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Assessment of Algeria’s electricity power demands during COVID-19 pandemic and wildfires incidents

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ABSTRACT

The COVID-19 pandemic has had enormous negative impacts on several activity sectors such as health, energy, and the economy. Aiming to limit its spread, extraordinary containment measures have been taken by the Algerian government by proclaiming the confinement on March 22, 2020, while maintaining the security of electricity supply to hospitals, critical infrastructures and the households. This manuscript presents a deep analysis of the impacts of the COVID-19 pandemic on the electricity power demands in northern and southwestern Algeria. The analysis covers the period from January 1, 2019, to December 31, 2021, and considers sudden and large changes (increase or decrease) in electricity power demand that may put power system reliability and stability at risk. One promising solution, which can avoid such situations, is to detect the power ramp rate; it is proposed as a power fluctuation indicator. In addition, the analysis also includes the impacts of wildfires that menace most of northern Algeria during the summer of 2021.

1. Introduction

1.1. Background and motivation

The coronavirus disease 2019 (COVID-19) spread on February 25, 2020, in Algeria, when an Italian citizen was tested positive for SARS-CoV-2. From March 01, 2020, an outbreak of contagion formed in the region of Blida, with sixteen members of the same family infected with the COVID-19 and soon Blida became a center of the pandemic. Casualties’ cases then spread over all of Algeria. Even though the Algerian government adopted strict policy interventions to slow its prevalence, COVID-19 spreads rapidly in the other regions, causing more than 5,240 deaths and more than 195,157 confirmed casualties as of August 2021. Fig. 1 exhibits the daily number of new cases of COVID-19, casualties affected, and the timeline of major measures taken by the Algerian government from March 01, 2020, to August 31, 2021 [1,2].

As of April 03, 2020, the number of casualties started to be frightening as it peaked at 185. From July to November 2020, newly confirmed casualties increased dramatically and peaked at 1,133 on November 24. After this high peak, the new cases showed a significant drop to reach a minimum of 89 casualties on March 03, 2021. As of July 05, 2021, the situation comes to be scary, and the number of casualties increased roughly to hit a peak of 1,927 on July 28, 2021. Aiming to prevent the spread, on August 04, 2021, rigorous partial lockdown measures have been taken, and some of the lockdown measures were relaxed or lifted in many regions. By the end of August 2021, the enacted measures allowed to reduce significantly the number of the new cases to 506 casualties.

Policy interventions and measures imposed by the Algerian government to prevent the spread of COVID-19 encompasses social distancing measures, lockdown of several socio-economic activity sectors, while nearly all commercial, public and private establishments (schools, gyms, etc) were closed. Similar to other countries affected by COVID-19, these interventions had direct impacts on the electric power demand (EPD). Feeding continuously the hospitals and residential load with electricity is essential for the security of a country; however, there are also serious challenges for power system operators. Besides, all the students and several employees were forced to work online.

Algeria has two important socio-economic developed and climate regions; the north and the south. Northern Algeria is the most socio-economic developed region and barely 87% of the population lives there. In early 2020, the total population reached more than 43.9

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million inhabitants [3], where the highest population densities are found around large cities (Algiers, Oran, Constantine, TiziOuzou, Annaba, Tipaza, Jijel, Chef, Skikda, Relizane, Tébessa, M’sila, Tiaret, Saïda, etc.).

In order to supply all consumers with electricity, Algeria is expanding its power systems by improving power transmission infrastructures and developing large-scale power productions, including combined cycle, gas turbine, and photovoltaic plants. Algeria’s northern interconnected grid that links coastal areas with the highlands and a few southern regions are supplied by a strong meshed power system, while the extreme southern regions, such as Adrar, Tamanrasset, Illizi, and Tindouf with weak industrial activity sectors, host each on a micro-power system. Fig. 2 illustrates the power grids map in Algeria up to January 01, 2019 [4].

Considering different weather conditions in Algeria, the correlation between electricity demand and air temperature differs from one region to another. As an example, the Adrar region located in the southwest of Algeria is one of the hottest regions in the world. During July and August, the temperature might overpass the 54°C. Under this high-temperature condition, the consumers need more electricity for cooling (air-conditioners refrigerators).

During summer 2021, Algeria and others countries faced high challenges due to the large spread of wildfires, causing high severity to secure safe operation of the power system; such situation might be aggravated under COVID-19 confinement periods.

Every year, the north of Algeria is affected by wildfires, with almost 1.5 million hectares were ravaged during the year 2020. Summer 2021 was a tragic year. In early July 2021, northeast Algeria witnessed large wildfires that devoured dozens of hectares, especially in the Aures region. Then, a second wave erupted on Monday, August 9, 2021, with more than 100 burning areas across 35 regions in the country, particularly the regions of Tizi Ouzou, Béjaïa, Bouira, Sétif, Jijel, Boumerdès, Bordj BouArréridj, Blida, Médea, Khenchela, Guelma, Tébessa, Tiaret, and Skikda. Consequently, several municipalities in Tizi Ouzou and other regions had no access to electricity, gas, or telephone. Besides, many petrol stations were closed after a gas explosion. Under such a situation, the risk of an upsurge in COVID-19 cases and the fight against the blazes cannot be fulfilled.

In the present paper, an assessment of impacts of the massive geographic scale and severity of wildfires coupled to the third wave of COVID-19 pandemic propagation on Algeria’s EPDs is proposed; it considers two different Algeria’s electricity power demands.

In addition, the proposed analysis is extended by further considering the impacts of wildfires that menaced the northern regions during summer 2021. A series of novel criteria are developed along with extensive quantitative details, visualization results, and discussions. In addition, the impact of temperature waves on EPD is also proposed.

1.2. Literature review

Due to the importance of the topic, several studies that addressed the impact of the COVID-19 pandemic on the EPD have been proposed. J.S. Kikstra et al. [5] developed a set of global climate mitigation scenarios to explore the effects of the COVID-19 on energy demand changes. The authors showed that the final energy demand may be reduced to 1–36 EJ yr-1 by 2025. As illustrated, by 2030, the imposed restrictions may contribute to reducing cumulative CO2 emission to 14–45 GT.
Aiming to substantiate the COVID-19 pandemic’s impact on US bulk power systems and electricity markets, G. Ruan et al. [6] presented a data-driven quantitative assessment study. Their analysis carried out from the period of March to July 2020 shows that the northeast regions are most affected by the pandemic, both EPD and electricity prices have discernibly dropped. C.M. Robert et al. [7] used daily electricity consumption and nighttime light intensity to examine the economic impact of COVID-19 in India. The policy interventions and measures taken on March 25, 2020, declined strongly the energy consumption; while it remained a quarter below normal levels throughout April. It recovered subsequently, but the electricity consumption remained lower even in September. A.Werth et al. [8] used the percent deviation index to assess the impact on electrical load of the policy interventions and measures taken in 16 European countries in 2020. In their paper, the authors analyzed exports and imports power exchanges between the European grids. Their results show that the load dropped in most European countries. On the other hand, to balance the demand and supply, and economically operate power systems by considering renewable energy.

| Abr | Economic activity sector | Number of customers 2019 | Number % | Number 2020 | Number % | Energy consumption 2019 GWh | Energy consumption 2020 GWh |
|-----|--------------------------|--------------------------|----------|--------------|----------|-----------------------------|-----------------------------|
| S1  | Residential customers (households) | 11 267 0.1 | 10 804 0.1 | 0.1 | 30.1 | 27.4 | 0.1 |
| S2  | Non-residential customers | 3 940 0.1 | 3 725 0.1 | 0.1 | 17 | 0 | 15.5 |
| S3  | Agriculture | 117 691 1.2 | 129 987 1.2 | 0.1 | 1 431.8 | 1 736.9 | 5 |
| S4  | Water & Energy | 96 564 1 | 101 658 1 | 0.1 | 1 364.8 | 1 600.1 | 4.6 |
| S5  | Hydrocarbons | 505 0 | 556 0 | 0 | 2.7 | 3 | 2.0 |
| S6  | Mines & Quarries | 60 0 | 110 0 | 0 | 0.5 | 0 | 1.3 |
| S7  | ISMME | 12 026 0.1 | 13 038 0.1 | 0.1 | 49.7 | 52.5 | 0.1 |
| S8  | Construction materials | 4 732 0.1 | 5 295 0.1 | 0.1 | 22.6 | 24.5 | 0.1 |
| S9  | Public works buildings | 6 857 0.1 | 7 936 0.1 | 0.1 | 51.4 | 59.4 | 0.2 |
| S10 | Agro-Food industries | 38 741 0.4 | 43 329 0.4 | 0.1 | 275.9 | 256.5 | 0.7 |
| S11 | Textile Industries | 4 435 0.3 | 4 313 0.3 | 0.1 | 16.6 | 14.7 | 0 |
| S12 | Leather industries | 9 234 0.1 | 9 287 0.1 | 0.1 | 49.7 | 52.5 | 0.1 |
| S13 | Drink. Paper. Cork | 16 478 0.2 | 16 856 0.2 | 0.2 | 67.8 | 63.3 | 0.2 |
| S14 | Various industries | 4 729 0.1 | 5 358 0.1 | 0.1 | 25.1 | 27.4 | 0.1 |
| S15 | Trade | 514 0.1 | 538 0.1 | 0.1 | 2.476 | 2.282 | 0.5 |
| S16 | Hotels / Restaurants / Cafes | 31 367 0.3 | 33 751 0.3 | 0.3 | 228.5 | 175.8 | 0.5 |
| S17 | Market services provided to businesses | 4 962 0.1 | 5 259 0.1 | 0.1 | 19.3 | 21 | 0.1 |
| S18 | Market services provided to households | 253 485 0.3 | 270 859 0.3 | 0.3 | 400.6 | 800.2 | 2.3 |
| S19 | Financial institutions | 1 324 0.2 | 1 287 0.2 | 0.2 | 378.9 | 354.9 | 0.5 |
| S20 | Real estate agencies | 1 279 0.2 | 1 889 0.2 | 0.2 | 153.8 | 153.8 | 0.4 |

*ISMME: Iron and steel industries, Metallic, Mechanical and Electrical.*

| Table 2 |

| Abr | Economic activity sector | Number of customers 2019 | Number % | Number 2020 | Number % | Energy consumption 2019 GWh | Energy consumption 2020 GWh |
|-----|--------------------------|--------------------------|----------|--------------|----------|-----------------------------|-----------------------------|
| S1  | Residential customers (households) | 1 0 2 0 | 0.1 | 0 | 0.1 | 0 | 0.2 |
| S2  | Non-residential customers (non-households) | 3 0 4 0 | 0.1 | 0 | 0.1 | 0 | 0.2 |
| S3  | Agriculture | 2 768 4.5 | 3 147 5 | 0.1 | 404.1 | 440.1 | 2.6 |
| S4  | Water & Energy | 15 170 24.6 | 15 356 24.2 | 0.1 | 4 045.6 | 4 142.6 | 2.4 |
| S5  | Hydrocarbons | 1 324 2.1 | 1 287 2.5 | 0.1 | 378.9 | 354.9 | 0.5 |
| S6  | Mines & Quarries | 15 170 24.6 | 15 356 24.2 | 0.1 | 4 045.6 | 4 142.6 | 2.4 |
| S7  | ISMME | 1 324 2.1 | 1 287 2.5 | 0.1 | 378.9 | 354.9 | 0.5 |
| S8  | Construction materials | 1 324 2.1 | 1 287 2.5 | 0.1 | 378.9 | 354.9 | 0.5 |
| S9  | Public works buildings | 1 324 2.1 | 1 287 2.5 | 0.1 | 378.9 | 354.9 | 0.5 |
| S10 | Agro-Food industries | 2 314 3.7 | 2 404 3.8 | 0.1 | 3 859.3 | 3 876.7 | 1.1 |
| S11 | Textile industries | 412 0.7 | 421 0.7 | 0.7 | 265.0 | 224.6 | 1.3 |
| S12 | Leather industries | 208 0.3 | 199 0.3 | 0.3 | 46.0 | 41.8 | 0.2 |
| S13 | Drink. Paper. Cork | 644 1 | 687 1.1 | 0.1 | 207.6 | 199.0 | 1.2 |
| S14 | Various industries | 420 0.7 | 475 0.7 | 0.7 | 118.0 | 121.3 | 0.7 |
| S15 | Trade | 2 433 3.9 | 2 548 4.0 | 0.1 | 481.0 | 438.8 | 2.6 |
| S16 | Hotels / Restaurants / Cafes | 742 1.2 | 799 1.3 | 0.1 | 282.5 | 227.5 | 1.3 |
| S17 | Market services provided to businesses | 128 0.2 | 138 0.2 | 0.2 | 18.4 | 19.8 | 0.1 |
| S18 | Market services provided to households | 172 0.3 | 219 0.3 | 0.3 | 16.7 | 22.3 | 0.1 |
| S19 | Financial institutions | 635 1 | 649 1 | 0.1 | 101.4 | 98.3 | 0.6 |
| S20 | Real estate agencies | 28 0 | 29 0 | 0.5 | 1.7 | 1.5 | 0 |
| S21 | Residential customers | 22 670 36.7 | 23 251 36.6 | 0.1 | 3 677.4 | 3 435.3 | 20.3 |
| S22 | Transport | 3 764 6.1 | 3 838 6.6 | 0.1 | 615.5 | 588.7 | 3.5 |
| S23 | Collective housing and outbuildings | 174 0.3 | 224 0.4 | 0.1 | 19.7 | 65.0 | 0.4 |
| S24 | Chemistry.Rubber. Plastic | 1 603 2.6 | 1 662 2.6 | 0.1 | 1 124.5 | 1 065.2 | 5.3 |
| S25 | Others | 12 0 | 1 0 | 0.5 | 0 | 1.4 | 0 |
| Total | 61 711 100 | 63 491 100 | 100 | 17 402.0 | 16 938.4 | 100 |
productions, the system operators reduced the power production from nuclear, coal, and natural gas. Ref. [9] reviews major challenges resulting from the COVID-19 pandemic on energy demand. The authors revealed that overall energy demand drops, while its spatial and temporal variations are complicated.

Many countries have pointed out that electricity supply security during the epidemic is critical to ensuring people’s livelihood. In this context, many studies have been oriented to perform an accurate prediction model of electricity demand during COVID-19 pandemic confinement days. H. Lu et al. [10] improved the accuracy and stability of the support-vector machine model by using enhanced data processing and a multi-objective optimizer approach. Aiming to overcome the shortcomings of data processing, ensemble empirical mode decomposition with adaptive noise was used too. Ref. [11] identifies in comparison to European countries, the impacts on mobility, electricity demand, and NO₂ emissions of preventive measures taken in

| Economic activity sector | Energy consumption by year (GWh) | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|--------------------------|---------------------------------|------|------|------|------|------|------|
| Water & Energy           |                                 | 2    | 3    | 2    | 3    | 3    |
| Hydrocarbons             |                                 | 325.1| 557.3| 652.9| 892.1| 210.4| 085.3|
| Mines & Quarries         |                                 | 960.9| 792.5| 970.6| 874.0| 915.9| 749.4|
| ISMME                    |                                 | 1    | 1    | 2    | 2    | 3    |
| Construction materials   |                                 | 2    | 2    | 2    | 2    | 2    |
| Chemistry, Rubber, Plastic |                           | 373.0| 375.3| 375.2| 483.9| 561.1| 441.7|
| Textile Industries       |                                 | 8.6  | 7.2  | 12.5 | 14.1 | 14.7 | 11.5 |
| Wood, Paper, Cork        |                                 | 30.5 | 32.5 | 28.8 | 30.0 | 15.0 | 9.3  |
| Transport                |                                 | 164.2| 169.1| 176.3| 205.7| 236.5| 162.4|
| Agro-food industries     |                                 | 29.5 | 34.0 | 46.7 | 46.9 | 27.8 | 13.2 |
| Hotels / Restaurants / Cafes |                          | 22.1 | 22.6 | 21.4 | 21.6 | 16.7 | 25.1 |
| Non-market service provided to the community | | -    | -    | -    | -    | 8.4  | 8.0  |
| Total                    |                                 | 9467.3| 9    | 10   | 11   | 12   | 12   |

| Economic activity sector | 2019 | 2020 |
|--------------------------|------|------|
| LV level                 |      |      |
| MV level                 |      |      |

| Economic activity sector | % by total energy consumption |
|--------------------------|------------------------------|
| Construction materials   | 0.03 | 2.8 | 0.04 | 2.7 |
| Public works buildings   | 0.08 | 0.8 | 0.09 | 0.7 |
| Textile industries       | 0.03 | 0.4 | 0.02 | 0.3 |
| Leather industries       | 0.08 | 0.1 | 0.08 | 0.1 |
| Drink, Paper, Cork       | 0.10 | 0.3 | 0.10 | 0.3 |
| Various industries       | 0.04 | 0.2 | 0.12 | 0.2 |
| Hotels / Restaurants / Cafes | 0.35 | 0.4 | 0.27 | 0.4 |
| Market services provided to businesses | 0.03 | 0.0 | 0.04 | 0.0 |
| Market services provided to households | 1.84 | 0.0 | 1.72 | 0.0 |
| Real estate agencies     | 0.01 | 0.0 | 0.24 | 0.0 |
| Transport                | 0.61 | 0.9 | 1.24 | 0.9 |
| Chemistry, Rubber, Plastic | 0.04 | 1.7 | 0.06 | 1.7 |
| Total                    | 3.2  | 7.6 | 4.0  | 7.2 |

| Year | Month | Total energy production | Distribution energy consumption | Industrials energy consumption |
|------|-------|--------------------------|-------------------------------|-------------------------------|
| Year 2019 | | | | |
| Year 2020 | | | | |
| Year 2021 | | | | |

| Peak (MW) | (Aug,15 655) | (Jul,14 714) | (Aug,16 224) |
|-----------|---------------|---------------|---------------|
| Peak power demand (MW) | | | |

| Month | Peak (MW) | Year 2019 | Year 2020 | Year 2021 |
|-------|-----------|-----------|-----------|-----------|
| Feb  | 8000      | 12000     | 14000     | 16000     |
| Mar  | 10000     | 14000     | 16000     | 18000     |
| Apr  | 12000     | 16000     | 18000     | 20000     |
| May  | 14000     | 18000     | 20000     | 22000     |
| Jun  | 16000     | 20000     | 22000     | 24000     |
| Jul  | 18000     | 22000     | 24000     | 26000     |
| Aug  | 20000     | 24000     | 26000     | 28000     |
| Sep  | 22000     | 26000     | 28000     | 30000     |
| Oct  | 24000     | 28000     | 30000     | 32000     |
| Nov  | 26000     | 30000     | 32000     | 34000     |
| Dec  | 28000     | 32000     | 34000     | 36000     |
Latin-American countries in order to fight the spread of Covid-19. YM. Al-Abdullah et al. [12] proposed a resource adequacy model to assess sufficient energy to meet Kuwait’s load demand. C. Graf et al. [13] proposed a machine-learning approach to predict the electricity market considering a large share of renewable energies. In Ref. [14], a socio-economic regulatory model based on an optimized tariff model was proposed to quantify the impact of the COVID-19 pandemic on the distribution electricity market and on the consumer’s habits in Brazil. As a result, alternative mitigation measures are suggested and compared to those taken by the Brazilian government.

A computable general equilibrium model proposed in Ref. [15] to assess the impact of COVID-19 on the macroeconomic indicator, energy consumption, and emissions in Indonesia. And so on, the authors’ proposed further policy recommendations for rebound economic and environmental improvement. A study of the implications of COVID-19 on momentary transition in electricity use was presented in [16]. Ref. [17] studied the impact of confinement measures taken in Spain on electricity consumption. The electricity consumption has decreased by 13.49% from March 14 to April 30, compared to the average value of five previous years. Daily power demand profiles, especially morning and evening peaks, have been modified at homes, hospitals, and in the total power demand. Ref. [18] studied different scenarios of power systems operation, the socio-economic and technical issues faced by the utilities in India. Further actions taken by the utilities/power sector have been presented. Ref. [19] applied Urban Modeling Interface tool to simulate the energy performance of a Swedish building mix. Besides, the authors proposed three levels of confinement for occupant schedules. A relatively smooth variation in electricity demands has been reached. Ref. [20] used data visualization and descriptive statistics to analyze considering a large share of renewable energies. In Ref. [14], a socio-economic regulatory model based on an optimized tariff model was proposed to quantify the impact of the COVID-19 pandemic on the distribution electricity market and on the consumer’s habits in Brazil. As a result, alternative mitigation measures are suggested and compared to those taken by the Brazilian government.

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A computable general equilibrium model proposed in Ref. [15] to assess the impact of COVID-19 on the macroeconomic indicator, energy consumption, and emissions in Indonesia. And so on, the authors’ proposed further policy recommendations for rebound economic and environmental improvement. A study of the implications of COVID-19 on momentary transition in electricity use was presented in [16]. Ref. [17] studied the impact of confinement measures taken in Spain on electricity consumption. The electricity consumption has decreased by 13.49% from March 14 to April 30, compared to the average value of five previous years. Daily power demand profiles, especially morning and evening peaks, have been modified at homes, hospitals, and in the total power demand. Ref. [18] studied different scenarios of power systems operation, the socio-economic and technical issues faced by the utilities in India. Further actions taken by the utilities/power sector have been presented. Ref. [19] applied Urban Modeling Interface tool to simulate the energy performance of a Swedish building mix. Besides, the authors proposed three levels of confinement for occupant schedules. A relatively smooth variation in electricity demands has been reached. Ref. [20] used data visualization and descriptive statistics to analyze considering a large share of renewable energies. In Ref. [14], a socio-economic regulatory model based on an optimized tariff model was proposed to quantify the impact of the COVID-19 pandemic on the distribution electricity market and on the consumer’s habits in Brazil. As a result, alternative mitigation measures are suggested and compared to those taken by the Brazilian government.
several European electricity systems operation during the COVID-19 pandemic with a focus on Germany. An important change in electricity consumption, generation, prices, and imports/exports have resulted. In [21], a deep-learning predictive model based on Bidirectional Long Short Term Memory is proposed for predicting UK’s daily EPD under COVID-19 lockdown. Furthermore, historical EPD as the number of coronavirus tests, renewable energy production, wind speed, and ambient temperature are used as inputs in the multivariate time series forecasting model.

A. Liu et al. [22] studied four different climate zones in Australia, the variations in the total electricity use, peak EPDs and its profiles resulted by lockdown and limitation of using of residential aged care facilities restrictions. The facilities in warm regions showed the largest reductions in energy use and peak EPDs. Ref. [23] used Joinpoint software to evaluate EPD trends in different geographic regions in Brazil.

The study carried out by L. Micheli et al. [24], analyzes the national electricity sector and the share of photovoltaics in the energy mix under the COVID-19 lockdown imposed by the Spanish government. S. Nundy et al. [25] presented the impacts of COVID-19 on socio-economic, energy-environment, and transport sector globally and sustainable development goals. Aiming to expose the impact of the COVID-19 on China’s electricity consumption, Ref. [26] combined autoregressive integrated moving average (ARIMA) and backpropagation neural network.

An advanced econometric framework to assess the impact of COVID-19 on renewable electricity generation in Denmark is proposed in [27]. Besides, the relationship between three channels of COVID-19 and renewable electricity generation was estimated using Fourier ADL cointegration analysis and Markov Switching regression. Regional electricity generation fuel mixes in NYISO, MISO, and PJM markets assessment study carried out in [28].

Ref. [29] reviews for various countries, the studies of the impacts of COVID-19 lockdowns on energy consumption in residential buildings and assess the changes in overall EPD. A demonstrative study based on a statistical analysis of energy supply in different sectors, such as hotels, transportation, commercial tourism city, and public utilities presented

Fig. 12. Average power rate and ramp rate of the power demand calculated during March 20 to 27, 2019 2020, and 2021.

Fig. 13. Daily power demand recorded during August 13 to 17, in 2019, 2020, and 2021.

Fig. 14. Daily power demand recorded during July 26 to 30, in 2019, 2020, and 2021.
in Ref. [30]. The case of Macao is compared with those of Italy, the United States, Japan, and Brazil. Based on the comparative regressive and neural network model, a significant effect on electricity and petroleum demand in China during the confinement period was revealed in Ref. [31].

To date, and for the Algerian context, there is no study carried out on electric power demand and the impacts of the COVID-19 pandemic. Most of the recently presented electricity energy evolution dated back to 2017 [32–34] and focuses only on the energy context.

2. Materials and methods

2.1. Power percentage deviation

Here, we propose power percent deviation as useful indicator for determining how the restriction measures taken during Covid-19 pandemic impact the change on power demand and energy consumption.

Fundamentally, percent deviation $S_y$, as given by Eq. 1, subtracts the actual data (power demand or energy consumption) of the year $y$ with the average data $A$ of the previous years (for example, i.e (2015, …2019)). That difference number is then divided by $A$, and then the result is multiplied by 100 to create a percent. A negative percent deviation shows that the average of the previous years (A) is higher. A positive percent deviation means that the data $X_y$ is higher [8].

$$S_y = \frac{X_y - A}{A}$$ (1)

$$A = \sum_{i=2015}^{2019} X_i / (t-1)$$ (2)

where $X_i$ and $X_y$ are the data in the $y$ and $i$ respectively, $t$ is the number of previous years.

For example, the $S_{2021}$ measures the deviation of the peak power demand of the year 2021 from the average of previous years without COVID-19 pandemic, in our case, the period considered is from 2015 to 2019.

2.2. Power ramp rate

Power demand changes continuously; throughout the day, the power demand moves up and down in a stochastic fashion. This behavior is called ramp rate.

There are several ways to define a ramp rate. The first modest model was proposed in Ref. [35] for wind power. In this model, the ramp rate detects the changes (large increase or decrease) in wind power output that surpasses a set threshold value ($P_{\text{threshold}}$) over a specified short-time period, typically, from half an hour to several hours.

The power ramp rate (PRR$_1$) is defined by the following empirical formulas [35]:

$$\text{PRR}_1 = \left| P_i(T + \Delta T) - P_i(T) \right| > P_{\text{threshold}}$$ (3)

As an alternative to this model, another definition detects the occurrence of the ramp rates if the ratio between the absolute difference of the power and the size of the interval $\Delta T$ exceeds a set of ramp rate reference; we obtain a modified ramp rate of equation (4) [35–39]:

$$\text{PRR}_2 = \frac{\left| P_i(T + \Delta T) - P_i(T) \right|}{\Delta T} > P_{\text{threshold}}$$ (4)

As equations (3) and (4) show, the feebleness of these models is that the new PRR$_2$ may not detect the largest change in magnitude that can occur between the two endpoints. As an alternative to PRR$_2$, a new model considers the ramp rates as the difference between the maximum and the minimum power demand that surpasses a set $P$ threshold over a specified short-time period [35–39]. Based on this, we define PRR$_3$ as shown by Eq. 5:

$$\text{PRR}_3 = \max (P(T, T + \Delta T)) - \min (P(T, T + \Delta T)) / P_{\text{threshold}}$$ (5)

where $P(T)$ is the power at time $t$, $\Delta T$ is defined as the ramp duration, and $P_{\text{threshold}}$ is predetermined threshold of the power. According to this ramp rate definition, $\Delta T$ referred as duration of the ramp rate, whose values can be predefined based on end users’ considerations, utilities and criteria of system operation.

In this study, the PRR$_3$ is used and defined as a power change occurred in a time span of quarter an hour the magnitude over the $P$ threshold , $\Delta T = 4$.

2.3. Average power rate

An alternative indicator to detect power ramp rate (Eq. 5), is calculating the average power rate. The latter is defined as the percent fluctuation of the power ramp rate (PRR$_3$) and the average power during a ramp duration $\Delta T$. We define average power rate (APR) as given by equation (6) [40].

$$\text{APR} = \frac{\max (P(T, T + \Delta T)) - \min (P(T, T + \Delta T))}{\sum_{t=T}^{T+\Delta T} P(i)/P(i)} \times 100$$ (6)

3. Presentation of Algeria’s economic activity sectors

Principally, the EPD depends on the weather and industries activities, as well as consumer’s behavior, which varies from working days to weekends and eventually holydays. In this context; and in order to study the impacts of COVID-19, it is important to illustrate the distribution of the energy consumption and the number of customers by economic activity sectors and voltage levels.

The Structure of Algeria’s national electric power network consists of three networks; the Northern Interconnected Network (extended over...
the north of the country and covered the south regions of Bechar, Hassi Messaoud, Hassi R’Mel, and Ghardaia), the Pole of Adrar-Insalah-Timimoun, and the South Isolated Networks. The voltage levels of the power networks are defined as follows [40]:

- Low voltage level (LVL): below 30 kV.
- Medium voltage level (MVL): 60 kV.
- High voltage level (HVL): from 90 kV to 400 kV. The customers supplied by this voltage level are those of industrial activity sectors.

Fig. 3a and Fig. 3b illustrate the repartition of energy consumption by voltage level in northern and southwestern Algeria recorded in 2020. A large amount of energy consumption is found at LVL with more than 54% (35,069 GWh) in the north and 79% (974 GWh) in the southwest [41], while the industrial sectors connected at HV level represent 19% of the total energy consumption.

In fact, the south of Algeria is not sufficiently developed, this can be translated by the lack of industrial activity sectors at HV level and the low percent sharing at MV.

For Algeria’s northern interconnected system, Tables 1 and 2 provide
respectively the repartition of energy consumption and the number of LVL and MVL customers by economic activity sectors recorded in 2019 and 2020, while Table 3 gives the historic evolution of HVL energy consumption by economic activity sectors from 2015 to 2020 [42].

These tables show that more than 10.4 million customers are connected at the LVL, and consumed more than 35 TWh of electrical energy in 2020, where the collective housing and outbuildings represented the largest energy consumption sector with a share of 65.6% of the energy consumption and 85.6% of the number of customers. At MVL, the water & energy sectors were responsible for about 24.5% of the energy consumption, followed by the residential customer’s sector with shares of 20.3%.

The comparison between the economic activity sectors in 2020 and 2019 shows that despite 2020, 37,7517 new collective housing and outbuildings customers added at LVL, the energy consumption in this sector dropped by 928.4 GWh compared to 2019. In contrast, at MVL, 50 new collective housing, and outbuildings customers are added and the energy consumption increased by 45.3 GWh compared to 2019.

At all voltage levels, the number of customers and energy consumption of agriculture and water & energy sectors increased from the previous year without the COVID-19, as people have spent more time at home.

The transport sector showed a significant decrease in energy consumption as it is concerned by the total and partial lockdown restrictions for a long time in 2020. At HVL, the energy consumption in this sector dropped by 31 %, from 263.5 GWh to 162.4 GWh. A low impact of COVID-19 on the transport sector connected at MVL is noticed with a drop from 615.3 GWh to 588.7 GWh. However, the impact of COVID-19 on the transport sector connected at LVL can be considered as important. In fact, despite 1,480 new customers being added, the energy consumption in this sector doubled to reach 800 GWh in 2020.

The hotels/restaurants/cafes sectors connected at LVL and MVL, which were for a long time concerned by total and partial lockdown restrictions, showed a drop in energy consumption by 23 % and 19.5 %, respectively, while the big hotels connected at HVL are not concerned by these restrictions, as they were used for hosting the persons came from outside of Algeria and doctors and nurses.

The analysis of the evolution of energy consumption between 2015 and 2019 is proposed in Table 3. It shows that the water & energy continued to represent the highest proportion of energy consumption at HVL, followed by the hydrocarbons, construction materials, and ISMME (that include the iron and steel industries, metallic, mechanical, and electrical activities) sectors. The ISMME sector experienced the highest increase in energy consumption. It has increased by about 175% between 2015 and 2020.

From the Table 2 and Table 3, the Robin chart of the energy consumption at LV and MV level recorded in the year of 2019 and 2020 is illustrated in Fig. 4, where S1, S2, ... S25 are the energy activity sectors abbreviations given in Tables 2 and Table 3. As can be seen, the highest rank or largest (red and blue layers) impact on the economic activity sectors is at LV and MV levels: collective housing and outbuildings (S23), residential customers (S21), trade (S15), agriculture (S3), and market services provided to households (S18) are the most affected by pandemic than that of the others sectors, showing the high relationship between the cited impacted activity sectors, while water & energy (S4), ISMME (S7), and agro-food industries (S10) at MV level, are the most impacted than that of the LV level or others sectors.

According to the Algerian government, the shutdown restriction during the first confinement period of the year 2020 impacted most of the economic activity sectors, as shown in Table 4. The total economic activity sectors that have been closed during the first confinement period of the year 2020 represent about 11.3% of the total energy consumption.

### 4. Results and discussions

Electricity load data is made available from the Operator of the Electric system (OSE-SONELGAZ) of Algeria (see go. https://www.os.dz/1287/courbe-de-charge). The electricity demand data for the present analysis is set from January 01, 2019, to December 31, 2021.

In this analysis, the industrial customers correspond to those customers connected at HVLs of 60 kV, 220 kV, and 400 kV.
4.1. Assessment of north Algeria’s electrical power demand

Fig. 5 illustrates the total monthly energy production, industrial energy consumption, distribution energy consumption, and maximum power demand, respectively, during the period starting January 2019 ending December 2021. As can be seen, the total energy consumption in 2020 decreased from that recorded during the previous year. This reduction is mainly due to industrial energy consumption that has been affected by the guarantee confinement. A maximum drop in industrial energy consumption of 22.4% is recorded in May 2020, and the energy dropped from 5,651 GWh to 5,557 GWh in 2020. In April 2020, both distribution and industrial energy consumptions decreased compared to the previous year (without the Covid-19) by 6.9% (from 4,034 GWh to 3,774 GWh) and 12.4% (1,024 GWh to 911 GWh), respectively. Later, the distribution energy consumption decreases by 8.9% in July 2020.

The monthly peak power demand illustrated in Fig. 6 shows the effect of COVID-19. A drop and month shift of the peak power demand is observed during the first year of the pandemic. The annual peak power demand of 15,656 MW recorded in August 2019 shifted to July 2020. In December 2020, the peak power demand started to increase because of both the increase of the number of customers (see tables II and III) and the left of the major restrictions. In 2021, an important increase in peak power demands of 16,224 MW that overpass the annual peak of previous years is recorded.

Fig. 7 shows also that the total losses in north Algeria’s electrical power network in 2019 and 2020 are stable and blow 4.5% of the total energy production.
energy production. More details of the total losses in the power network are represented in Fig. 8, showing that the total losses increased during the summer season (June to August). It is important to note that during the summer season from June to August 2021, the total losses increased significantly to reach 6.7 % in August, this is due to the heatwave that hit most parts of the northern regions of Algeria, as the losses in transmission lines and transformers are strongly depended on the temperature and current. After that, the total losses were restored to the normal value as the temperature returned to its normal season level.

By using Eq. 4, the percent deviations of daytime and overnight power demands are presented in Fig. 9. Fig. 10 compares for overnight and daytime the power demand during the pandemic, the historic power demand without the pandemic, and their average value. The first year under the pandemic has seen a low deviation in the evolution of the power demand and both overnight and daytime power demands are close to the average value of the previous year without the pandemic. After the reopening of the most economic activity sectors, the power deviation in 2021 returns to the level before the pandemic. It can be observed that the peak power demands are always recorded during the first two days of the total lockdown.

Fig. 11 plots the historical daily EPD recorded in northern Algeria under the total lockdown restrictions, from March 20 to 27, 2020, and compares with the same period in 2019 and 2021. A significant drop in power demand is recorded during the three first days of imposing the total lockdown. Some of the indispensable economic activity sectors listed in Table 4 are concerned only by partial lockdown restrictions, and are authorized to open from 7 am to 5 pm. On normal days, the moment of wake up of most Algeria’s citizens and opening of small economic activity, such as supermarket is at 7 am. It can be seen from Fig. 11 that this habit was changed during the lockdown restrictions, and the impact is well seen in power demand behavior.

In fact, the impact of the first lockdown restrictions is also observed on March 20 at 17:30 pm, and on March 22 at 23:45 pm, exactly, the power demand dropped from 7,280 MW in 2019 to 6,723 MW in 2020, which represents a reduction of 7.7 %. Moreover, during the first days of the total lockdown restrictions, from March 20 to 27, 2020, an average of 8.8 % in dropping of the power demand was recorded. On the contrary, compared to 2021, an average of 12.3 % increase in power demand was recorded.

Fig. 12 shows the average power rate and ramp rate of the power demand calculated during the first days of the total lockdown restrictions period (from March 20 to 27, 2020), and compared with that without the pandemic (2019) and relaxed restriction measures imposed in the same period in 2021. Through power ramp rate and average power rate indicators, we explored the effect of Covid-19 and showed that a large variation in power demand is recorded during the summer season.

In our case, we have proposed two limits of $P_{\text{threshold}} = 800 \text{ MW}$, and $P_{\text{min}} = 400 \text{ MW}$, which are equivalent to a rated power of two and one unit of a gas-fired cycle installed in Algeria’s power system.

As described in Fig. 13, both the two proposed indicators show in different manners that Covid-19 impacts the variations of hourly power demand. Most time, the average power demand is low than 15 %, even under the total or without lockdown restrictions. An exception for the first time of the total lockdown restrictions imposed in 2020, a maximum average power rate of 29.4 % is recorded on March 22, 2020, at 9 p.m. Despite this high variation, the power ramp rate did not exceed the minimum ramp rate fixed in our case at 400 MW.

Regarding the power ramp rate figures, the same period of exceeding the limits is recorded with the same level. An exception was detected on March 25, 2020, at 8 p.m., with a power ramp rate of 974 MW that exceeded the maximum fixed limit of 800 MW.

A new peak in power demand of 16,224 MW reached on Sunday (a weekend day), August 15, 2021, at 03:00 pm, an increase of 10.3 % (an additional power demand of 1,510 MW) compared to the busiest day at the same period in 2020 (14,714 MW recorded on July 28, 2020, at 02:30 pm), see Fig. 13 and Fig. 14.

This high demand for electrical energy is due to the heat wave that the country has known for several days, aggravated by deadly fires in several regions of the country. The temperatures recorded were 8°C higher than the seasonal norms; since the average temperature for the day of August 15, 2021, was 40°C; 8°C higher compared to the peak day of the month of August 2020. The last historical peak in consumption was recorded on Wednesday, August 7, 2019, at 2:30 pm. The peak power demand reached 15,656 MW, ie a rate of change of 2.6 %.

According to the operator of the system electric, for a scenario of summer at high temperature and although the strong power demand, the bulk power system has been safeguarded and the availability of the production park has even made it possible to ensure the commercial export of electricity to Tunisia and Morocco respectively of 300 MW and 200 MW.

Fig. 15 shows the color map of the hourly power demand recorded during the periods of March-April and July-August in 2019, 2020, and 2021, respectively. It well illustrates how the first lockdown restrictions imposed in April 2020 decreased the power demand overnight. An important drop of about 1,000 MW is observed in April 2020, between midnight to 08:00 am. As the reopening was successively implemented, the power demand gradually recovered in July.
Fig. 16 compares for each studied period (March 01 to 30 April and from July 01 to August 31), the normal distributions function of the power demand and its ramp rate, while Fig. 17 compares the normal distributions function of the average power rate during the same periods, as a function of count of hours of the power demand, ramp rate, and average rate levels.

Illustration of the normal distribution function of the power demand shows the changes that drove the evolution of the power demand in northern Algeria. It is well illustrated the decrease in the average power demand during the first month of the confinement period. An important increase in the number of hours for the power demand below the average value of 7,000 MW is observed. For example, the hour number that the power demand is below 6,000 MW increased from 30 hours in 2019 to 80 hours in 2020, while it decreased to 15 hours after the total reopen in 2021. By contrast, a small change in the average, minimum, and maximum power demands as well as in the number of hours is recorded. An important impact on the average power ramp rate is observed in 2020 and 2021.

In our work, we have proposed the time step of one hour to calculate the power ramp rate and average power rate. A high ramp rate indicates unstable evolution of the power demand. As can be seen, the impact of COVID-19 on the power ramp event is significant in the summer season (July and August). During this season, the number of hours of the power ramp rate that overpass the threshold limits, in our case, 400 MW and 800 MW, increased significantly, with more than 380 and 350 hours in 2020 and 2021 respectively. In 2019, without the COVID-19, the
number of hours that reached the threshold limits were below 180 hours.

The operators of Algeria’s power system made huge efforts to maintain the power system stability and reduce the ramp rate that may affect the reserve margin, and increase the transit exchange between the interconnected counties (Morocco and Tunisia). These efforts are translated by reducing the maximum ramp rate during the two studied periods even under strict restrictions or without. A similar impact of COVID-19 could be observable using the average power rate shown in Fig. 16, exemplifying that the maximum average power rate during the first months of COVID-19 spread decreased from 34.4 % in 2019 to be below 15 % in 2020 and 2021, while it slightly increased during the summer season of 2020.

- Electric power system situation under COVID-19 pandemic

The year of 2020 was harmful at various levels, both on the social level and energy, where the value of uncollected debts during the first six months of 2020 amounted to 89,672 million dinars [43], while a loss of 30 million dinars per day for every 400 megawatts at the level of the production company. While electricity sales at LVL only recorded 3 % of the development. Electricity sales for high voltage experienced a significant decrease from 6,452 GWh in the first six months of 2019, to 6,015 GWh in 2020.

In this regard, the development plan 2020 to 2030 was reviewed in order to reduce the burden and reduce the 2020 budget for investment by 30 % and the budget for exploitation by 7 %, whereby an amount of 149 billion dinars was saved. The plan for the summer of 2020 was also reviewed, and non-urgent projects were cancelled, as well as stopping electricity cuts for customers until further notice, which resulted in the accumulation of dues in light of non-payment by customers, and the recruitment of intervention teams at all levels in order to provide comfort to citizens during periods of home stone.

4.2. Assessment of southwest Algeria’s electricity power demand

In this section, we assess the impact of COVID-19 on electricity demand in southwest Algeria. Fig. 17 presents the percent deviation of overnight and daytime power demands, and in Fig. 18, we present the overnight and daytime power demand and their average power. As described in Fig. 17, a very small drop in overnight peak power demand is recorded in the first year under the COVID-19 pandemic.

The second-year under the pandemic recorded an increase in both overnight and daytime power deviations. Daytime power deviation increased from 18 % in 2020 to reach 23 % in 2021. The evolution from 2015 to 2021 of the peak power demands (overnight and daytime) illustrated in Fig. 18 shows that the pandemic did not affect the power demand deviation in southwest Algeria.

Fig. 19 plots the southwest Algeria’s power demand recorded during the first days of confinement restriction, studied in the previous section and compared with that recorded in the same period in 2019 and 2021. As illustrated, an increase in electricity demand is recorded during the first days of the pandemic spread. This reveals that the COVID-19 did not affect the evolution of the power demand in south Algeria.

Fig. 20 shows the power fluctuation (left side) and power ramp rate (right side) calculated during the first days of COVID-19 and compared to the same period in 2019 and 2021. Again, no impact of COVID-19 on these indicators is observed. We can note that the power ramp rate is below the rated power of a gas turbine of 25 MW, which is installed in the isolated Adrar power system. Under the first year of COVID-19, the peak of the daytime power demand of 376 MW was recorded on August 28 at 15:30, a growth by 5 % compared to 2019 that peaked at 359 MW on August 10 at 13h15 pm, and 7 % compared to the second year under the pandemic, which hit 404 MW on July 17 at 16:45. Fig. 21 and Fig. 22 illustrate the daily power demands for the period spans from July 15 to 19 and August 26 to 30. As exemplified, on August 27 to 31, 2020, the period of 00:00 to 10:30 am showed a drop in power demand compared with the previous year without the Covid-19 and even in 2021.

Fig. 23 and Fig. 24 plot for the periods of March-April and July-August, the color map of the power demand recorded in the years of 2019, 2020, and 2021. The minimum power demand during the period of March-April varies between 43 MW to 88 MW representing two to three gas turbines installed in the Adrar power system. Fig. 24 shows that the Covid-19 pandemic affects the power demand during the daytime by increasing its level. The period of July-August has undergone a remarkable increase in the power demand between 10:00 and 17:00.

It should be noted that the isolated Adrar-In Salah power system hosts a total installed capacity of variable renewable energy of 63.2 MW, shared between seven photovoltaic power plants (53 MW) and a wind farm of 10.2 MW. In fact, under high renewable energy production and with low power demand, maintaining a weak power system stability and reserve margin can be a severe challenge for power system operators, which they must order to shut down several gas turbines, as consequence, reducing power system inertia. In this context, we perform the normal distribution function to investigate how the power demand was changed under COVID-19.

The following Fig. 25 illustrates the normal distribution function of power demand, power ramp rate, and average power rate as a function of hours count. These figures show a slight difference in the mean, minimum, and maximum occurs on the studied parameters (power demand, average power rate, and power ramp rate), while the impact of COVID-19 is observed on the number of hours that these extreme values occur.

As explained before, important occurrence hours of high power ramp rate, significant that the power demand was changed several times and this is exemplified in these figures. The maximum power ramp rate occurred during the first confinement period, increased from 38 MW to 83 MW, and reached a level of 133 MW in the same period in 2021. The summer period experienced an increase from 96 MW in 2019 to almost 116 MW in 2020. It returned to nearly the same level before the pandemic to reach the level of 109 MW.

Interestingly, how the mean of the power ramp rate and the average power rate slightly changed, while their occurrence hours increased.

5. Conclusion

This research describes an assessment of the impacts of extraordinary containment measures imposed against the spread of COVID-19 on electricity demand in northern and southwestern Algeria using three indicators; power ramp rate, average power rate, and percentage deviation. Exclusively, the impact on the distribution of energy consumption by voltage level and economic activity sectors is presented.

The residential sector connected at a low voltage level dominates the energy consumption in Algeria, which represents 54 % of the total energy consumption in the north and 79 % in the south. Compared to the previous year without the pandemic, northern Algeria, with a high population, showed a slow decline of 1.22 % in the total energy consumption in this sector. The total electricity production during the year 2020 reached 73,8379 GWh, a drop of 2.9 % compared to 2019. South Algeria characterized by low population and industrial sectors that were less affected by the COVID-19 pandemic, recorded a growth of 134 GWh in the residential sector.

The summer of 2021 was very sorrowful for Algeria; large wildfires menaced the North region, and, grievously, the third wave of COVID-19 peaked during this period. The operators and managers of the power system made huge efforts to feed all the customers; nonetheless, some communities were impacted, and even the hospitals remained without electricity. Fortunately, this situation had no negative impact on the stability of the bulk power system.

In summer 2021, the extreme temperatures, besides being responsible for wildfires, are also the cause of the increase of the power demand
and total losses in 2021. The annual peak power demand reached 16,224 MW in August, while it declined from 15,656 MW in August 2019 to 14,714 MW in July 2020. This research finds that a larger number of COVID-19 infections during the national lockdown resulted in a larger decline in nighttime light intensity in districts.

The results presented above reveal that the electric power demand and energy consumption are more heavily affected in the northern than in the southwestern region. The impact of COVID-19 on north Algeria’s power demand behavior, however, is more remarkable on occurrence hours of the extreme power ramp rates and average power rate that increased during the first months of imposed the strict restrictions compared to the same period before the pandemic and during the relaxed restrictions in 2021. Interestingly, we determined the same impact in south Algeria.

Future studies are intended to precisely assess the electricity and gas energy demands during the COVID-19 pandemic and contemplates the full data of the year of 2021.

CRediT authorship contribution statement

S. Makhloufi: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. S. Difa: Conceptualization, Supervision, Formal analysis, Writing – original draft. Ch. Ould-Lahoucine: Writing – original draft, Writing – review & editing. M.M. Hadjlat: Supervision, Conceptualization. K. Abdeladim: Supervision, Conceptualization.

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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