Electricity demand during pandemic times: the case of the COVID-19 in Spain

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Abstract

Electricity demand and its typical load pattern are usually affected by many endogenous and exogenous factors to which the generation system must accordingly respond through utility operators. Lockdown measures to prevent the spread of COVID-19 imposed by many countries have led to sudden changes in socioeconomic habits which have had direct effects on the electricity systems. Therefore, a detailed analysis of how confinement measures have modified the electricity consumption in Spain, one of the countries most affected by this pandemic, has been performed in this work. Its 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. These changes generate a greater uncertainty for the System Operator when making demand forecasts, but production deviations have increased by only 0.1 %, thanks to the presence of a diversified generation mix, which has been modified during this period, increasing the proportion of renewable sources and decreasing CO_2 emissions.

Keywords: power demand drop; COVID-19 pandemic; lockdown; electricity consumption; impact on power grids; power generation mix;

1. INTRODUCTION

The whole world is witnessing the coronavirus pandemic declared by the World Health Organization (WHO). The new SARS-CoV-2 virus produces a new respiratory disease, COVID-19, for which there is currently no effective therapy. Since the end of February, the new virus has spread through most countries of the world, and as of early May, there have already been more than 3.5 million cases worldwide with more than 250,000 deaths.

To slow the spread of the virus effects governments across the world have adopted restriction measures, imposing the shutdown of most social and economic activities. Some of these measures are partial or complete lockdowns, including daytime curfews and bans on public assemblies, closure of non-essential businesses, and even educational institutions (Karnon, 2020)(Gentilini et al., 2020) (International Energy Agency (IEA), 2020a).

Spain has been one of the countries in which this pandemic has had a greater incidence during March and April, so the measures adopted have been more restrictive than in other countries around it. A significant percentage of society has been forced to curtail their daily habits, stay inside the home, and wait until the coronavirus pandemic is under some sort of control. In this country, the restrictions in response to the coronavirus began on March 14, when the government imposed a state of alarm (Ministerio de la Presidencia Relaciones con las Cortes y Memoria Democrática (MPRCMD), 2020a), and on March 30 even stronger confinement measures, with the shutdown of all non-essential business (Ministerio de la Presidencia Relaciones con las Cortes y Memoria Democrática (MPRCMD), 2020b), were proposed.

Such measures taken by governments have affected many sectors (Ivanov, 2020)(Folinas and Metaxas, 2020), generally impacting on the economy of the countries implied (Huynh, 2020)(Michie, 2020) (Lyu and Nie, 2020). Energy supply is one of the sectors considered critical infrastructure. The energy demand, and in particular electricity, is closely related to people's activity (Santiago et al., 2014), but especially to work activities. This influence of economic activity on electricity demand, also named economic signal on electricity demand, has been evident in almost all the countries where restriction measures have been adopted. Some studies have pointed out that in some of the most affected countries, such as Italy, electricity demand has been reduced by almost 25% (Walton, 2020) (Cicala, 2020).

Electrical energy in Spain, after the country overcame the last economic crisis in 2008, had been growing since 2015, at a rate even higher than the growth in employment (REE, 2019). However, the orders of stay-at-home and the shutdown of a great percentage of businesses have led to a reduction in the electricity demand of the largest in Europe (Cicala, 2020) (Armstrong, 2020).

In this scenario, the objective of this work has been to carry out a detailed analysis of how to limit both the movement of people and economic activity, to reduce the impact of the coronavirus disease pandemic, has influenced the demand for electricity, which is one of the factors that directly reflects the socio-economic activity of a country . For this aim, a search and gathering of information have been carried out to expose and evaluate how the restriction measures have affected total daily power demand patterns, on weekdays and weekends, and how these changes have had some effects in some important aspects such as the management of the grid and the generation mix, to adapt electricity generation to a variation of the demand profile not found in previous situations. The evolution of electricity prices, the reduction of CO_2 emissions caused by electricity production, or the demand profiles of some specific consumers such as a hospital or a residential house, have also been analyzed. The strategies adopted by the System Operator (SO) in this exceptional and unprecedented scenario have allowed showing the capacity of response of the network to this anomalous situation, highlighting some issues for the future transition to a scenario with an even higher percentage of renewable energies.he remainder of the paper is organized as follows. Section 2 indicates the origin of the data used to perform this analysis, and section 3 shows the results obtained and a discussion of them. Finally, the conclusions of the study appear in section 4.

2. METHODOLOGY

To carry out this study, first of all, the data made public by REE, the Spanish Power System Operator, have been used (www.ree.es). This public company, which manages nearly 44,000 km of power lines, has as its main objective to guarantee the security and continuity of the electricity supply and to develop a reliable transmission network. It is responsible for the correct coordination between the production system and the transmission network, ensuring that the energy produced by the generators is transported to the distribution networks with the quality conditions required under current regulations.

To carry out the analysis of electricity demand, daily records of expected ($EE_{demand\_n\_2020}$) and actual or real demand ($RE_{demand\_n\_2020}$), for the period 24 February to 30 April 2020, have been downloaded from the website. These have been compared with those of the same period for the years 2019 to 2015 ($RP_{\mathrm{demand\_n\_2015\text{-}19}}$). The data had been recorded with a frequency of 10 minutes. A total of 366 files have been transferred to different spreadsheets and processed by the MATLAB software. Values of total daily real electricity consumption (DRE_{demand_2020}) have been calculated, adding up all the daily instantaneous demand values for each day of the period analyzed

$$DRE_{demand\_2020} = \sum_{n=1}^{144} RE_{demand\_n\_2020} \qquad (1)$$

where the sub-index n represents each of the 144 daily records made every 10 minutes. To determine the total daily values in the previous five years the average total daily real demand ($DRE_{demand\_\mathrm{av(2015\text{-}19)}}$) has been calculated for each day in March and April for the years 2015 to 2019

$$DRE_{demand\_av(2015-19)} = \left(\sum_{y=2015}^{2019}\left(\sum_{n=1}^{144} RE_{demand\_n\_y}\right)\right)/5 \qquad (2)$$

For this comparison, the Sundays of each year have been made to coincide, to evaluate the difference in consumption considering the weekdays and weekends.

The files analyzed correspond only to the peninsula area of this country. Electricity consumption in the two archipelagos (Mallorca and Canarias) has not been included as this data appeared on the web disaggregated by islands. Consumption in the cities of Ceuta and Melilla is not included either.

The percentage of reduction in electricity demand in 2020 respect the previous five years have been calculated

$$reduction = (DRE_{demand\_2020} - DRE_{demand_{av(2015-19)}}) * 100/DRE_{demand_{av(2015-19)}} \quad (3)$$

To determine the deviation between the expected and the real demand values that took place for each day during the lockdown in 2020 ($deviation_{2020}$) and the same period in 2019 ($deviation_{2019}$) the average daily percentage of the absolute value of the deviations in the different daily records (every 10 minutes) has been calculated

$$deviation_y = \sum_{n=1}^{144}[\left|RE_{demand\_n\_y} - EE_{demand\_n\_y}\right| * \frac{100}{RE_{demand\_n\_y}}] \quad (4)$$

where the sub-index *y* represents the year analyzed, 2020, or 2019.

Data corresponding to the total daily electricity produced for the peninsula by all the technologies involved in the generation mix, as well as the CO_2 emissions corresponding to that electricity generation, have also been downloaded from the REE website.

In this work, the electricity prices for the small consumer in this period of confinement have also been analyzed. Although trading companies can also offer free prices, this paper discusses those corresponding to the Spanish regulated market. They are used by consumers with a contracted power below 10 kW. The price of the kWh changes every hour, depending on the differences between demand and supply, considering the prices of all forms of production present in the generation mix. Specifically, there are three regulated tariffs for small consumers with an intelligent meter in this country, named PVPC (voluntary small consumer price) By Default, PVPC Two Periods Efficiency, and PVPC Electric Vehicle. Data corresponding to prices of these tariffs have been obtained from the Markets and Prices section of the website of the System Operator's information system, so-called E-SIOS (https://www.esios.ree.es/es). For the analysis, it has been necessary to download a file for each of the 61 days of the lockdown's's period. Each of the files contained the hourly data of the three above-mentioned tariffs.

Data corresponding to the electricity demand of the house included as an example in the paper has been provided by the company Endesa (https://www.endesa.com/es), which is the marketing company that provides the electricity for that home. In the customers' area of its website, the owners of the house can consult data of the electricity consumption just activating their account. Consumption data are recorded by the company on an hourly basis. This house is in a building located in the city of Cordoba, having 4 residents, and both the air conditioning and water heating of the building work with electricity.

Data corresponding to the demand of the hospital included in the work corresponds to the so-called "Hospital de la Axarquía", Torre del Mar (Málaga), in the south-east of Spain. It is a medium-sized hospital with numerous medical specialties. It has 190 hospitalization beds. The data have been registered in the hospital and have been provided by its maintenance staff. Total daily data has been provided, from February 24 to April 30, 2019, and 2020, as well as daily data (recorded every 15 minutes) for the same period in 2020. The measures have been collected by network analyzers located in the hospital and included in a control facility of the building, to optimize the consumption of its different areas and improve its energy efficiency. The data used in this work were those corresponding to the general consumption of the hospital, which includes all of its uses and services, and also that corresponding to the consumption of refrigeration, which is the demand originated by the cooling plants and secondary air conditioning pumps. The power demand values represented in this work correspond to the sum of both, which reflects the complete electrical consumption of the building and all its services.

Data for the analysis of the self-consumption coverage for the house has been recorded on an actual photovoltaic (PV) installation with a peak power of 17.82 kW and which is located on a roof of a building in the same city where the housing is located, in an area close to the housing. This installation consists of three inverters of the commercial house SMA, model SMC-5000, to which three strings of PV modules with a total power of 5.94 kWp are connected. The modules are from the commercial house BP, and all are located with an inclination of 30º and a deviation from the south of 18º. A more detailed description of the technical aspects of the installation can be found in a previously published paper (Santiago et al., 2017). The values of electricity generated by the PV installation recorded by its inverters have been used to simulate the electricity production in the house under study.

3. RESULTS AND DISCUSSION

3.1.- Total power demand

Figure 1 shows the total daily electricity consumption in Spain (peninsula area) (DRE_{demand_2020}), in GWh, in March and April 2020, together with the average daily values for the previous five years (2015-2019) ($DRE_{demand\_av(2015\text{-}19)}$). The graph shows the demand values from Monday 24th February to Thursday 30th April. As it has been previously noticed, in this graphic representation, and the comparisons made, the Sundays of each year have been made to coincide, to evaluate the difference in consumption considering the weekdays and weekends. The days of the month considered in the axis of the figure correspond to the days of the year 2020.

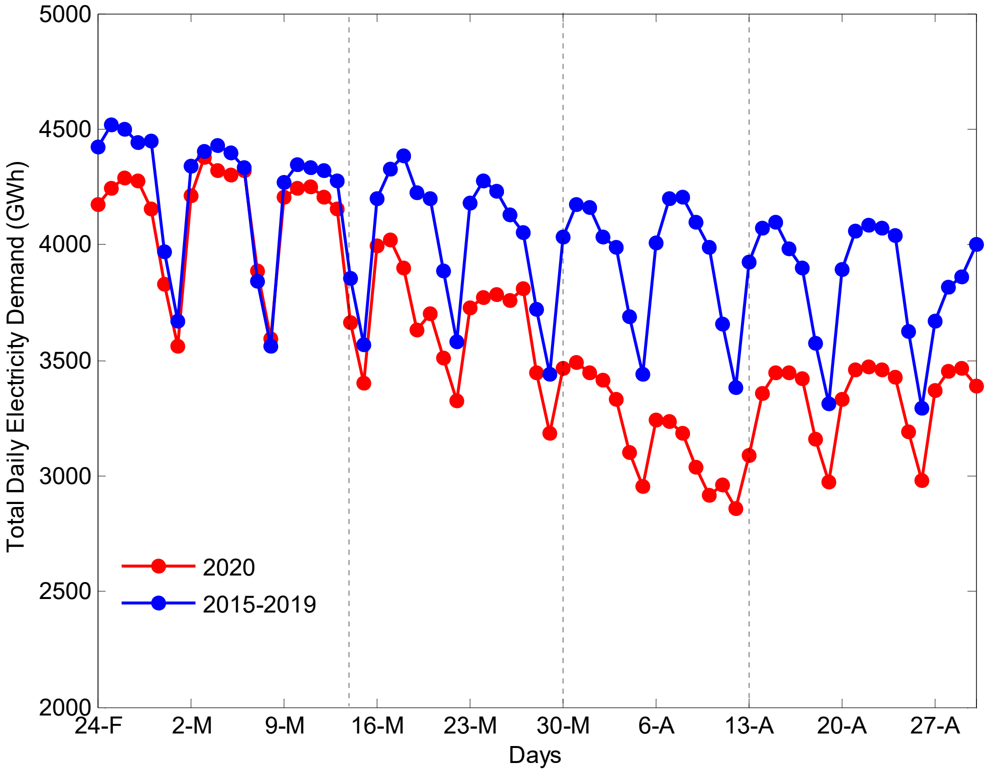

Figure 1. Total daily electricity demand (GWh) in 2020 and the average value of 2015-2019.

Figure 1 illustrates the evident reduction in electricity demand that has taken place this year since the beginning of the lockdown measures adopted by the Spanish government, which took place on Saturday, March 14, the day on which the state of alarm of the country was decreed (Ministerio de la Presidencia Relaciones con las Cortes y Memoria Democrática (MPRCMD), 2020a) (this date is reflected in the figure through a broken line). From March 14 to April 30, electricity consumption was 25,441.17 GWh lower than the total consumption for the same period in the previous five years (average value for the five years), which represents a total reduction of 13.49 %. The percentage variation in consumption on each of the days in the period represented can be seen in Figure 2.

During the first three weeks shown in the graph, corresponding to the last week of February and the first two weeks of March, consumption was slightly lower than in previous years (2.75 %

lower on average in these three weeks). But it is from Saturday, March 14 when a significant reduction in demand begins, reflecting the reduction in activity in the industrial sector and a large part of the service sector. With the start of the lockdown, during the period from Saturday 14 to Sunday, March 29, the reduction in total electricity consumption was 8.84 %, with an even greater reduction as of Monday, March 30, the day on which the government adopted the measure to force companies that were still in operation to halt their activity and provide their workers with 9 days of paid rest (hours that must subsequently be recovered by the workers throughout the year) (Ministerio de la Presidencia Relaciones con las Cortes y Memoria Democrática (MPRCMD), 2020b). The beginning of this period, from this day on, is also represented by a dashed line in the graphs. From this stricter measure, the electricity demand presents a reduction of 15.71 % during the first week, which is further reduced in the week of April 6-12, coinciding with the Easter holiday, with values that reach over 25 % reduction in demand concerning the values of previous years. From Monday 13 April, a recovery in the power demand can be seen, with the return to work of some sectors (the beginning of this new period is also reflected in the graphs with a broken line), however, during the last two weeks of April, the demand has still been 13.54 % lower than the average value of the previous five years.

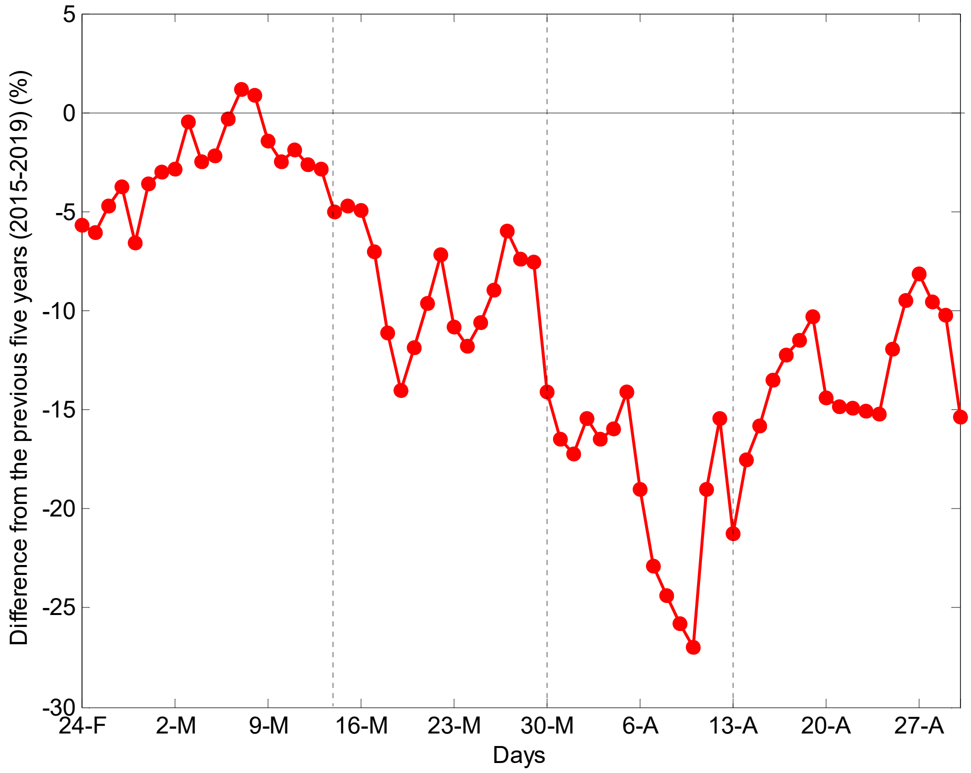

Figure 2. Difference (%) between the electricity demand in 2020 and the average values in five previous years (2015-2019).

The value of the temperature has a direct effect on electricity demand, as can be seen in Figure 1, with a progressive decrease in the average value of total daily consumption for the previous five years throughout the period represented, due to an increase in temperatures that takes place in these months of the year, from the last week of February to the last week of April. However, it is the labor character of the days, one of the aspects that most influence the electricity demand (López-Rodríguez et al., 2013) (Santiago et al., 2014). On working days, from Monday to Friday, demand is higher than on weekends or public holidays, as shown in Figure 1. The working day with the least demand is usually Monday, due to the inertia of the weekend shutdown. Consumption is reduced on Saturdays and so even more on Sundays. It is therefore on working days that the electricity demand has fallen most in this period of confinement.

In the graph presented in figure 3, the working days and weekends have been separated, representing the percentage reduction in demand for each type of day in 2020 to the average value of demand for the previous five years. In the period from March 14 to April 30, electricity demand has been reduced on working days by 13.79 % (17,995.45 GWh less consumed than in the same period in the previous five years), while on weekends electricity consumption has been reduced by 10.62 % (5,312.74 GWh less consumption).

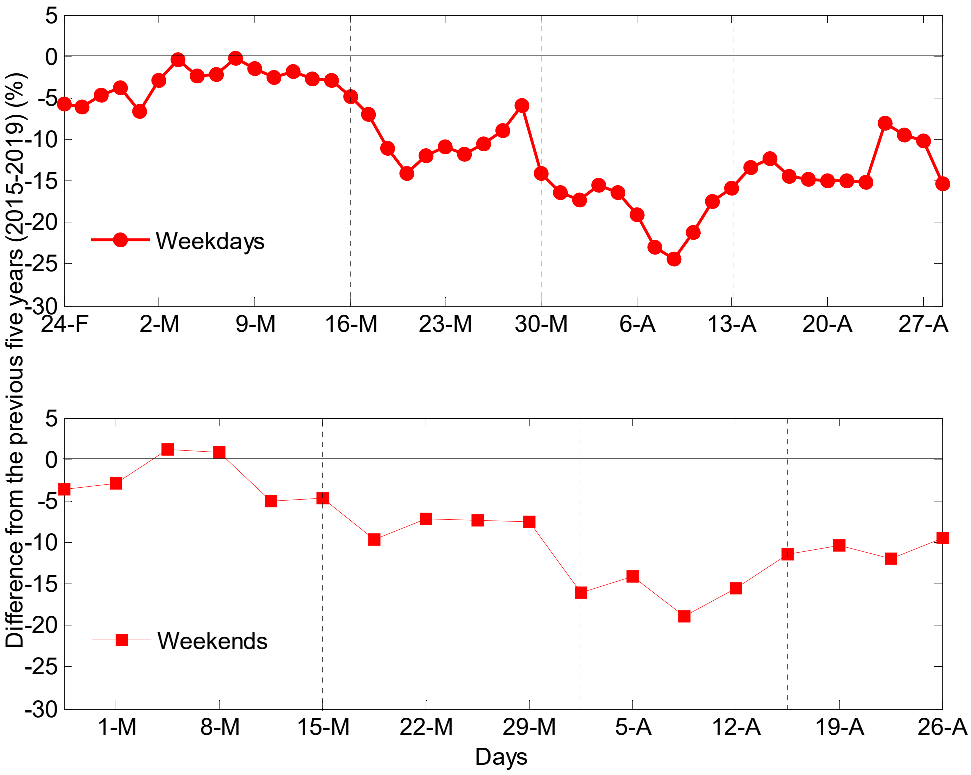

Figure 3. Difference (%) between the electricity demand in 2020 and the average values in five previous years (2015-2019), on weekdays and weekends.

In addition to a reduction in the total daily consumption of electricity demand, the change in the daily demand profile that has taken place since the restriction measures were adopted is also noteworthy. Figures 4 and 5 show the daily electricity demand profiles, with values recorded every 10 minutes, for the years 2020 and 2019 respectively, from Monday 24 February to Thursday 30 April.

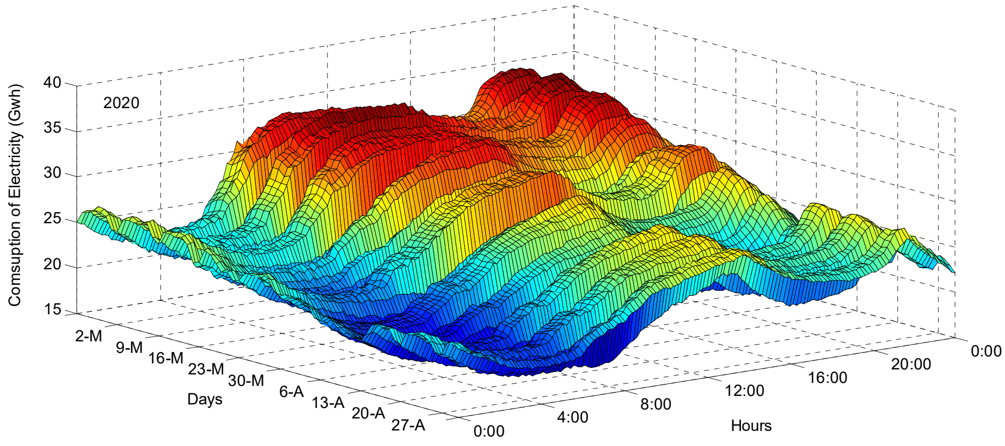

Figure 4. Daily profiles of electricity demand during March and April 2020

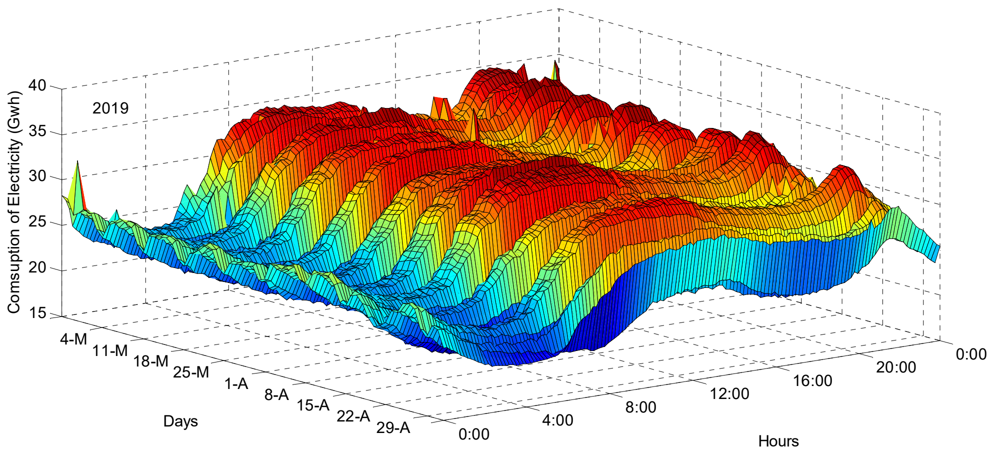

Figure 5. Daily profiles of electricity demand during March and April 2019

In these figures, the reduction in electricity consumption in 2020 compared to that of 2019 can be observed, but the change in the demand profile throughout the day is also noteworthy. The regularity of consumption and the hours and demand values of the periods of maximum consumption have been modified by the lockdown. Although the decline in electricity demand takes place throughout all hours of the day, the greatest reduction occurs in the morning and evening peaks. This behavior has also been observed in other countries such as the United Kingdom (Ghaseminejad Liasi et al., 2020), although the shape of the curves are different, given that they were previously different due to the different scheduling habits of the two countries (López-Rodríguez et al., 2013).

For a more detailed analysis, Figure 6 shows the daily electricity demand profiles in Spain every Wednesday (working day) in the two months analyzed. Wednesdays have been chosen as they are one of the working days with the highest total daily electricity demand throughout the week. The Wednesday daily profiles for the three weeks before the confinement are shown with broken lines, and they have very similar daily profiles. On March 11, there was a slight drop in demand (1.54 % less than on Wednesday, March 4), since in some Autonomous Communities such as Madrid, schools were closed that day and many people remained in their homes by teleworking. But it was the first Wednesday of the nationwide lockdown period, March 18, when a significant reduction in demand took place, as electricity consumption on that day was 8.34 % lower than on the previous Wednesday, March 11, and 9.75 % lower than on Wednesday, March 4. This reduction took place during all hours of the day. On Wednesday, March 25, an even greater drop was observed, 12.40 % lower than Wednesday, March 4, and excluding April 8, which was the day with the least demand (coinciding the activity shutdown and the Easter Week), the rest of the Wednesdays in April present fairly similar profiles, with consumption lower than that which took place during March (19.95 % lower than consumption on Wednesday, March 4). Although there has been an increase in temperatures, which would also lead to a reduction in demand, consumption and daily profiles are significantly different from those before the confinement period.

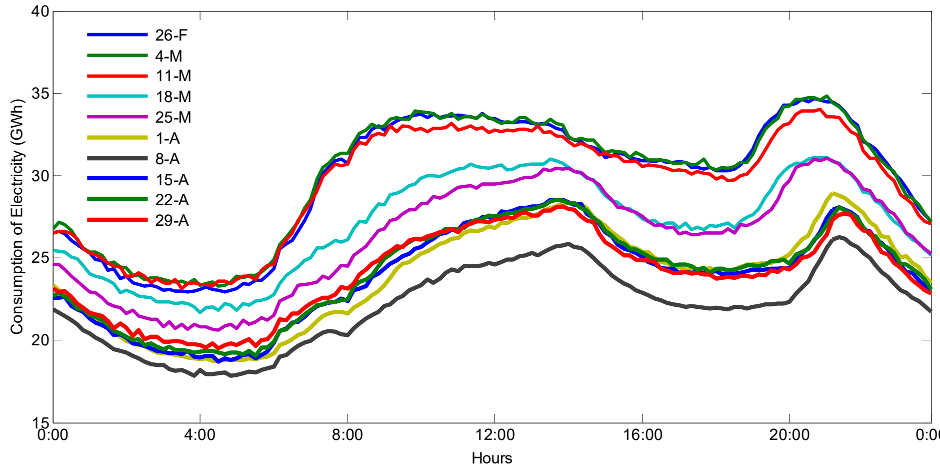

Figure 6. Daily demand profiles for Wednesdays in the period analyzed (March and April 2020)

It is worth noting the reduction in electricity consumption that has taken place at the morning peak and during the night peak. Concerning the morning peak, if before the lockdown the demand was practically constant from 8:00 to 14:00h, during the confinement the daily increase in demand after the night valley, which starts around 5:30 h, continues practically throughout the morning. Peak morning demand is now reached between 14:00 and 15:00 h, but without getting the maximum values achieved before the COVID-19 restriction period. This same later and more gradual morning ramping period has also been observed in cities such as New York (García, 2020). After this peak, the electricity demand begins to decrease in the afternoon valley area, which now is more pronounced and with a duration longer than before. In addition to the shutdown in the industrial sector, the service sector also plays a fundamental role in the demand for electricity at these hours of the day. The service sector integrates a heterogeneous group of activities, basically related to the office, commerce, hotels and restaurants, health, and education sectors, and this sector has its greatest presence between 7:00 and 19:00 h (REE, 2019). In the paper of (Palacios-Garcia et al., 2018) the activity curves of different industrial and service sectors can be seen, in days of continuous and split schedule, and a great part of the activity developed in the afternoon has been suspended during the alarm state, giving rise to the consumption decrease observed at these hours. And in the last hours of the day, the night peak has also changed its shape, it has a shorter duration, of only about 1 hour, when previously it had a duration of about three hours, and a lower demand value. The peak has been displaced towards 21:30-22:00 hours, not only due to the increase in sunlight at this time of year to the weeks prior to the confinement, but mainly due to the interruption of work activity during the afternoons. At this time of the night peak, the impact of the demand due to the residential sector could be more than 30 % (REE, 2019), since at this time of the day the working day ended in many sectors and the highest active occupation of the houses took place, producing the highest demand of electricity of this sector (López-Rodríguez et al., 2013) (Santiago et al., 2014). During the period of lockdown, consumption in the home was more spread out over the whole day, as will be shown in this paper later. Also during the night valley, there has been a notable decrease in electricity demand, and it is in the early morning when the industrial sector reaches a greater weight in the demand curve (REE, 2019).

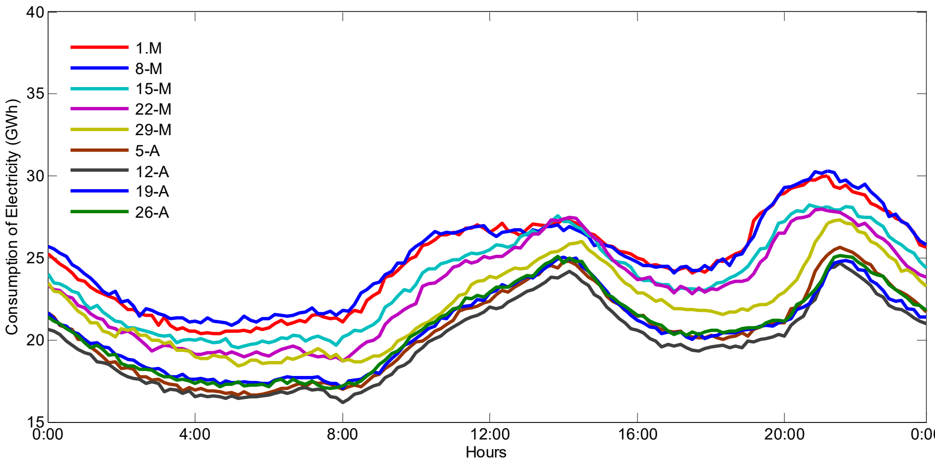

Figure 7. Daily demand profiles for Sundays in the period analyzed (March and April 2020)

Figure 7 shows the daily demand profiles for Sundays in the period analyzed. The electricity demand on Sundays is lower than on working days, but it can be seen that there has also been a reduction in demand during the containment period, and also a change in the daily demand profile, affecting to a greater extent, as on working days, the morning peak and the evening peaks. And the reduction in demand in both the night and the afternoon valley is also quite noticeable.

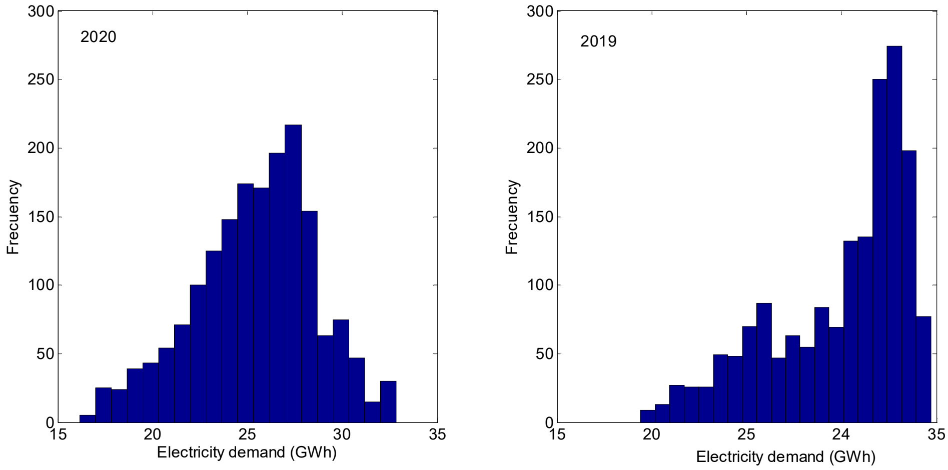

Figure 8. Histograms corresponding to electricity demand, between 8:00 and 14:00 h from March 14 to April 30 in 2020 and 2019

The magnitude of the variation in demand during the morning peak is shown in Figure 8, where a histogram corresponding to electricity consumption between 8:00 and 14:00 h from March 14 to April 30 in 2020 has been represented, together with another histogram for the same months and hours, but now for the year 2019. It can be seen, that at this time of day, in 2020, electricity demand values are almost 5 GWh lower than in 2019, when the most likely values were around 30 GWh (values are recorded every 10 minutes). It is therefore obvious how important the industrial and service sector is in the demand for electricity during morning hours. Industry accounted for 23.4 % of total energy consumption in Spain in 2017 (Ministerio para la Transición Ecológica. Gobierno de España, 2019) so the closure of these economic activities that has taken place has had a direct impact on the energy demand, and particularly for the electric power demand daily curve along the morning. At the same time, these hours are those in which generation through energies such as solar PV is the highest. This indicates that, although the role played by domestic self-consumption is important, it is essential to undertake initiatives that encourage self-consumption in the industrial and service sectors, to increase the participation of clean energies in the generation mix, given that these are sectors that have a very significant weight in electricity demand during the hours of maximum generation by photovoltaic.

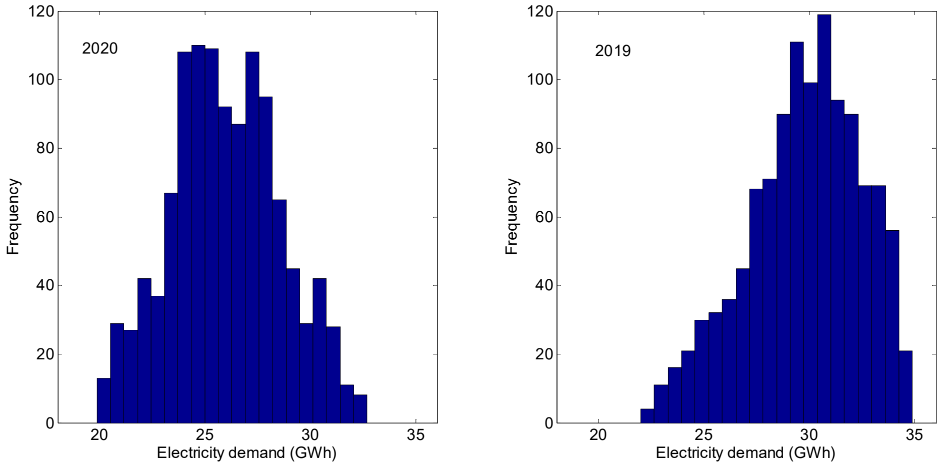

Figure 9. Histograms corresponding to electricity demand, between 19:00 and 23:00 h from March 14 to April 30 in 2020 and 2019

The variation in demand at the night-time peak is analyzed in Figure 9. A higher incidence of values around 25 GWh can also be seen in 2020, when in 2019 the highest incidence was around 30 GWh, which shows the reduction in electricity demand that has taken place at the second peak of the day (between 19:00 and 23:00 h) This is when the daily demand value takes its highest values that become higher than those in the morning, especially on weekends. It has already been indicated that at these hours the residential sector plays an important role in the demand but given that consumption in homes has been distributed throughout the day, the nightly peak has reduced its maximum value. The demand from the restaurants and leisure sectors has also stopped working at this time, which has contributed to this reduction in the peak demand at night.

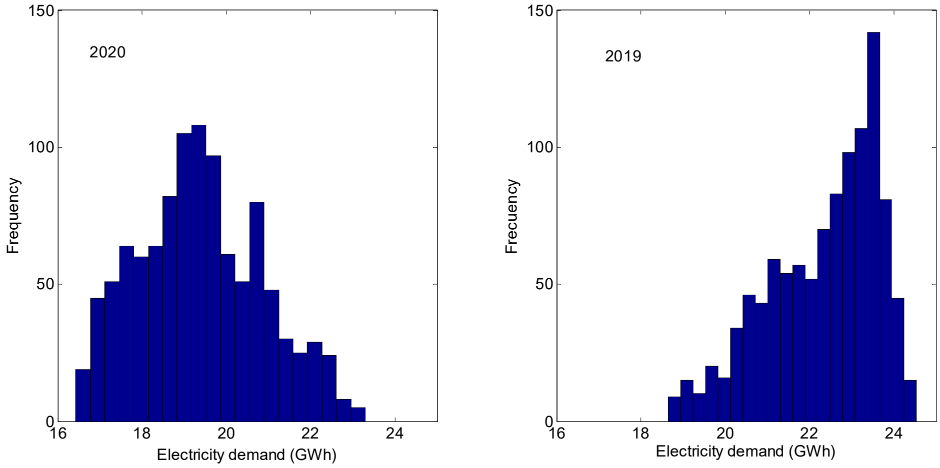

Figure 10. Histograms corresponding to electricity demand, between 02:00 and 05:30 h from March 14 to April 30 in 2020 and 2019

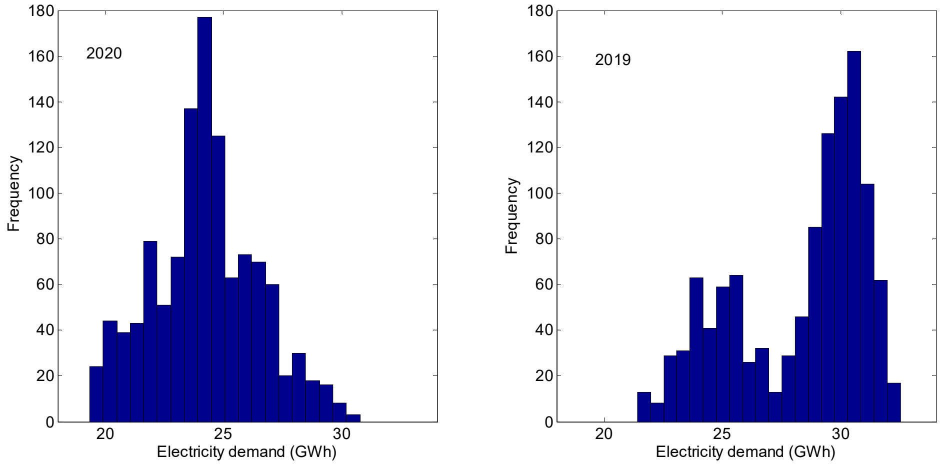

Figure 11. Histograms corresponding to electricity demand, between 15:00 and 19:00 h from March 14 to April 30 in 2020 and 2019

Concerning the valleys, figures 10 and 11 reflect the consumption histograms of the two daily valleys, during the night and in the afternoon, respectively. Concerning the night time, electricity demand has been represented between 02:00 and 05:30 h, and as can be seen in the histograms in the year 2020 the highest incidence takes place at values around 19 GWh, while for the same period last year, the highest incidence at those hours was for demands of around 23 GWh. At this time the role of the industry is important, representing up to 35 % of the total demand (REE, 2019).

And in the case of the afternoon valley, between 15:00 and 21:00 h, it can be observed how the behavior of demand has also been modified, with the greatest incidence moving to values around 24 GWh when last year the values with the greatest incidence at those hours were around 30 GWh. As already mentioned before, the service sector has slowed down and even paralyzed its activity throughout confinement, with the demand at this time of the day being largely responsible for this reduction.

3.2.- Electricity consumption in a house

The residential sector accounts for 25 % of total daily electricity consumption (Institute for Diversification and Saving of Energy (IDAE), 2011), but at certain times of the day, it can represent more than 30 % of total demand (REE, 2019). This sector is experiencing an increase in demand during confinement, due to the closure of schools, the obligation to remain in housing, and because a large proportion of workers have either lost their jobs or are teleworking from their own homes. Figure 12 shows an example of the electricity demand in a 4-member dwelling during the period analyzed in this work, located in a city in southern Spain. As has already been indicated, both air conditioning and hot water use electrical energy in this dwelling. The demand for electricity in this house from March 14 to April 30 was 6.74 % higher in 2020 than in 2019, mainly due to a longer stay of the residents in the house during the lockdown period. During the two months analyzed, temperatures have been moderate and the demand for electricity for heating and cooling has not been very significant. However, it should be noted that daily demand peaks are higher in 2019. This is because, as people remain in their homes throughout the day, the electricity demand is more distributed throughout the daily profile in 2020, and not just during the morning and afternoon peak hours, as is the case in 2019. This can be seen in detail in Figure 13, where the electricity demand for a working day at the end of April (Friday, April 24) is represented. In 2019, the demand for electricity is concentrated in two important peaks, between 7:00 and 9:00 h, and from 20:00 h onwards, due to residents being away from their homes during the working day. In contrast, in 2020, because residents are forced by the confinement situation to stay in the house, the demand is spread over the morning, and the night peak shifts an hour later and presents now a lower demand than in 2019. Although it is a particular example, it could be considered a sample of what is happening in many homes during the period of confinement, and which has been reflected in the behavior of the nightly peak demand throughout the Spanish peninsula.

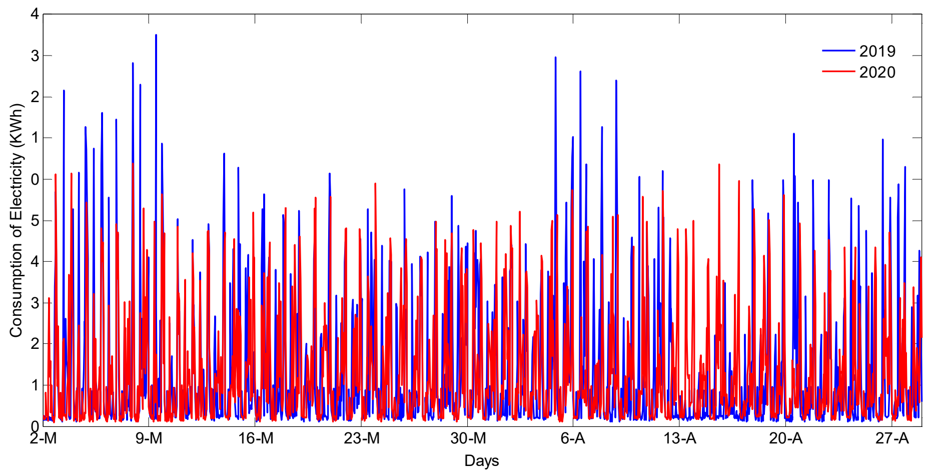

Figure 12. Hourly electricity demand in a 4-member household during March and April, in 2020 and 2019

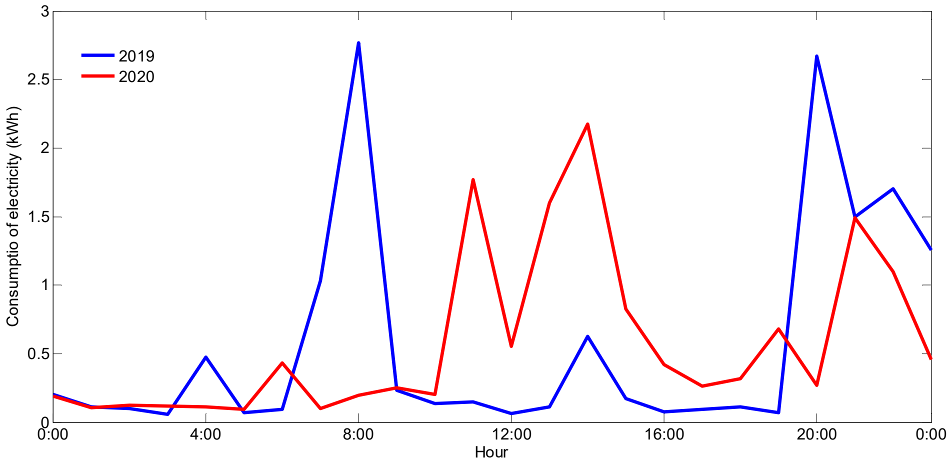

Figure 13. Hourly electricity demand in a 4-member house on 24 April 2020 and the same day of the week corresponding to 2019

Some authors consider that during pandemic times the residential sector should be regarded as a high priority load. The operation of household appliances and devices in the home should be assured to guarantee the permanence of its residents in their homes (Ghaseminejad Liasi et al., 2020). Also, electricity ensures the use of Internet and communication services in the home, which for many people have become essential tools for carrying out their telework or their social relations in the period of lockdown.

3.3.- Electricity consumption in a hospital

However, if there have been priority loads during this pandemic, they have been hospitals. In this case, ensuring the electricity supply has been an absolute priority. Electric power is not just important for the overall functioning of the health facility, as it had been until now, but it is critical for direct patient care due to electric ventilators are being a key tool to reduce the likelihood of death from COVID-19 (Lewis and Hebner, 2020). Figure 14 shows the total daily demand of a hospital, which has already been indicated as located in southern Spain, from February 24 to April 30. Consumption for the same period last year has been included for reference purposes. In the figure, the Sundays of both years have been made to coincide, although the days reflected in the axis of the figure correspond to 2020. The demand for electricity in the hospital has been reduced since the beginning of the state of alarm. Although in the three previous weeks, the last week of February and the first two weeks of March, the hospital's electricity consumption was even higher than in 2019, from the start of the restriction measures on March 14 until April 30, power demand has been 19.49 % lower. To avoid an increase in COVID-19 infections and to prevent the collapse of health systems, some of the hospital's activities, such as some non-urgent programmed surgery and outpatient consultations, have been reduced during this period, which has been reflected in this lower consumption of electricity. It can thus be seen that even in this critical sector, there has been a decrease in consumption due to the reduction of some of its daily activities.

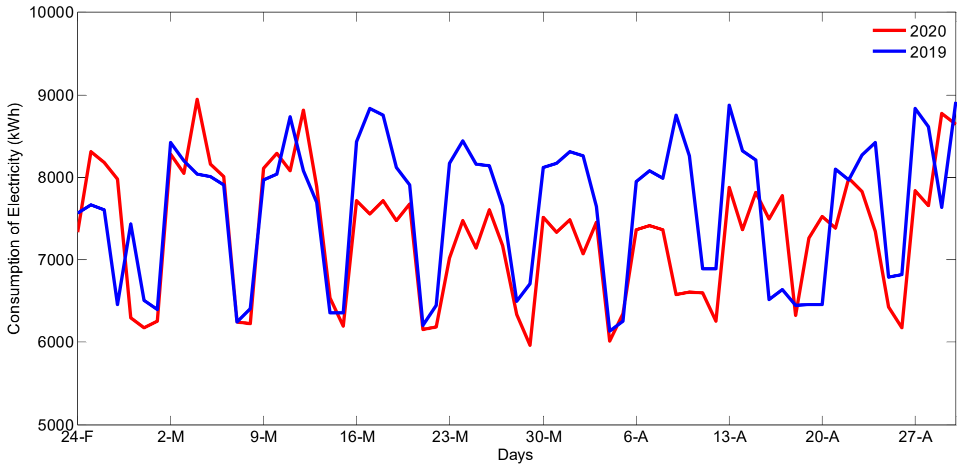

Figure 14. Total daily electricity consumption of a hospital in south-east Spain from February 24 to April 30 in 2019 and 2020.

Figure 15 shows the daily electricity demand curves for the hospital for three Mondays, March 9, before the confinement, which is shown as a dotted line, and March 16, and April 30, two Mondays belonging to the period of confinement. It can be observed that the reduction in demand takes place mainly between 9:00 and 17:00 h compared to the Monday before the declaration of the state of alarm. But a slight increase in demand has been observed during the night for the two Mondays of the confinement period, due to the restructuring of some of their daily activities. To solve or prevent the possibility of an explosive increase in the demand of patients affected by the COVID-19, most of the facilities associated with hospital activities that were cancelled during this period have remained in operation, and on some occasions, their operating hours have even been increased as a result of the modifications or restructuring applied to the operation of the hospital during this period. Thus, during these weeks, spaces previously used for healthcare activities with morning and/or afternoon schedule have been adapted as spaces for 24-hour operation, hence the nightly increase in electricity consumption that has occurred. For example, the number of beds dedicated to observation rooms has been doubled, with the usual beds dedicated only to patients of COVID-19, the space of the Oncology Day Hospital has been fitted out as a new and provisional Emergency Observation, or the ICU beds have been doubled using the space previously used for surgical reanimation.

Other adopted measures include changes in the programming of the electrical installations and especially the hospital's air conditioning, to achieve greater air renewal in the affected spaces. Thus, for example, the flow rates of impulse and extraction from the Emergency Department, ICU, and Emergency Observation have been increased. During the pandemic, recovery and/or free-cooling of most air-conditioning installations have also been eliminated. Therefore, the usual activity of control of consumption and energy efficiency has taken a back seat during this phase, considering it a priority, as it could not be otherwise, to establish the best guarantees of safety. All these modifications adopted in the operation of the hospital have led to a modification of its daily electricity demand profiles reflected in Figure 15.

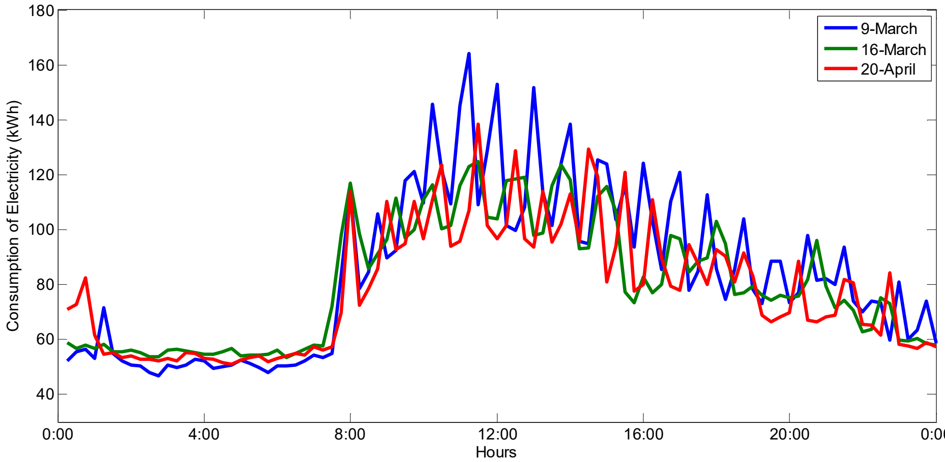

Figure 15. The daily curve of electricity consumption of a hospital in south-east Spain on Mondays (March 9 and 16, April 20, 2020).

These sectors must be prepared for possible problems and contingencies that may arise. But they are rarely prepared for unlikely combinations of events, such as a hurricane or fuel shortage together with a pandemic. Hospitals have back-up generators, but although a failure during emergencies is rare, it is not impossible. After some catastrophes like hurricane Sandy there was an emphasis on microgrids to enhance the resilience of this type of installations, and generally for the power grid (Lewis and Hebner, 2020).

3.4.- Other consideration on the results

It is therefore obvious the effect that reduced demand in the industrial and service sectors, including possible reductions in usual consumption in hospitals, has had on the overall demand curve throughout the day during the period of confinement, even despite increased demand in the residential sector. As an illustrative example, Figure 16 shows the daily demand curve for Thursday 29 March 2012, the day on which a general strike took place in Spain. The same figure includes, for comparison purposes, the demand curve for the day before the strike. Also included is the electricity demand for two working Thursdays in this year's 2020 lockdown period, corresponding to March 26 and April 2. The electricity demand curves are one of the data used to see the incidence and participation in a day of a general strike, such as the one that took place in 2012. The day of the strike meant a reduction in electricity demand from the previous day of 13.90 %. Apart from the differences in demand in 2012 compared to 2020, it can be seen from the demand curve on the day of the strike, which is shown in red in the figure, that there was a reduction in consumption during all hours of the day, largely affecting the morning peak. But the profile of that strike day, mainly during the morning hours, was different from the profiles that have been registered during the working days of confinement, given that on the day of the strike, during the morning the consumption grew at a slower pace and a few hours later, but when the peak was reached the demand remained practically constant from 10.00 to 14.00 h. However, during the confinement, the demand continues to increase throughout the morning, reaching a peak at around 14:00 h for scarcely an hour, and then begins to fall towards the values of the valley in the afternoon. It should also be noted that the demand for electricity on Thursdays in April 2020, during the lockout, was even lower than the demand on that day of the general strike (apart from the differences in the economic situation and the weather in the years compared in the graph), and this lower demand was mainly during the morning hours. At the night peak, a modification like that occurring on days of confinement occurred, reducing the demand and the duration of the peak and displacing it one hour later.

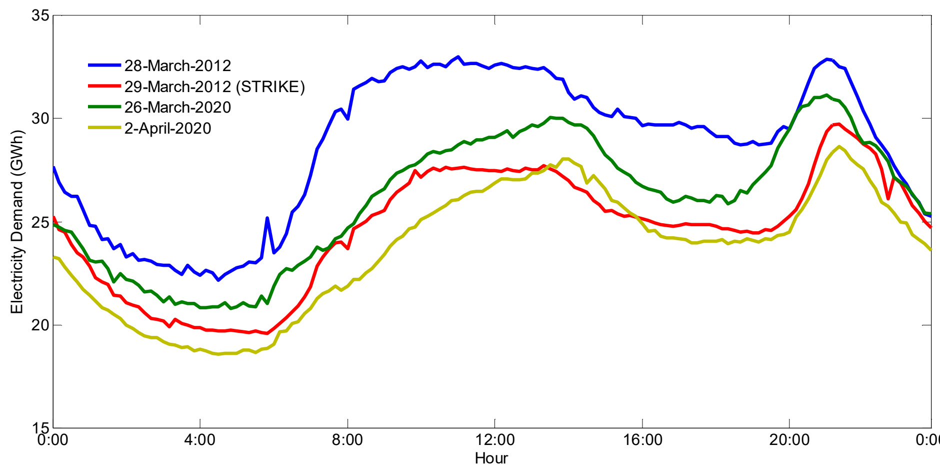

Figure 16. Hourly electricity demand profiles during the general strike on Thursday, March 29, 2012, along with quarantine demand profiles

It is therefore obvious the change that takes place in the shape of the demand curve as a function of the workload of the days. Labour and economic activity, together with temperature, are factors that directly affect the forecast of electricity demand to adjust production to demand, and which in Spain is carried out by REE, which has already indicated that it is the System Operator (SO). This involves a sequence of markets in which, at different timeframes, generation and demand exchange electrical energy, i.e. generators and traders or consumers participating in the market, can buy and sell energy for each hour of the day ("Red Eléctrica de España"). Forward markets, earlier, and mainly in the daily market (the day before), the production is adjusted to a demand forecast. But it is in the six intraday markets currently in existence, the latter with shorter time horizons, that energy is exchanged to make the necessary adjustments to keep the electricity system in physical balance and within an adequate level of security. In these intraday markets, management is carried out due to possible technical restrictions, management of complementary services, which resolve imbalances between demand and production through the margins of variation of the production systems, both upstream and downstream, which are contemplated in the primary, secondary and tertiary regulation systems, in which the different generation systems that have this surplus capacity or margin of variation must offer it for use in case it is necessary. Pumping consumption can also be used. And finally, the management of deviations would come into play. In this management, adjustments are made over an even shorter period, and it is also carried out through readjustments in the production levels or systems of some more flexible types of energy or through pumping consumption, also taking into account variations produced in the forecast of renewable energy production.

The changes in the labor situation caused by the measures against COVID-19, have given rise to a greater complexity to make the forecast of the electricity demand that has to be generated during a complete day, to try to adjust the production in the most optimal way to the real demand that finally takes place. The imbalance in this forecast, and above all the need to make some adjustments in shorter time frames, is one of the many factors that have an impact on the price of electricity that users will subsequently pay. This also affects the economic performance of the various production or demand systems that have moved furthest away from the real values in their forecast.

Figure 17 shows the mismatch between the expected demand values and the real demand values that took place for each of the days in March and April 2020 ($deviation_{2020}$) and 2019 ($deviation_{2019}$). The average daily percentage of the absolute value of the deviations in the different daily records (every 10 minutes) has been represented (therefore it is not considered in the figure whether the deviations were positive or negative). In 2019 there were a few days when the average daily deviation was 1.8 and 1.4 %, but in general, most days in March and April the deviation was around 0.6 %. In contrast, in 2020, and from the beginning of the confinement, a slight increase in this average daily deviation can be seen, which is around 0.7 %.

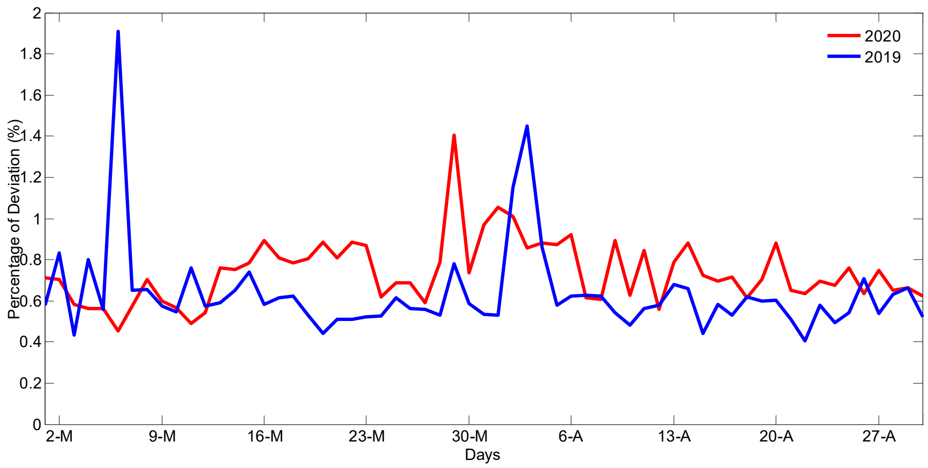

Figure 17. Average daily deviation (%), in the absolute value of the expected versus real power demand during March and April in 2020 and 2019

It has already been indicated that the uncertainty with which the system operates has a direct consequence on the price of electricity since that price is influenced, among others, by adjustment services. However, this slight increase in deviation has not had a direct impact on the total price of electricity that users have had to pay during the confinement period analyzed. Figures 18 to 20 show the price during March and April 2020 of the three regulated electricity tariffs for small consumers in Spain, which are the so-called PVPC By Default, PVPC Two Periods Efficiency, and PVPC Electric Vehicle.

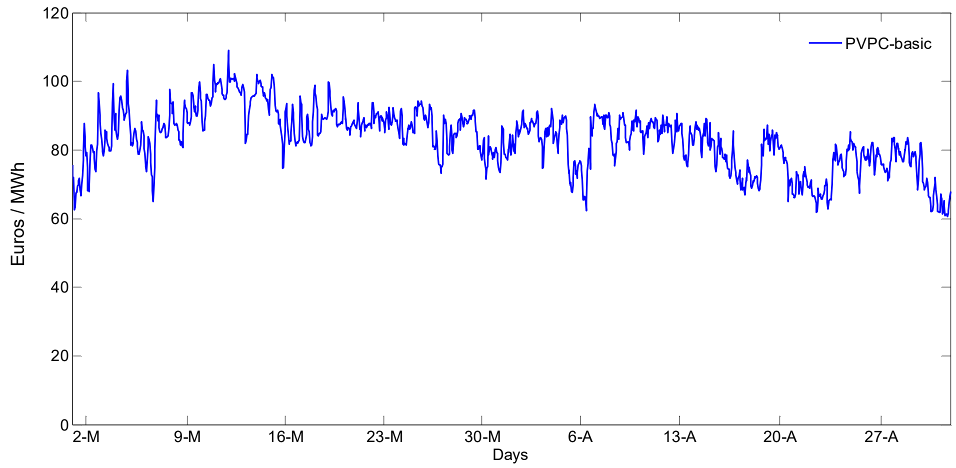

Figure 18. Hourly electricity prices during March and April 2020 (PVPC By Default tariff)

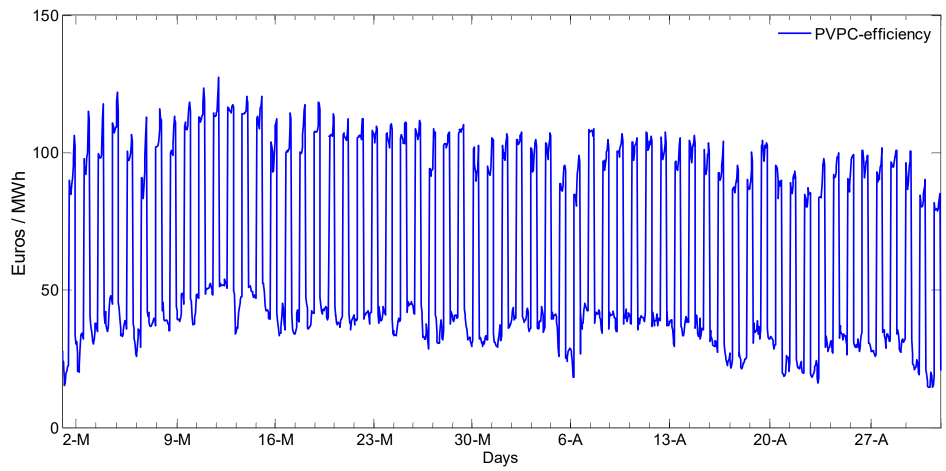

Figure 19. Hourly electricity prices during March and April 2020 (PVPC Two Sections Efficiency tariff).

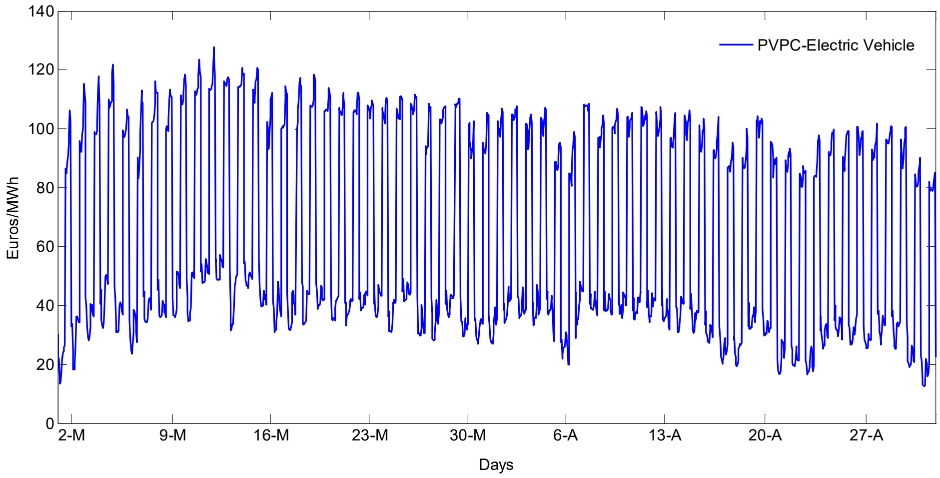

Figure 20. Hourly electricity prices during March and April 2020 (PVPC Electric Vehicle tariff)

It is reflected in these three figures that for all three tariffs a slight downward trend can be observed in the price that the small consumer, including the residential user, has had to pay for electricity consumption.

In general, the sensitivity of energy demand to price variations, which is known as the electricity price elasticity, varies across countries, sectors, and time. In some countries such as Spain or Italy, there is a greater response of electricity demand to a variation in prices, unlike other EU countries, where the behavior is more inelastic (Huntington et al., 2019) (Gil-Alana et al., 2020) (Pérez-García and Moral-Carcedo, 2016) (Pérez-García and Moral-Carcedo, 2017). However, even in these countries, electricity demand in the residential sector is more price inelastic, with values of elasticity lower than in the industrial sector (Huntington et al., 2019) (Pérez-García and Moral-Carcedo, 2017). Determining all the factors and the extent to which they affect the demand for electricity in a particular place is quite complex (Gil-Alana et al., 2020) (Lehto, 2011) (Pérez-García and Moral-Carcedo, 2016) (Moral-Carcedo and Pérez-García, 2019). And although the price is a significant factor, the electricity demand elasticity is not easy to assess during the lockdown period in which, not only the previous scenario has not been maintained, but many socio-economic habits being suddenly and mandatory modified. Therefore, authors do not have enough information in this work to be able to assess the variation in electricity demand in response to this price drop, and how this reduction is going to influence the entire electricity supply chain in the short and middle term will later require a more detailed study that escapes the objectives of this paper.

This decrease in small consumer tariffs during March and April, whose reasons will be discussed in a later section, will compensate for the increase in electricity bills that consumers will have to pay, caused by the increase in demand due to the longer time in the house. If the electricity consumption profiles shown in Figure 13 are considered for a four-resident dwelling on 24 April 2020, consumption on that particular day is practically the same as in 2019 (slightly lower by 0.2 % in 2020). If the hourly prices of the PVPC By Default tariff of that day (April 24) are applied to both profiles, with the 2019 consumption profile the price of the total daily consumption is 4.67 % more than with the 2020 profile. This is because the consumption of the day in 2019 is mainly concentrated in the early morning and in the night peak, hours at which there is a greater demand and prices are usually higher, while in 2020 the consumption is distributed to the different hours of the day, due to the permanence of the residents in their home. It can, therefore, be seen that shifting consumption to other times, instead of concentrating it mainly on two peaks, leads to a saving in the total daily price, which has allowed many users to compensate in their bill for the monthly increase in demand during the confinement period, thanks to the change in consumption habits. However, to carry out, under normal circumstances, demand management measures in the residential sector, which it has been already mentioned that is not characterized by a very elastic behavior concerning price variation, some authors suggest that for an effective impact on household electricity demand it would be required adopting not only measures based on prices (taxation and so on) or subsidizing investment in more efficient technologies but also psychology based incentives or even compulsory measures (Pérez-García and Moral-Carcedo, 2017).

3.5. The possible contribution of self-consumption

This imposed change in habits at dwellings during lockdown has also influenced the improvement of the demand coverage factor in PV self-consumption installations in the residential sector. Although this type of renewable facilities cannot generate energy at night peak, they can play a fundamental role during the morning hours. A simulation has been made assuming that the dwelling for which the demand data have been shown is equipped with a 2.97 Wp self-consumption facility. To calculate its production values real data monitored in a photovoltaic plant located on a rooftop in a building close to the dwelling analyzed are used, as described previously in the methodology section. This analysis considers the demand for housing in 2019 and 2020, as shown in Figure 13 above, during the period of confinement, from March 14 to April 30. And for the generation, only the production data of the PV installation in the same period of 2019 have been taken, to compare the two demand profiles, the usual one of the house and the one that has taken place during the confinement, with the same electricity production in the self-consumption installation.

The results for a specific day are reflected in Figure 21, where the electricity demand on April 24 is represented at the top for both 2019 and 2020, also including the electricity production that would take place in the home in that geographical location and for that time of year, considering a weather stable day, in which there is no passage of clouds. The graph below shows the energy exchange that the house would have with the grid for the production and demand represented. The positive values correspond to the energy consumption in the dwelling from the electricity grid, while the negative values correspond to the energy that the dwelling's installation injects into the electricity grid.

For the peaks in demand that take place around 8:00 and 20:00 h, which are greater in the 2019 profile, as the production of PV energy is practically zero at those hours, the energy must be demanded from the network. But during the morning period, the demand for the 2020 profile, which takes place because people must stay in their homes all day, has been largely covered by the production of the self-consumption installation. By contrast, for the 2019 housing demand profile, virtually all production had to be injected into the grid. This shows that for such a demand profile, it is not optimal to have self-consumption systems, since most of the demand for housing would have to be made with energy from the grid, and practically all the production has to be injected into the grid as surplus. This would not be profitable for the user in a scenario where the surplus is paid with some restrictions or even is not paid, or net metering is not contemplated, as is currently the case in Spain.

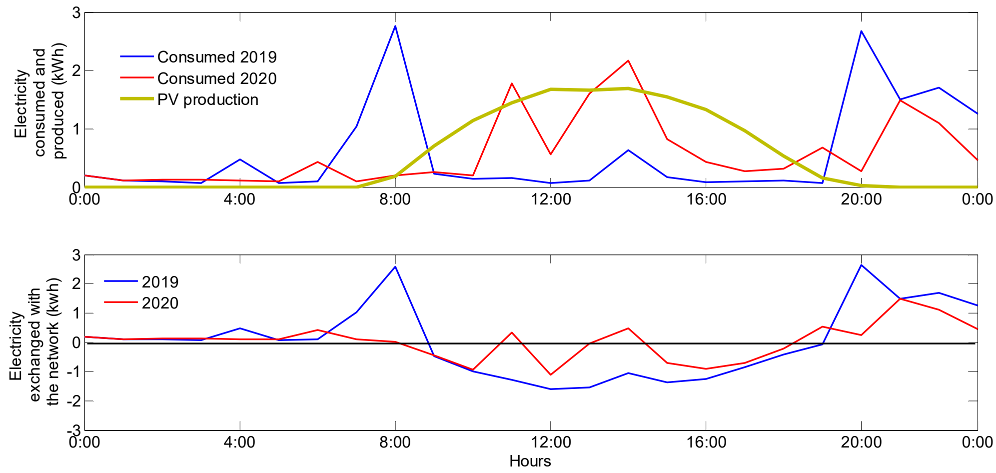

Figure 21. Electricity consumed in the home on 24 April 2019 and 2020, electricity generated by a PV installation for self-consumption, and exchange of electricity with the electricity grid.

The entire lockdown period, from March 14 to April 30, has been analyzed with actual PV production data for 2019. It is obtained that for the demand data of 2020, which is a profile in which the electricity consumption is 6.74 % higher but is distributed throughout the day, the energy demanded from the network would decrease by 11.00 % compared to what would correspond in 2019. But it is also noteworthy that the energy injected into the grid as surplus has been reduced by 32.89 % with the 2020 demand profile. Although these data cannot be generalized since they correspond to a particular house, with a demand profile conditioned by working hours (Endesa, 2019) and the analysis corresponds to only two months of the year, in which consumption for air conditioning is also low (Palacios-Garcia et al., 2018), certain conclusions can be extracted. Firstly, there is still a high demand for electricity at night peaks, even if one stays in the house all day, partly due to the inertia of the habits residents had and which results in a significant part of the electricity consumption in the house taking place at these hours when there is no production of PV energy. The Electric Power Research Institute (EPRI) in EEUU has conducted a survey of 2,000 consumers which shows that only 23 % of the respondents if their employment situation had not changed, had modified their energy use habits at home during the crisis of COVID-19. Of those who had lost their jobs, this percentage increased to 41 % (Siddiqui and Long, 2020). In general, it is important to raise residents' awareness to change their power demand habits, to make them more efficient for their economy and the operation of the network, or to apply demand management mechanisms that help or motivate residents to change these habits. Another challenge with self-consumption facilities is to try to minimize the injection of surpluses into the grid, so as not to saturate their hosting capacity and so that reverse flows of electricity do not affect their operating parameters and power quality (Palacios-Garcia et al., 2017). During the period of confinement, this injection into the grid is reduced by a significant percentage, but equally, by changing residents' habits, this percentage can still be improved, to benefit residents and the network operation.

3.6. Changes in the generation mix

The reduction and modification of the power demand profile during lockdown have also led to changes in the generation mix, modifying the proportion in which the different generation sources participate at any given time, to achieve in the grid a balance between power demand and generation, as it can be seen in Figure 22. The most remarkable feature of the data reflected in this figure is that electricity production from non-renewable sources has decreased during the confinement period analyzed in this work, adjusting to the lower power demand. On the other hand, renewable generation sources such as photovoltaic have increased their percentage share in the generation mix. This behavior has also taken place in other countries such as Italy, with an electric system with similarities to the Spanish one (Ghiani et al., 2020).

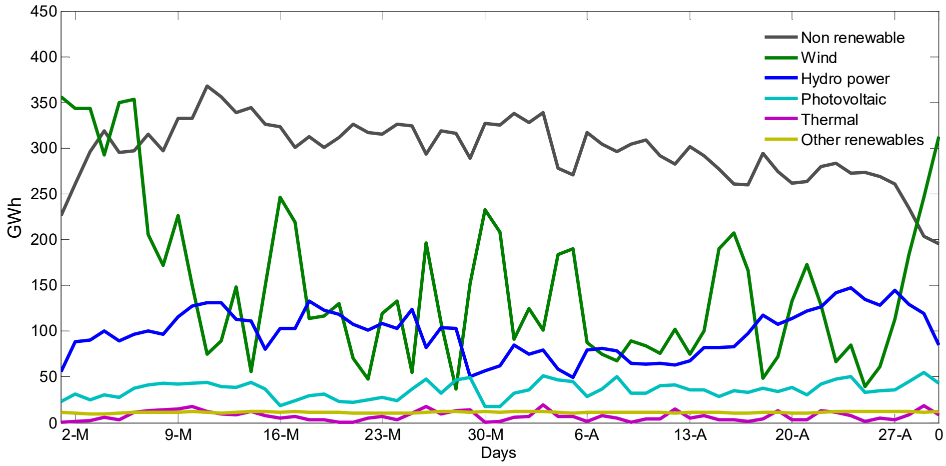

Figure 22. Generation of electricity in Spain (peninsula) by different types of renewable sources and total non-renewable, from March 1 to April 30, 2020.

Figure 23 shows electricity generation from non-renewable sources during March and April 2020. These energy sources have reduced their production to be able to adjust to the reduction in power demand. Nuclear power, the largest component in the non-renewable production mix, has experienced a decline in production during the confinement period mainly from the first week of April. This type of facility has a more rigid operation and cannot be used for daily deviation adjustments, as its capacity for short-term variation is very limited, although it has the advantage of the security of supply it presents. The reduction of its production must be planned in the longer term. The output of coal-fired power stations, which have also suffered a reduction in their contribution to the generation mix mainly in the first weeks of the lockdown period, is also relatively rigid. The most flexible are combined-cycle power plants (Alexopoulos, 2017), which, together with pumped-storage plants, enable to be used to adjust generation and demand, when variations in expected demand or fluctuations in renewable production occur. This type of generation has experienced a variation in its participation percentage during this period, as can be seen in Figure 23.

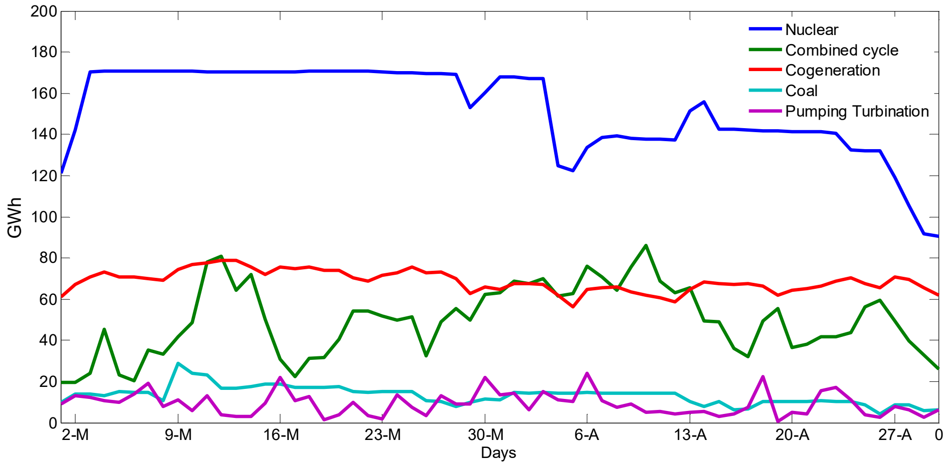

Figure 23. Generation of electricity in Spain (peninsula) by different types of non-renewable sources from 14 March to 30 April 2020

In electricity production, each technology is particularly suitable technically and economically to be able to provide a specific service to the coverage of demand, so all technologies are necessary, as they complement each other in terms of cost and security of supply to generate the energy that is demanded at any given time and to provide the necessary ramping flexibility. The wind and solar sources are clean energies, quite competitive economically, and help to reduce CO_2 emissions, but present a high level of intermittency and randomness, to a greater extent the wind, so that its character is little dispatchable, and do not provide security of supply at a particular time. Therefore, the security of supply not provided by dispatchable sources must be provided by non-renewable technologies, which support the former, especially those that are less rigid.

This variation in the generation mix, as a result of reduced demand, has led to a reduction in wholesale and retail electricity prices (this latter previously reflected in Fig. 18-20). The daily electricity prices are based on bids and offers from all market participants, and they are determined by the intersection point between the market's supply and demand curves in day-ahead, intraday, and deviation management markets. In the previous day's market, electricity sellers submit their bids to the market for each of the following day's hours. The Electricity Market Operator (OMIE in Spain) aggregates and orders them by ascending price, resulting in the market supply curve for each hour. On this supply curve, the lowest prices correspond to the generation by nuclear and renewables, with the highest prices corresponding to the most obsolete thermal power plants. The different technologies in the mix are characterized by their different cost structures and their ability to adapt to variations in demand sufficiently quickly. This makes it efficient that several different technologies are producing electricity at the same time. Those that can respond on a smaller time scale are those used in the intraday and deviation management markets to match production to demand and to control the grid state.

During the first weeks of confinement, the reduction in demand was adjusted mainly by a reduction in production in coal-fired power plants. The reduction of the amount of energy supplied by this conventional and with higher cost sources, and a higher percentage in the generation mix of renewable energies, which enter the market at zero cost, have caused the price to be set with these cheaper technologies. From the second week of April, there has also been a reduction in nuclear energy production, together with a significant increase in production in hydraulic power stations, with the reduction in prices moderating at this stage. In addition to this, fluctuations in the price of raw materials such as coal, fuel, or natural gas have also taken place during this period (Holder, 2020) (Ding et al., 2020). Oil and natural gas have experienced during this period an unprecedented reduction of their selling prices (Ghiani et al., 2020) which has also been reflected in the total price of electricity (Alexopoulos, 2017) (Furió and Chuliá, 2012).

In general, the utilities and the System Operator (SO) have had as a priority to guarantee the electricity supply and the power quality, along with the difficulty of regulating frequency and voltage variations in a scenario where forecasting real demand has been difficult due to the change in consumption experienced. They have also focused their efforts on taking care of the health of the personnel specialized in different management and maintenance tasks, to have the necessary resources to face the unexpected events that could arise (Nicolas et al., 2019) (Karagiannis et al., 2017) (Aziz and Than, 2020). However, the adjustment of production to a significant reduction in real power demand has posed another challenge during this period. Some countries, such as the UK, have considered taking action against possible significant operational risks caused by the imbalance due to a large drop in demand, in which the disconnection of distributed generation, including residential solar energy, has been proposed (Stoker, 2020). In Spain, the incorporation into the generation mix over the last decade of renewable energy facilities and plants supporting their random fluctuation, such as combined cycle plants, has led to a diversification of the generation mix. This, together with the design of the regulatory market, has constituted a system flexible enough to adapt to the reduction and variation of the daily demand profile experienced in this country during the confinement period.

Although the production of renewable energies such as wind power may be one of the most suitable to be disconnected at times of low demand if there is an excess of generation (Energía y Sociedad), it has been proven that in this case the renewable energy has received priority in the grid and are not asked to reduce their output to match demand, insulating them from the impacts of lower electricity demand. It has been observed, as indicated by the International Energy Agency (IEA), that the renewable energy has been the energy source most resilient to COVID-19 lockdown measures (International Energy Agency (IEA), 2020b).

Definitively, this period has led to a better understanding of cleaner electricity systems, which future power grids point to, with an even higher proportion of renewables in the generation mix or a reduction in electricity demand due to a possible scenario with a higher degree of self-consumption in the residential, industrial, or service sectors. And although there has been a change in the demand profile with few precedents, the flexibility of the system has allowed it to adapt without a direct impact on users. Power utilities have had opportunities to improve their response plans and temporary guidelines, as well as to enhance their emergency response strategies, to ensure the continuity and balance of energy supply (Avendaño and Patel, 2020). The lower economic profitability of generation systems (including renewables), caused by the price drop in this period, could have a medium to long-term effect on users, or even on future investments in renewable plants, but it's still early to know these effects. It is expected that finally, a stimulus to this type of clean energy will be one of the pillars for a green recovery, as it seems to be proposed in the European Union (Rojo-Martín, 2020).

3.7. Carbon emissions during the lockdown.

So far, this drop in demand and modification of the generation mix has made it possible to achieve a reduction in CO_2 emissions, as can be seen in figures 24 and 25. Figure 24 shows the CO_2 emissions that took place in March and April 2020 due to the production of electricity in Spain (in the area of the peninsula), using non-renewable generation systems, where a reduction in emissions can be seen from the start of the confinement. Figure 25 compares total emissions in this period in 2020 with those in the same months in the previous three years (2019-2017). It has been verified that in these two months 1.73 million tons of CO_2 less have been emitted than in the same period in 2019, which has meant a reduction of 32.61 %. The reductions compared to 2018 and 2017 are 33.19 and 43.24 % respectively. Globally, the IEA has indicated that the stunning declines in energy demand in Q1 2020 resulted in a major drop in global CO_2 emissions, surpassing any previous declines (International Energy Agency (IEA), 2020b). These data agree with the results of other researches, which has shown a reduction in various pollutant emissions and an improvement in air quality as a result of the actions against COVID-19 (Tobías et al., 2020) (European Space Agency (ESA), 2020)(Molintas, 2020) (Ecologistas en Acción, 2020) (Zambrano-Monserrate et al., 2020).

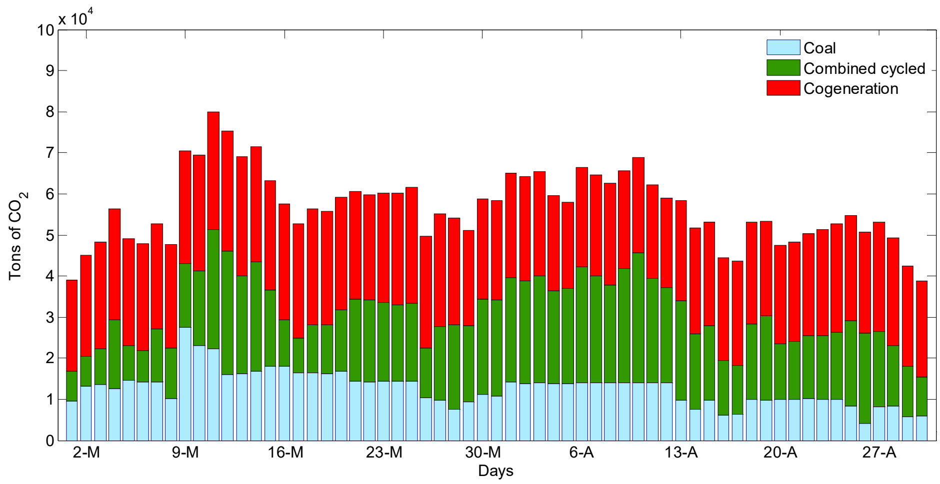

Figure 24. Tons of CO_2 emitted by non-renewable electricity generation sources in Spain (peninsula) during March and April 2020

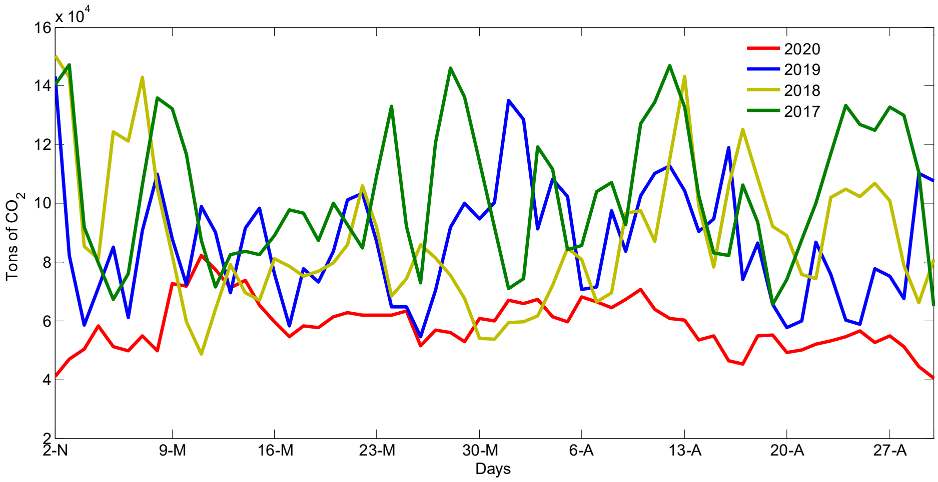

Figure 25. Tons of CO_2 emitted by the electricity generation system in Spain (peninsula) during March and April in 2020-2017

4. CONCLUSIONS AND POLICY IMPLICATIONS

This work has shown that since the beginning of the period of confinement in Spain, from March 14 to April 30, there has been a reduction in electricity consumption of 13.49 % compared to consumption during the same period in the previous five years (2019-2015). This reduction has mainly affected working days, with a 13.79 % reduction, although weekends have also experienced a 10.62 % reduction. The reduction in electricity consumed has taken place at all hours of the day, with demands of between 3 and 7 GWh lower than in the weeks preceding the confinement at all hours of the day. But it is the shape of the demand curve during the morning that undergoes the greatest change in its profile. During the confinement, between 8:00 and 14:00 h, there has been a growing demand throughout the morning, instead of constant demand, as it happened in the previous week. The night-time peak has also been modified, reducing not only the demand but also the duration of the peak, which has also been moved to one hour later. The reduction in demand from the industrial and service sectors, due to the mandatory shutdown of their activity, has led to this change in power demand and therefore in the generation, which has also been influenced by a greater household energy demand. Although electricity consumption in dwellings has taken place more regularly throughout the day, as an indication of their higher active occupation, peaks in demand of dwellings may still be too high in the morning and evening peak hours, indicating inertia to modify habits related to power demand. If these habits are to be changed, it is important to establish demand response policies that offer a visible reward to customers that motivates them to participate.

The reduction in demand during the confinement period has led not only to a reduction in CO_2 emissions but also to a change in the generation mix, in which the share of non-renewable energy has been reduced, increasing renewables. This situation has shown the presence of a resilient grid to successfully deal with these unforeseen changes, thanks to the measures taken in previous years to adapt the grid to the presence of less manageable renewable sources. Production management has been flexible, and deviations from demand forecasts have only increased by 0.1 %. This has not been reflected in an increase in prices, as thosefor small consumers have even fallen slightly, due to a reduction in production in higher-cost plants, such as coal-fired power stations, and by a drop in the price of natural gas or fuel oil that has also taken place during this period. However, this same situation in months with a greater dependence on electricity, such as the hardest winter months with lower temperatures, or the hottest summer months with very high temperatures, would have led to greater demand for air heating and cooling and a different scenario. This highlights the importance, not only of having grids that are resilient to events that could put supply at risk but also of having a diversified and flexible generation system to deal with the stress involved in managing the power grid in these situations where demand curves are changed unexpectedly.

Although the increase in electricity demand will reflect the return to work, this situation must be used to link economic recovery to a transition to a sustainable and climate-friendly economy, leading to greater decarbonization of the generation mix, in line with the EU's proposals. Solar energy, as the cost-effective, scalable, and popular renewable energy source, can play an important role in ensuring a clean transition, and in countries like Spain, with its potential for solar energy, it should be one of the main focuses of economic recovery, which could be a source of employment generation, and would allow cleaner levels of electricity generation to be maintained. The presence of support systems for the randomness production of renewable plants is the key to greater integration of this type of clean generation sources and to provide the network with flexibility against unforeseen variations not only in production but also in demand, as has occurred during the pandemic. Further progress must also be made towards increasingly smart grids, that easily integrates different distributed energy resources. Perhaps the boost to microgrids, which have advanced control, communication, and management systems, and also with greater points of redundancy and interconnection, may be an important element to take into account. The intervention of consumers, both at work and in their private lives, in changing their habits towards more environmentally responsible practices and in promoting self-consumption facilities, both in the industrial and service sectors, must also play an important role in this transition.

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