment represents 0.6 % of the total energy demand in 2020. Thus, there is a shortage of necessary capacity to meet the peak demand in this scenario. Kuwait will have to rely on importing electricity under scenario 12.

It is important to note that capacity margin by definition is calculated for normal operation without any generation outage (North American Electric Reliability Corporation, 2019; NERC, 2014a, b). In fact, one main reason for maintaining a healthy capacity margin is to mitigate generation contingencies and replace lost generation. Thus, comparison of capacity margin with the desired level should only be made for the scenarios without a generation outage (baseline, scenario 4, scenario 7, and scenario 10). The capacity margins reported in Table 4 may seem too low for some scenarios with outages, but it should be noted that those numbers are calculated for contingency cases and a lower capacity margin may very well be acceptable. Since generation contingency is not included in capacity margin calculations, the only information in the scenarios that affects capacity margin is load growth. As Table 4 shows, the capacity margin drops below the North American Electric Reliability Corporation (NERC) benchmark of 15 %. When comparing only safe capacity margin for the baseline, the capacity margins for scenarios 4, 7, and 10 is always below the 15 % NERC standard. When including safe and 'unsafe' capacity, the Kuwaiti power system is within this standard for the baseline and scenario 4. In scenarios 7 and 10, while there is no curtailment (load shedding), the capacity margin falls to 11.1 % and 7 %, respectively.

There are 8 extreme scenarios (scenarios 13–20) representing an unusually large outage of 2400 MW paired with all load growth rate scenarios, 2 %–25 %. Under these more extreme conditions, only scenarios 13 and 14 exhibit no curtailment because the load growth of 2% and 4% was low and there was still enough capacity to meet demand even with an extreme outage of 2400 MW. Additionally, scenario 13 does not require any energy from 'unsafe' capacity, whereas scenario 14 does rely on it and requires the 'unsafe' capacity to produce 0.37 GW h of electricity. The remaining scenarios, 15–20, exhibit curtailment, meaning that even relying on 'unsafe' capacity is not enough. For scenario 15 and 16, load growth was 10 % and 15 %, respectively, with an extreme outage of 2400 MW. For scenarios 17 through 20, load growth was the extreme case of 25 % paired with outages of 0, 920, 1440, 2400 MW, respectively. In all scenarios with curtailment, this would mean that Kuwait would no longer be able to fulfill its own needs and would have to depend upon the GCC interconnection to supply its needs. These results are shown in Table 4 below.

4.1. COVID-19 effects on Electricity Demand in 2020

Under normal circumstances, Kuwait's electricity demand historically has grown between 2 and 4 % annually. COVID-19 was a life-changing event, precipitating abnormal circumstances. As and more and more of Kuwait's residents became infected with the virus, the government-imposed curfews, and then starting May 10, 2020, it imposed a full lockdown that lasted twenty days. As can be seen from the top-left chart of Fig. 8, comparing the same week of May 2020 and May 2019, electricity demand was lower overall in 2020 than 2019. After emerging from the full lockdown, the government still imposed a partial curfew with only 25 % of the workforce allowed to return. The effect of this change in policy can be seen in the top-right chart of Fig. 8, where the demand for 2020 was lower overall. Until the government removed all curfews, electricity demand was lower in general for 2020 compared to 2019. Once these curfews were removed, electricity demand became higher (bottom-left of Fig. 8). The Kuwaiti government did consider reimposing a curfew when infections rose, but ultimately chose not to reimpose one. Thus, the load in 2020 remained higher overall compared to 2019 once the curfews were removed (bottom-right of Fig. 8). Due to the government's actions, Kuwait's electricity demand was depressed

Table 5
Comparison of Kuwait's actual peak load, minimum load, average load, and electric energy consumed between 2019 and 2020.

Metric	Year 2019	Year 2020	Growth 2019–2020
Peak Load (MW)	14420	14960	3.7 %
Minimum (MW)	4490	4730	5.3 %
Average (MW)	8614.25	8589.31	−0.3 %
Energy (TWh)	75.46	75.38	−0.1 %

slightly in 2020 compared to 2019 (75.38 TW h vs. 75.46 TW h). As a result, on average, hourly demand fell by 0.3 % in comparison to 2019. As for peak load, it grew in 2020 to 14,960 MW, a growth of 3.7 %. However, this peak occurred once the full lockdown and partial curfews were lifted. Similarly, the minimum load grew by 5.3 % as well compared to 2019. These results can be viewed in Table 5.

Since COVID-19 conditions were unprecedented in Kuwait's history, the MEW was concerned it might not be able to meet the demand for electricity due to these unforeseen circumstances. The MEW was concerned it would not be able to meet demand. This concern arose from the fact that Kuwait's electricity demand is dominated by space cooling needs. However, the lockdowns and the curfews curbed the activities of the commercial, public, and industrial sectors of Kuwait and thus, electricity demand was lower overall. Electricity demand in general did not exceed 2019 levels until the curfews were lifted. In the end, as the government removed restrictions, demand increased. These results and our previous analysis demonstrated that Kuwait had sufficient capacity to meet demand under these unforeseen events.

4.2. Outcomes and recommendations

In this paper, an analysis of Kuwait's electric power system is provided under the conditions of the COVID-19 pandemic. First, historical electricity demand in Kuwait was examined and load growth projections were made. Based on the historical data, the most likely load growth of 2020 is expected to be approximately 4 %, under normal conditions compared to 2019. Utilizing the load growth projections and a resource adequacy model, we then simulated whether Kuwait's power system could meet demand. Under most simulations, the Kuwait power system is able to meet demand, even when there is a supply outage. The analysis offered in this paper suggests that most likely Kuwait's power system will not face a supply shortage. Only under extreme circumstances will the system face supply deficiency. Even then, this shortage is expected to be relatively mild. This rather reliable performance is due to the substantial investment in new generation capacity over the past 10 years, which has made the country's power system resilient. The annual capacity and peak load since 2000 are shown in Fig. 9.

It is extremely important that the Ministry of Electricity and Water monitor the load during late April and the entire month of May to understand the load trajectory in the summer to determine which load scenario is closer to reality, as shown in Fig. 10. This will alert the Ministry if any mitigation action may be required during the summer.

To mitigate low-probability supply shortage events in the summer, the MEW can exploit the large deviations in the daily load with demand response programs. Fig. 11 shows the simulated hourly load curve for the peak week in 2020, with a more extreme case of 15 % load growth and 1,440 MW outage. The figure shows a difference of about 4500 MW

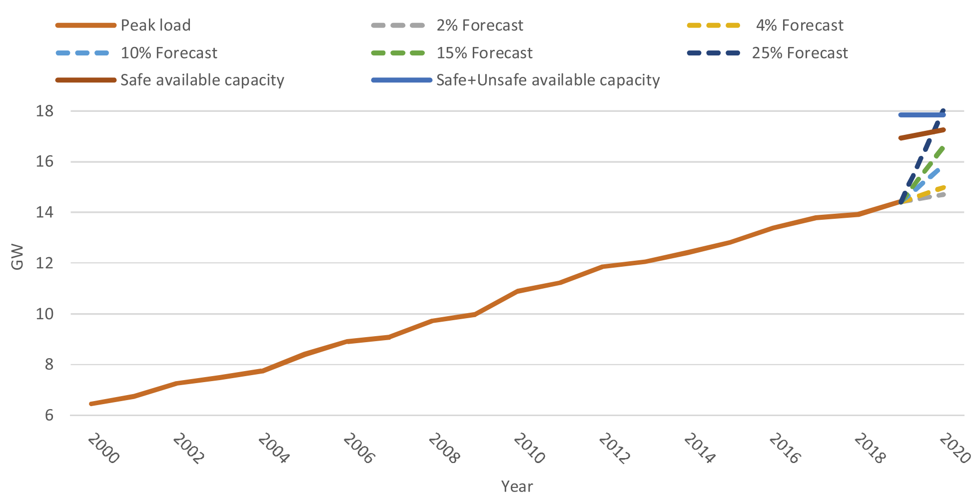

Fig. 9. Safe and unsafe capacity compared to the peak load since 2000.

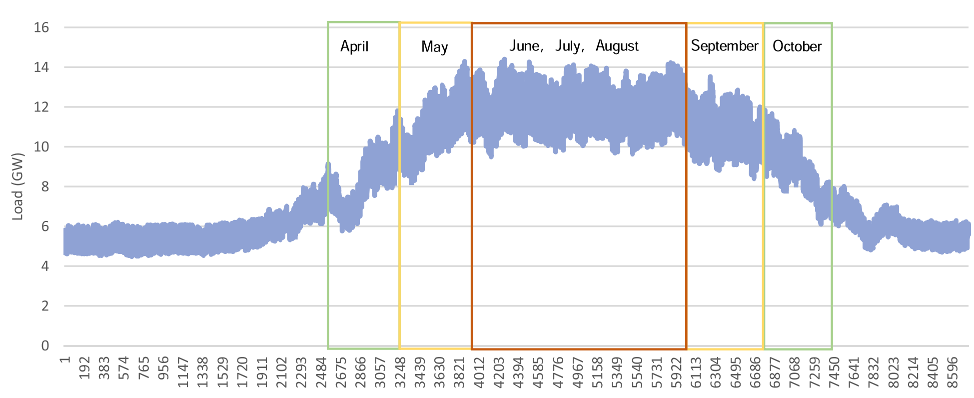

Fig. 10. Hourly load curve for 2019.

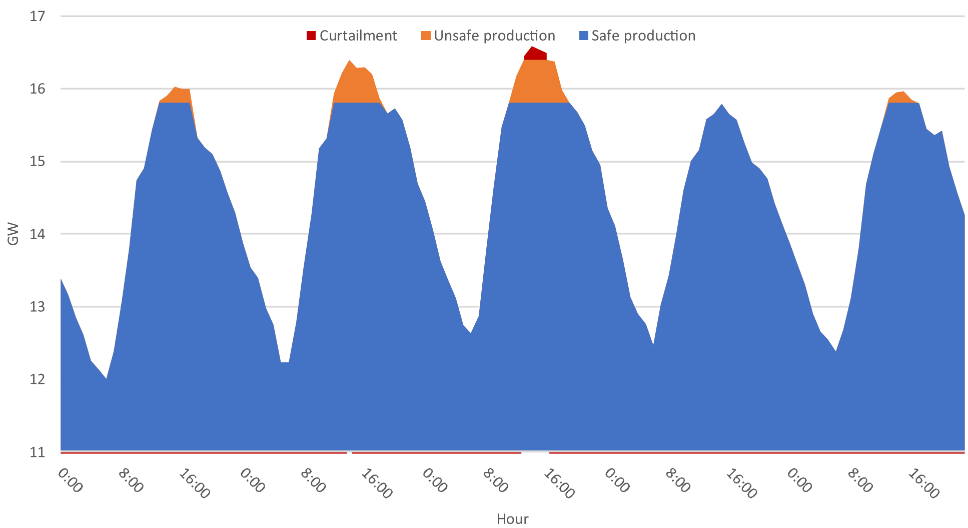

Fig. 11. Simulated load demand with extreme growth of 15 % for 2020 with capacity outage of 1,440 MW.

between peak and off-peak load. This significant difference will require the MEW to implement effective demand response strategies through the reduction of industrial/commercial activities during the peak hours in order to mitigate an unlikely supply shortage. Industrial and commercial activities could be shifted to another time of day so that these activities could still occur, but not during peak load hours.

Moving forward, Kuwait and the MEW need to adopt actionable energy efficiency policies. Electricity consumption per capita has been on the rise even during the pandemic. The MEW reported that per capita electricity consumption was 15.2 MW h per capita. From their data, per capita electricity demand was approximately 15 MW h. While this demand has remained stable in recent years, it became this high due to lax energy efficiency standards in the past. Most recently, the MEW updated their building code for government and commercial buildings in 2017 (Ministry of Electricity & Water, 2017) and changes due to this code will take time to manifest. The main type of electric nergy demand is space cooling due to long hot summers where temperature regularly surpass 40 °C. This is a prime target for energy efficiency policies. The MEW estimates that demand for space cooling and heating contributes 70 % of total residential energy consumption. According to these approximations, 22 TW h was needed in 2020 to fulfill the demand for space cooling.

Kuwait can target space cooling demand by setting more aggressive energy efficiency targets, mandate product energy efficiency labeling, and create incentive programs for the adoption of even more efficient air conditioners and even other appliances by building owners. These policies should not be developed just for the residential sector, which according to the MEW consumes approximately 44 % of all electricity consumption, but also the commercial, government, and services sectors of Kuwait that consume 25 % of all electricity. These sectors would also have a high demand for space cooling. Targeting space cooling would have significant impact on energy efficiency because all of these sectors comprise almost 70 % of all electricity demand. Furthermore, the need for space cooling is correlated with peak electricity demand and thus energy efficiency policies targeting space cooling would lower the peaks simulated in Fig. 11. While electricity demand was lower due to COVID-19, the peak demand still grew by 3.7 %, likely due to the need for space cooling. By developing actionable energy efficiency policies, Kuwait would not have to keep increasing generation capacity.

Simshauser, (Simshauser, 2019; Simshauser, 2010), demonstrated how important energy policy decisions can be in his analysis of Australia's energy only market. He traced market imbalances to policy decisions made a decade earlier, leading to blackouts and a black system event. Although Kuwait does not have the same form of electric energy market as Australia, Simshauser's cautionary account of energy policies gone awry apply universally. While Kuwait has an abundance of oil, its trajectory towards energy security needs to be guided by prudent energy policies so that no matter what extreme circumstances occur, Kuwait would still be able to meet its electric energy demand. Kuwait is currently on an unsecure trajectory because energy demand, in particular electricity demand, is ever increasing. To meet this demand, Kuwait must keep increasing generation capacity. Unless Kuwait adopts energy efficiency policies, which include setting aggressive energy efficiency targets, creating incentive programs, and mandating product energy efficiency labeling, this trajectory will continue. For example, Kuwait has energy labeling for vehicles in Kuwait, but these practices do not extend to air conditioners and appliances. Adopting energy efficiency policies is even more relevant in times of crisis, such as the circumstances it faced in 2020 with the COVID-19 pandemic. Kuwait will find it more difficult to increase generation capacity if industrial activities continue to be restricted. Thus, Kuwait will need to move forward with its energy efficiency policy in the future to ensure its energy security.

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