Resilience of the Milan distribution network in presence of extreme events: Covid-19

Gaetano Iannarelli
Dept. of Technological Development
Unareti SpA
Milan, Italy
& Dept. of Astronautics, Electrical and Energetic Engineering
Sapienza University
Rome, Italy
gaetano.iannarelli@unareti.it

Alessandro Bosisio
Dept. of Energy
Politecnico di Milano
Milano, Italy
alessandro.bosisio@polimi.it

Bartolomeo Greco
Dept. of Planning
Unareti SpA
Milan, Italy
bartolomeo.greco@unareti.it

Cristina Moscatiello
Dept. of Astronautics, Electrical and Energetic Engineering
Sapienza University
Rome, Italy
cristina.moscatiello@uniroma1.it

Chiara Boccaletti
Dept. of Astronautics, Electrical and Energetic Engineering
Sapienza University
Rome, Italy
chiara.boccaletti@uniroma1.it

***Abstract*— The pandemic generated by Covid-19 caused social and economic consequences that constituted a global challenge for all countries. Italy was one of the first nations to be affected by the pandemic, especially in the heart of its production system and in the most densely populated area: the Lombardy Region. Starting in February 2020, there was a progressive slowdown until a total lockdown that paralyzed almost all social and economic activities, until a partial resumption of normal activities in May and a further increase in mid-June. The study was motivated by the fact that the electricity demand strongly decreased and changed in its typical characteristics, introducing new critical issues in the system at both the transmission and distribution levels. The goal was to analyze the strong impact of this changes on the distribution network and the transmission grid, focusing on the distribution network of Milan during the whole period. The results provide a useful example of the effects of such a pandemic and can constitute a reference valid also for many other big cities in the world.**

Keywords—Distribution network, Pandemic, Electricity consumption, Electricity demand pattern, Network resilience.

I. INTRODUCTION

The pandemic generated by Covid-19 caused social and economic consequences that constituted a global challenge for all countries. Unlike other pandemics of the past, a large part of the world's population could count on a more widespread and resilient energy system, which allowed metropolises to provide healthcare, food and services to millions of people isolated in their homes. The electricity system has supplied energy to hospitals and households continuously, allowing to manage the emergency services, and to guarantee telecommunications (including internet and voice calls) and other indispensable services, particularly in the cities. Italy was one of the first nations to be affected by the pandemic, especially in the heart of its production system and in the most densely populated area: the Lombardy Region. The escalation of the infection has forced the Italian Government to take drastic measures day by day to limit the contagions and minimize the effects on public health. There was a progressive slowdown of each activity in the months of February and March 2020, and the Legislative Decrees adopted by the Italian government through the weeks led to a long lockdown period that paralyzed social and economic activities first in Lombardy, then in the entire Italian country [1]. The main provisions are those of March 9th, 2020, with limitation of displacements on the national territory, and of March 22nd, 2020, when Italy entered the total lockdown. In this phase, most production activities were stopped, but those functional to essential services, like food production and delivery, healthcare, communication and technical products manufacturing, etc.. As a consequence, all industries limited or completely stopped production and processes; tertiary sector companies resorted massively to smart working or layoffs, social gathering places such as schools or shopping centers were closed. The severe measures adopted by the Italy government, characterizing the month of April, were called "Phase 1". "Phase 2" begun in May with the end of the lockdown and a partial recovery of economic and social activities. The resumption of normal activities further increased in "Phase 3", which occurred in mid-June. The electricity system proved to be an extremely meaningful indicator of the energy needs of a country, a region or a city, not only as an overall amount, but also as a consumption pattern. The reduction in (almost) all production activities induced a proportional lower demand, which changed in its typical characteristics (seasonal, weekly, daily), introducing new critical issues on the system at both the transmission and distribution levels.

In this paper, the whole period starting from the beginning of the pandemic and the first restrictions imposed by the Italian government, until mid-June 2020, when the so-called "Phase 3" was established, are analyzed from the point of view of the Milan distribution networks. Being Milan one of the cities most affected in Italy and worldwide by Covid-19, the accurate analysis and discussion of real data are particularly interesting and can be used for future reference.

This paper is structured as follows. In Section I, the research issues are introduced, and the main reasons which led to develop this work are explained. In Section II the lockdown impact on social and economic sectors is presented, together with mobility effects and economy statistics. Section III presents the impact on the electricity demand in Milan and a comparison between the pre-lockdown and post-lockdown electricity consumption. Section IV contains the variations in the daily pattern of electricity demand and the increase of the reactive power introduced into the transmission grid by the distribution networks. Finally, the main results are presented and discussed in the conclusions.

II. LOCKDOWN IMPACT ON SOCIAL AND ECONOMIC SECTORS

A. Mobility effects

The lockdown had the primary objective of limiting people-to-people contacts, strongly reducing people displacements, and allowing just a small number of people to go to workplaces. In this way, all large in-person gathering were avoided, in order to limit contagion. The actual application of these measures can be verified through several sources. For instance, during this period ANAS, an Italian National independent road company, posted a reduction in heavy and light vehicles of 50% and 80%, respectively [1].

The government of Lombardy, a region in Northern Italy epicenter of the contagion, has activated a people displacement monitoring based on the tracking of mobile phones in the area, assisting the law enforcement and providing an argument to insist inviting population to stay at home. The region recorded a negative peak of 77% compared to the pre-Covid period (the monitoring activity was stopped in the last week of May) [2]. In particular, the city of Milan had a negative peak of 80% and therefore the greatest decrease in displacements compared with rest of the Lombardy Region [3]. In all Italy, since the first Covid-19 outbreaks, the people's mobility started a slowdown which became substantial in mid-March and then settled at minimum values in the second half of March and throughout April 2020 ("Phase 1"). Figure 1 shows these trends in details, confirming an effective slowdown in social activities (more people at home) and economic activities (fewer people who need to go to work).The latest available data correspond to the mobility situation in the first day of "Phase 3" (June, 15th) for the Lombardy region and the city of Milan compared to January 2020. These data show a still incomplete recovery of social-economic activities.

B. Economy statistics

A confirmation of the slowdown in Italian production can be found in the statistical data of the Italian Statistical Institute (ISTAT) which reports that on average, 45% of companies with three or more employees suspended their activities during "Phase 1" (from March, 9th, to May, 4th). The corresponding value for Lombardy Region is 44.6% [4]. The same institute highlights that 78.1% of companies were unable to implement the smart-working mode to continue their activities, while 21.9% was able do to it only partially . Table I summarizes the ISTAT activity data for sectors that did never stop even during the lockdown. Particularly energy-consuming sectors, such as mineral extraction, industry and construction have been the most affected. Overall, the sector of Services was less affected, but for some energy-intensive services the figures are very low: trade has stopped 46% of the activities, accommodation and food 6.1%, sports and entertainment centers 7.6%. In a highly-industrialized region such as Lombardy, these data correspond to a significant economic impact. In particular, the city of Milan suffered from the sharp slowdown of many industrial companies, but also in sectors such as Construction and Services (shopping centers, tourism-related activities, etc.).

TABLE I. PERCENTAGE OF RESIDUAL ACTIVITIES BY SECTOR DURING PHASE 1

Sector and percentage	
Sector	***%***
Extraction of minerals from caves and mines	11,02
Industry	25,31
Supply of electric energy, gas, steam and air conditioning	89,9
Water supply, sewerage and waste management activities	69,79
Construction	14,59
Services[a]	36,78
Total	32,5

[a]Trade, Banking, Telecommunication, Industry, Tourism, Professional offices, Education, Entertainment and Sport.

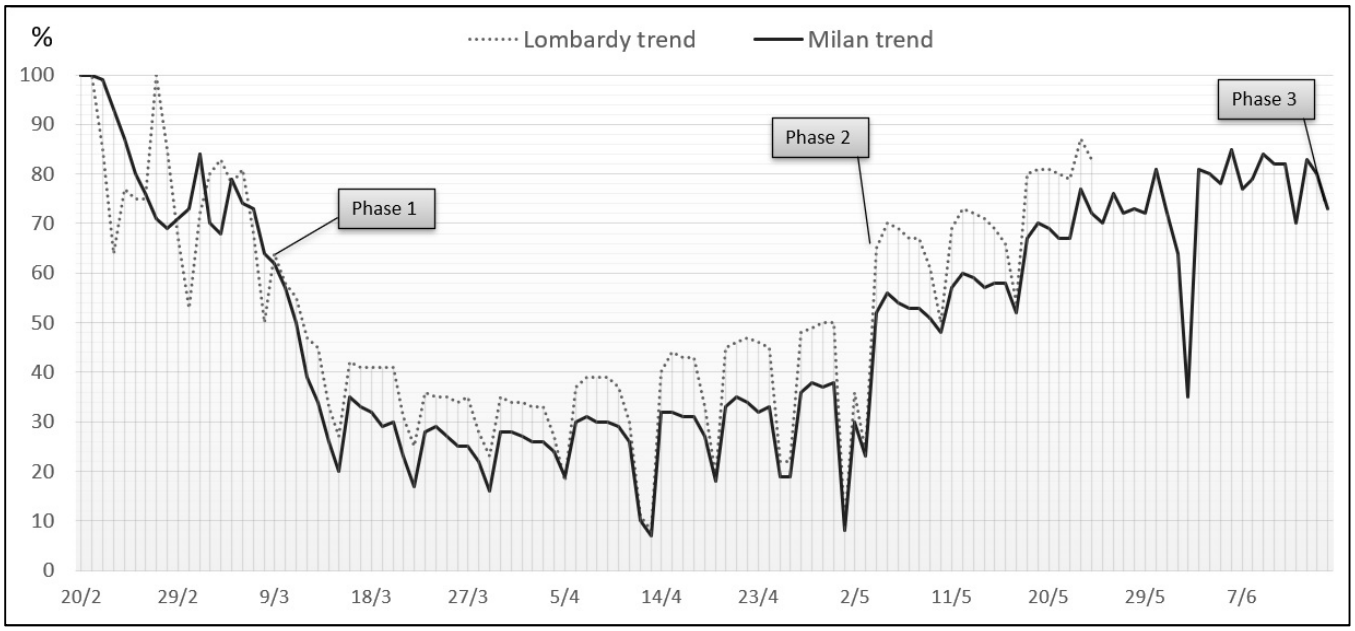

Fig. 1. Percentage of people's displacements in Lombardy Region and in the city of Milan with respect to January 2020 (pre-Covid-19 situation).

III. IMPACT ON ELECTRICITY DEMAND IN MILAN

The effects of the slowdown, in social and economic activities, are reflected in electricity demand in Italy similarly to what happened in the electrical systems of other States in the world [6]-[9], in the worldwide distribution networks of other operators [10], [11] and in other metropolises like Milan [12] ,[13]. Furthermore, in this paper it has been analyzed how the absorption of power from the distribution network of the city of Milan changed from January to June 2020. Basically, two periods can be identified: i) a first transition period before the lockdown, in which there was a slowdown in electricity consumption, and ii) a second transition period, in which there was a gradual resumption of social and economic activities.

Figure 2 shows the aforementioned two phases by comparing the electricity demand in the city of Milan from January to June, in 2019 and 2020, respectively. At the beginning of March 2020 there was a reduced consumption compared to 2019. This trend was maintained for several weeks, and, as a consequence, in April the electricity demand was just above 600 MW. Despite the gradual restart of activities from the beginning of May, the consumption level remained low especially in June, while in 2019, particularly in the second half of the month, there was a record of electricity absorption, because of the strong use of air conditioning, due to the torrid ambient temperatures.

Considering all the data illustrated in Section II, it can be deduced that the low consumption was due to the reduced activities of industries, factories, business companies, schools and offices. However, the actual impact and the distribution over time of the electricity consumption is affected by the different pattern of the contribution of the residential sector. Anyway, the general trend is very similar to that related to the movement of goods and people illustrated in Section 2: a gradual lowering until April, and then a return to higher - although not "fully normal" - values. The two periods will be analyzed in detail in the following sub-section.

A. Pre-lockdown

In the last ten days of February 2020, according to the initial measures of the Italian government, there is a gradual consumption reduction. Figure 3 reports the Milan consumption during one average week in February, April, and March, compared to the average absorption of one week of January 2020. The graph shows a clear decrease in consumption through the months. The electricity consumption reaches a new regime in April, when it stabilizes around 600 MW, a value lower than the 800 MW of the same period of 2019 and far from the 2019 peak of 1635 MW.

In order to better highlight the differences with the previous year, the percent decrease in electricity consumption of the city of Milan is calculated month by month with respect to 2019 values in Table II.

Table III shows the distribution of the consumption decrease over the week, especially evident in the weekdays and in the central hours of the day. Indeed, compared to an average consumption decrease of about 8% in the night hours of April, it can be inferred that the decrease in the central hours of the day is strongly affected by activities such as industries, companies, offices and the tertiary sector, reaching 14% on working days. These data can be indicative for any month in spring and autumn, when the air conditioning utilization is very limited and does not affect the consumption.

B. Post-lockdown

Figure 4 shows the electricity demand in the second transient starting from April 2020. On May, 4th the first re-openings established by the Italian Government caused a marked increase. In the central hours of the day, the consumption is much higher, indicating a first recovery of social-economic activities. The morning peak is again greater than the evening peak, which is definitively "absorbed" in June, when the typical city pattern of consumption in weekdays is recovered.

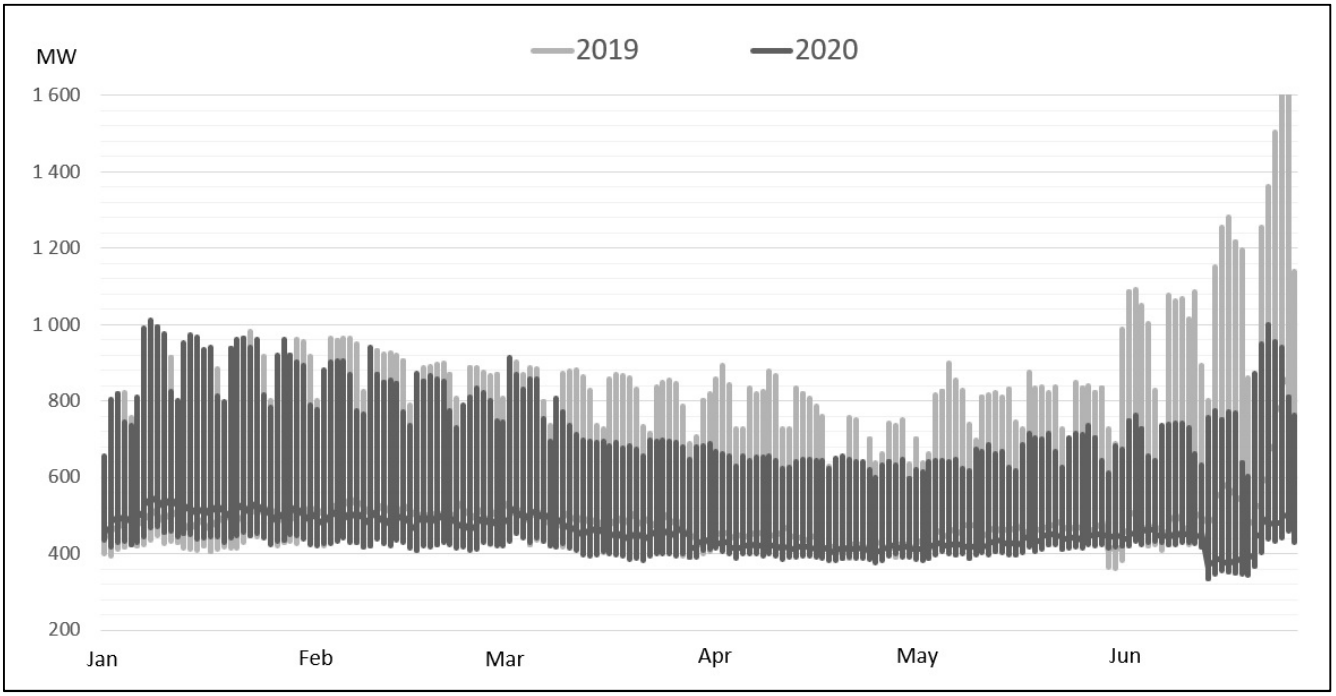

Fig. 2. Comparison of the electricity amount supplied by the distribution network of the city of Milan from January to June in 2019 and 2020.

The decrease in consumption, already evident from March to May in comparison with the same months of 2019, was certainly more marked in June, due to a mix of factors. On the one hand, the activities had not been completely resumed ("Phase 2"), on the other hand, the weather conditions were certainly milder than the torrid June 2019, when there was a historical record of absorption of the Milan distribution network.

Furthermore, the air conditioning was used only in private homes, while in public places its operation was still not allowed, as part of the measures taken to reduce the risk of contagion and limit the effects of the pandemic.

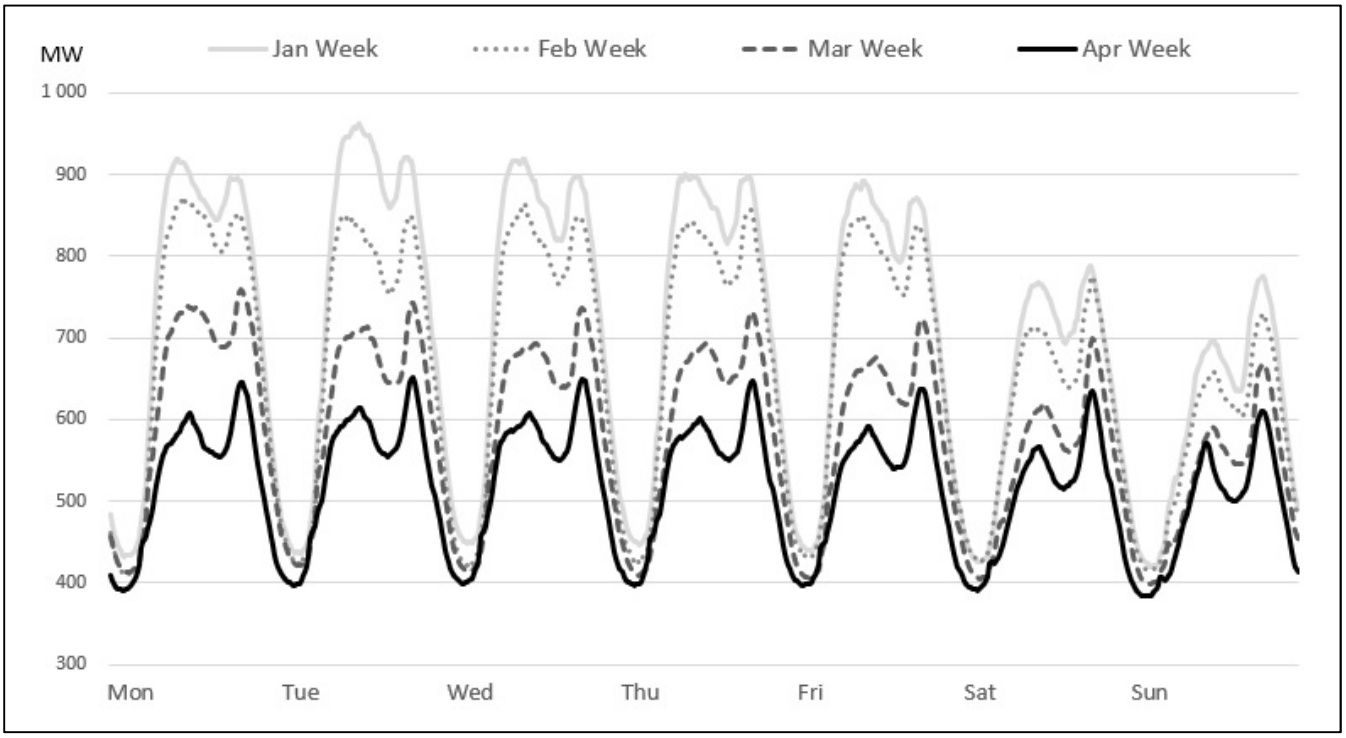

Fig. 3. Comparison of the average weekly electricity consumption of the city of Milan in the period January - April 2020.

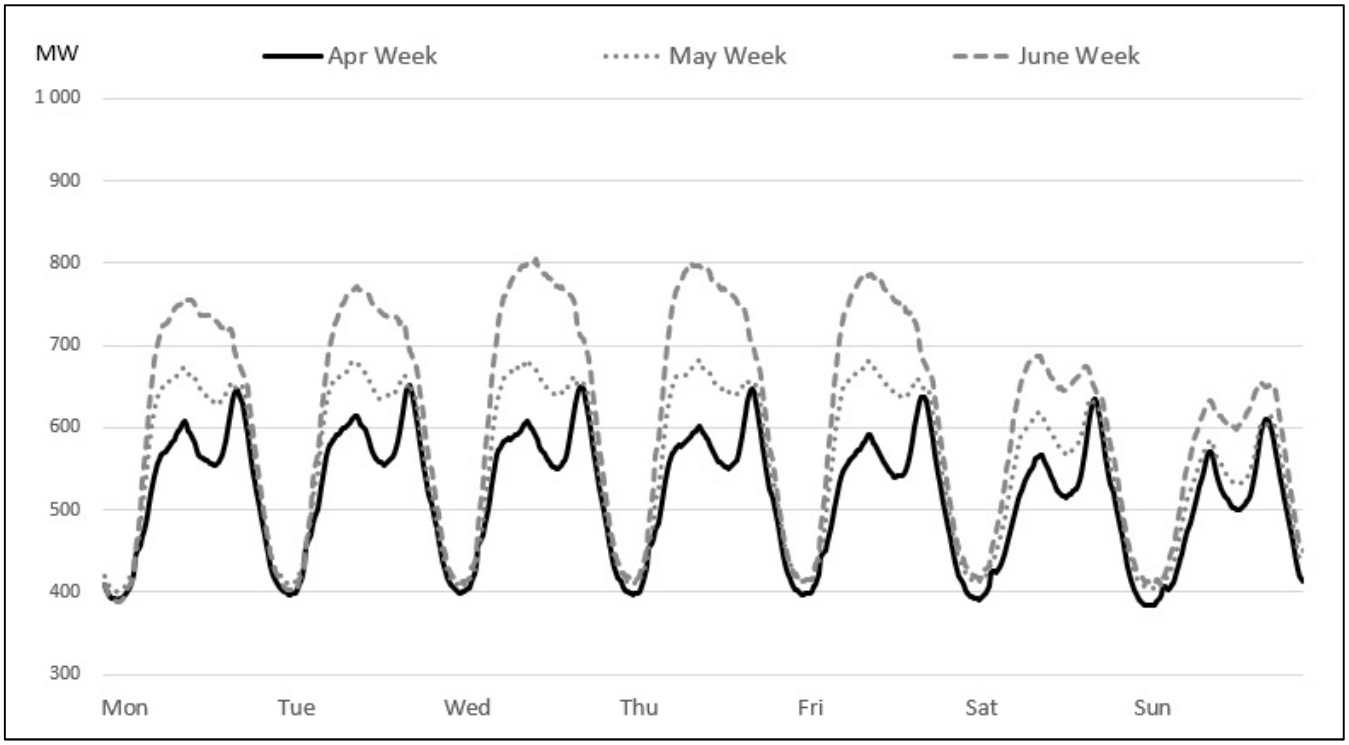

Fig. 4. Comparison of the average weekly electricity consumption of the city of Milan in the period April -June 2020.

To highlight the impact of the stop of production activities on the electricity demand, and therefore on the distribution network, the analysis of 2 MV city feeders, serving different areas, is reported in the following. In particular, Fig. 5 corresponds to a medium-voltage line that feeds a residential district and Figure 6 corresponds to a line that feeds a factory in a peripheral area of the city. The curves represent one average week in April 2020 compared to the same month of 2019. Figure 5 shows how the energy absorption increases for residential customers in the morning hours, remaining almost identical in the evening and on weekends. Instead, Figure 6 shows the marked decrease in the electricity demand of the industrial compound, which maintains a similar base absorption for all days of the week, while the greatest contribution of working days is canceled.

TABLE II. VARIATION OF THE ELECTRICITY CONSUMPTION IN THE CITY OF MILAN

Variation of the electricity consumption in Milan compared with 2019 month-by-month	
Month	***%***
February	+4
March	-11
April	-17
May	-16
June	-25

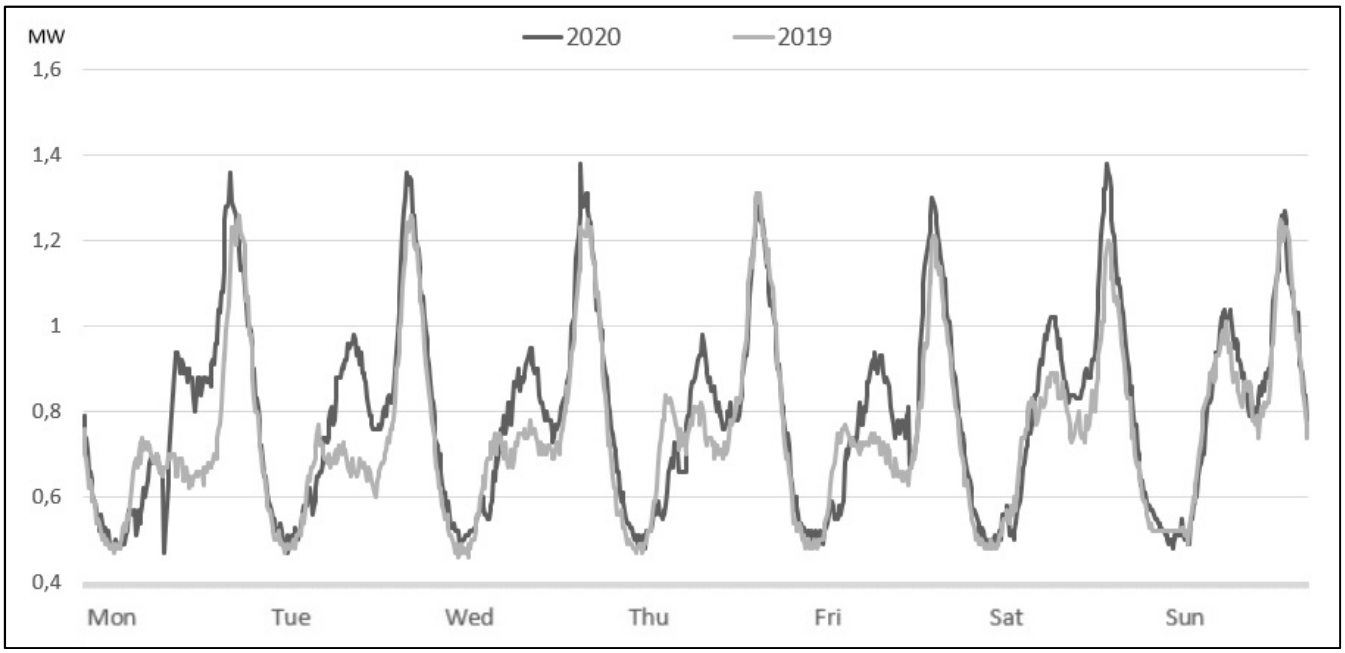

Fig. 5. Comparison of the weekly electricity demand in April for a feeder serving a residential area of Milan between 2019 and 2020

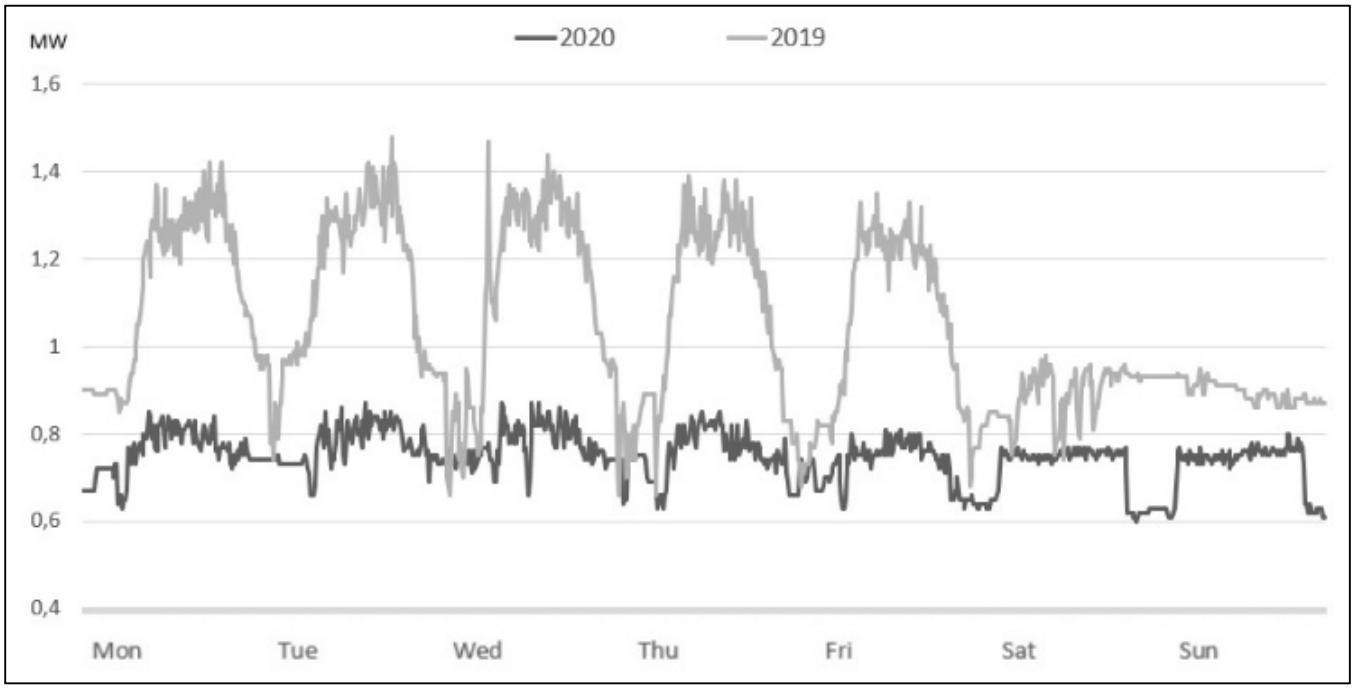

Fig. 6. Comparison of the weekly electricity demand in April for a feeder serving an industrial area of Milan between 2019 and 2020

Table IV shows the percent variation in the two cases, subdivided according to the day of the week and the time slot, for residential (R) and industrial (I) users, respectively. Globally, the residential feeder data show a 6% load increase, while the industrial district experienced a 27% decrease of electricity absorbed by the network in the week of April 2020 compared to 2019. In particular, the residential sector shows a + 9% in the central hours of working days and a + 11% on Saturday evening. For industrial users the decrease in absorbed energy drops to -36% in the 6am - 8pm range of working days.

TABLE III. VARIATION OF THE ELECTRICITY CONSUMPTION IN THE CITY OF MILAN IN THE MONTH OF APRIL 2020 BY DAY AND TIME SLOT

Percent variation of Milan electricity consumption between April 2019 and April 2020				
Time slot	***Working day***	***Saturday***	***Sunday***	***Average***
00:00-06:00	-9%	-8%	-7%	-8%
06:00-20:00	-22%	-15%	-12%	-16%
20:00-24:00	-8%	-7%	-6%	-7%

TABLE IV. VARIATION IN ELECTRICITY CONSUMPTION FOR AN INDUSTRIAL DISTRICT AND A RESIDENTIAL AREA, RESPECTIVELY, IN THE CITY OF MILAN, FROM APRIL 2019 TO APRIL 2020

Percent variation in electricity consumption for an industrial district (I) and a residential area (R)						
h	***Working day***		***Saturday***		***Sunday***	
	I	***R***	***I***	***R***	***I***	***R***
00:00-06:00	-15%	+5%	-16%	+5%	-28%	+3%
06:00-20:00	-36%	+9%	-16%	+7%	-16%	+2%
20:00-24:00	-27%	+3%	-30%	+11%	-24%	0%

IV. MAIN EFFECTS OF DEMAND REDUCTION ON MILAN DISTRIBUTION NETWORK

A. Variations in the daily pattern of electricity demand

The load demand forecasting in an unprecedented scenario represented a difficult challenge for the electricity system, and especially for the Italian dispatching operator TERNA. Figures 3 and 4 clearly show that the consumption decreased compared to January 2020, but also that the pattern of Milan electricity demand changed radically. The daily patterns of both working days and weekends are analyzed in detail in the following.

The data in the graphs are average weekly data for the considered period (several months included in the first half of 2020). As illustrated in Section 3, between January and April there has been a progressive reduction in the electricity demand. Usually, in the non-summer months the consumption has a trend similar to that of the average week of January in Figure 3 (months with no air conditioning). The curve is characterized by two peaks, a wider one in the morning hours, and another one, of lower value, in the evening hours. However, analyzing in detail the evolution of the pattern from January to April for a working day (Figure 7), it is evident that the reduction between January and February is fairly uniform in the central hours of the day and in the evening, while both daily peaks drop until becoming comparable as maximum power. In March this decrease is more considerable, and there is a greater drop in the daily hours, approximately between 6 am and 4 pm. This difference is even more marked in April, where the highest peak of the day becomes the evening peak, while the morning peak flattens.

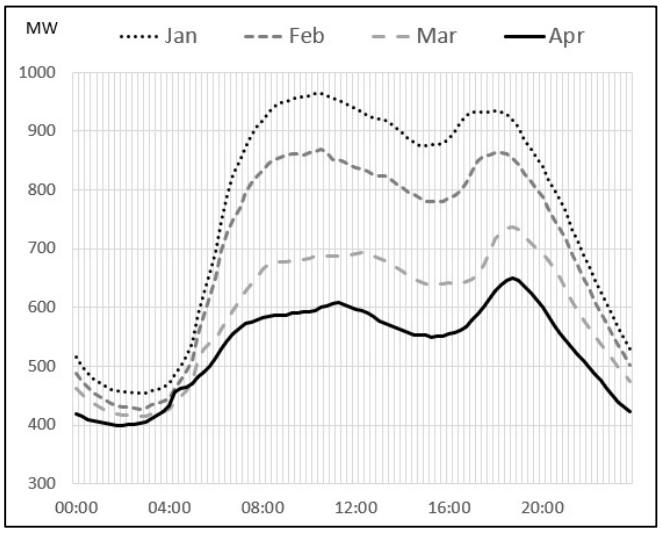

Fig. 7. Evolution of the electricity demand pattern of Milan in working days between January and April 2020.

Instead, Figure 8 shows the pattern for a weekend day. In this case the reduction causes the evening peak to go down, moving it closer to the morning peak. The maximum effect of these phenomena is achieved in the month of April, when the patterns of all the days of the week tend to be very similar, making the electricity consumption in weekdays comparable in average level and shape to that of the weekend days. This aspect is evident by comparing Figures 7 and 8, and also in Figure 3 where the patterns of all the days of the week for the month of April are shown side by side.

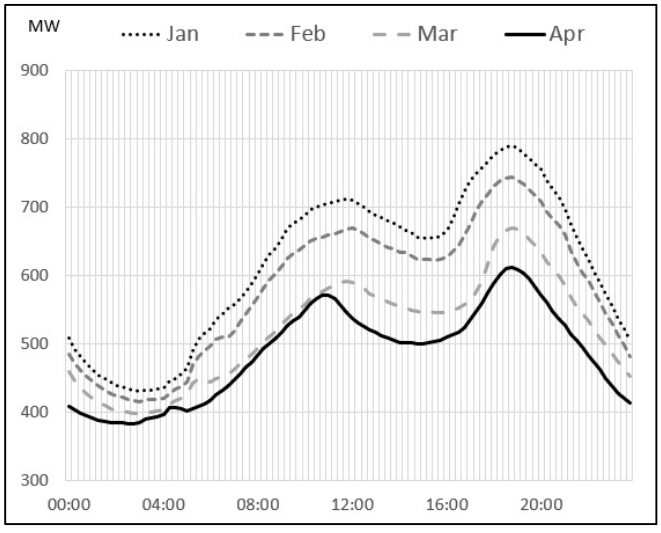

Fig. 8. Evolution of the electricity demand pattern of Milan in weekend days between January and April 2020.

In the period between April and June, the consumption starts to rise and the patterns of both working days and weekends evolve towards the typical summer shape. Figure 9 shows that the consumption in May increases compared to April, especially in working days between 6 am and 8 pm.

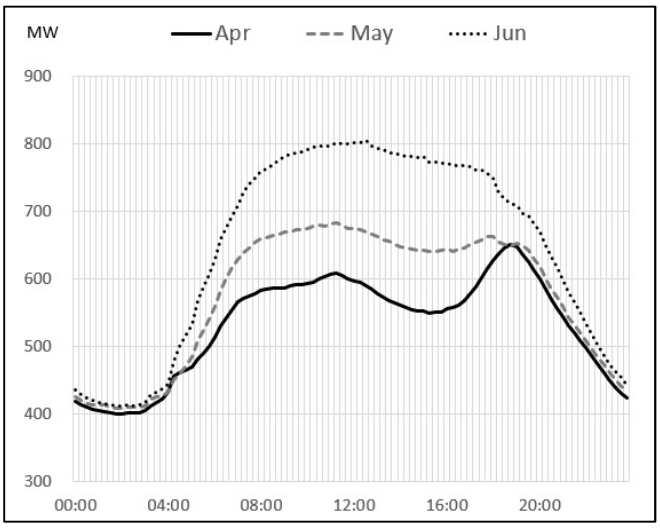

Fig. 9. Evolution of the electricity demand pattern of Milan in working days between April and June 2020.

This recovery is less marked over the weekend as shown in Figure 10. In June, the consumption level recovery is evident and the pattern of working days returns to its typical shape. Figures 9 and 10 show that the peak in the evening remains almost constant through the weeks, while in the middle hours of the day the consumption raises again, a sign of recovering of social and economic activities.

Such a variable pattern, different from the typical and historical ones for the considered period of the year, made the planning of electricity production and dispatching really difficult. Indeed, it was very difficult for the Italian TSO to plan the production and to provide ancillary services necessary for the stability and security of the National electricity system. On one hand, the dispatching market presented several exceptional situations as highlighted in many studies [14] [15] and evident from data [16], on the other hand, from the point of view of the distribution network, a further criticality is represented by the presence of the distributed generation (DG), especially the non-programmable one, like that based on photovoltaic generators (PV), largely present in the city of Milan [17].

The sum of the uncertainties linked to both the demand forecast and the DG, represented a great test of resilience for the distribution network and for the whole Italian electricity system, especially in April, when the PV generation usually contributes a lot to match the load demand [18].

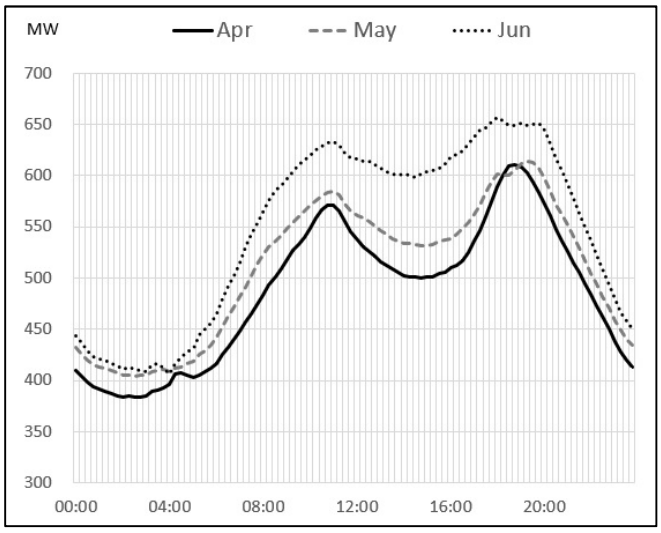

Fig. 10. Evolution of the electricity demand pattern of Milan in weekend days between April and June 2020.

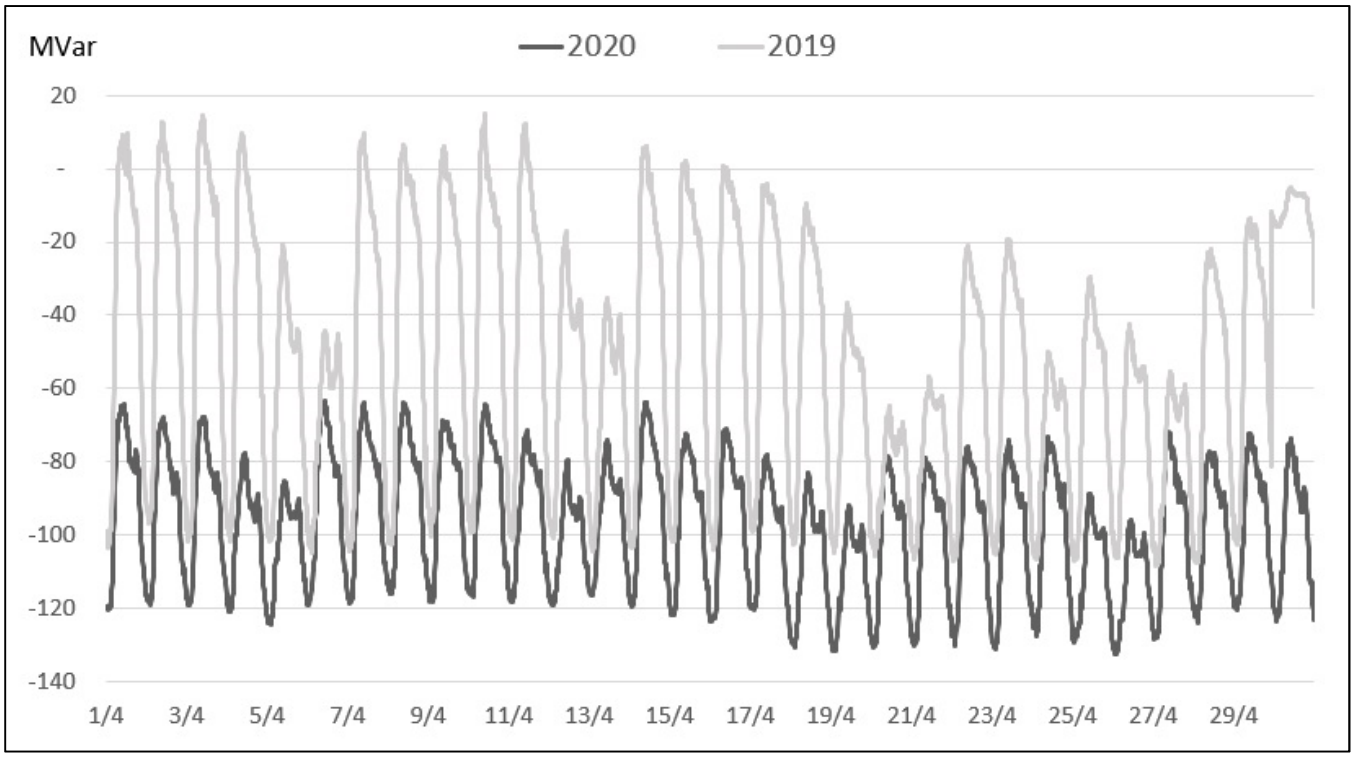

Fig. 11. Comparison between the reactive energy exchanged in April 2019 and April 2020 in the city of Milan.

B. *Increase of the reactive power introduced into the transmission grid by distribution networks*

The Milan distribution network is composed almost entirely of cable lines. This aspect has a strong impact on the amounts of reactive energy that the distribution network can exchange with the transmission grid. An unloaded cable network tends to introduce reactive power into the high voltage network, while absorbing it when it is charged. Thus, there is a cyclical release in the night hours, on holidays and during weekends, while there is an absorption in the hours of high demand, that is, in the central hours of the working days.

Figure 11 shows that in April 2020 the levels of reactive power which entered the transmission grid (negative sign) are much more significant than in 2019. The level of reactive power generated by the cable lines is such as to constantly enter the grid throughout the month.

The TSO had to compensate for a greater reactive power in 2020 than in 2019. The effect is well known by DSOs and TSO, and it was confirmed also in this period as one of the most critical aspects of the National electricity system.

This phenomenon produces effects on the voltage level and limits the electricity transmission capability at both the transmission and distribution network level. As above mentioned regarding the consumption pattern changes, these negative effects on the electrical system require proper services managed and programmed by the TSO, with additional costs for the system during the period under consideration.

To contrast this phenomenon, the Italian Authority is promoting various measures to limit both the introduction and the transit of reactive energy in the National electricity system in the future, imposing even more stringent limits than in the past and hypothesizing penalties for their exceeding [19]. The phenomenon presented here is being studied by the DSOs, in order to find technically and economically feasible solutions to be applied in the future.

CONCLUSIONS

In this paper, the effects of the Covid-19 pandemic on the distribution network of a big city like Milan have been analyzed in detail.

Such an accurate study, based on real data, provided a useful insight into the complex relationship linking the electricity patterns and overall amounts of consumption to the effects of governmental restrictions on the social and economic activities in an unprecedented scenario like that experienced by the whole planet in 2020.

The peculiar characteristics of Milan, a big industrialized city, with a highly developed tertiary sector, and large residential areas, allowed to catch all facets of the possible effects of the pandemic on the electricity systems, not only relevant to the Italian context, but paradigmatic for many other cities in the world. Moreover, the detailed analyses that a DSO can perform, makes its role essential for the electricity system in guaranteeing an appropriate monitoring and management of the local phenomena, especially in extreme conditions like those occurred on the occasion of the Covid-19 pandemic.

REFERENCES

[1] Italian Ministry of Health, “Covid-19 - situazione in italia”, http://www.salute.gov.it/ nuovocoronavirus (in Italian), last access: July, 15th, 2020.

[2] ANAS, “Osservatorio del traffico, edizione speciale andamenti settimanali periodo marzo-maggio 2020”, www.anas.it (in Italian), last access: July, 15th, 2020.

[3] Regione Lombardia, “Lombardia notizie on line - monitoraggio spostamenti”, https://www.lombardianotizie.online/coronavirus-monitoraggio-spostamenti/ (in Italian), last access: July, 15th, 2020.

[4] Enel X, “ Emergenza COVID-19-mappa di mobilità” https://www.enelx.com/it/it/smart-city/soluzioni/soluzioni-smart-city/dashboard-covid-19 (in Italian), last access: July, 15th, 2020.

[5] ISTAT, “Situazione e prospettive delle imprese nell’emergenza sanitaria Covid-19”, www.istat.it (in Italian), Last access: July, 15th, 2020.

[6] UK Energy Research Centre UKERC, “Electricity demand during week one of COVID-19 lockdown”, https://ukerc.ac.uk/news/electricity-covid-lockdown/, last access: July, 15th, 2020.

[7] International Energy Agency IEA, “COVID-19 Exploring the impacts of the Covid-19 pandemic on global energy markets, energy resilience, and climate change”, https://www.iea.org/topics/covid-19, last access: July, 15th, 2020.

[8] S&P Global, “COVID-19-related load impacts are being reported by several US grid operators”, https://www.spglobal.com/, last access: July, 15th, 2020.

[9] Electric Power Research Institute EPRI, “COVID-19 bulk system impacts: demand impacts and operational and control center practices”, http://mydocs.epri.com/docs/public/covid19/3002018602R2.pdf, last access: July, 15th, 2020.

[10] Eurelectric, “COVID-19 impact on the power sector”, https://www.eurelectric.org/news/covid-19/, last access: July, 15th, 2020.

[11] Energy Networks Australia, “Commercial down v residential up: COVID-19’s electricity impact”, https://www.energynetworks.com.au/news/energy-insider/2020-energy-insider/commercial-down-v-residential-up-covid-19s-electricity-impact/, last access: July, 15th, 2020.

[12] U.S. Energy Information Administration (EIA), “Hourly electric grid monitor”, https://www.eia.gov/beta/electricity/gridmonitor/dashboard/electric_overview/US48/US48, last access: July, 15th, 2020.

[13] BluWave-ai, “Impact of COVID-19 related shutdowns on utility-scale electric demand and forecasting: an indian metropolitan area case study”, https://www.bluwave-ai.com/impact-of-covid-19-shutdowns, Last access: July, 15th, 2020.

[14] Ricerca Sistemi Energetici RSE, “Dossier”, https://dossierse.it/14-2020-covid-e-carico-elettrico-verso-la-ripresa-analisi-delle-reti-di-milano-e-brescia/ (in Italian), last access: July, 15th, 2020.

[15] E. Ghiani , M. Galici, M. Mureddu, and F. Pilo, “Impact on electricity consumption and market pricing of energy and ancillary services during pandemic of COVID-19 in Italy”, Energies MDPI, July 2020.

[16] Gestore Mercati Energetici GME, “ L’aggiornamento mensile sui principali trend del settore energetico”, http://www.mercatoelettrico.org/ (in Italian), last access: July, 15th, 2020.

[17] G. Iannarelli, A. Bosisio, B. Greco, C. Moscatiello, and C. Boccaletti, “Flexible resources dispatching to assist DR management in urban distribution network scenarios including PV generation: an Italian case study”, IEEE 20th International Conference on Environmental and Electrical Engineering, June 2020.

[18] TERNA, “L’evoluzione del mercato elettrico: tutti i dati”, https://www.terna.it/it/sistema-elettrico/statistiche/evoluzione-mercato-elettrico (in Italian), last access: July, 15th, 2020.

[19] ARERA, “Criteri per l’aggiornamento infra-periodo della regolazione tariffaria relativa ai servizi di trasmissione, distribuzione e misura dell’energia elettrica”, https://www.arera.it/allegati/docs/19/481-19app.pdf (in Italian), last access: July, 15th, 2020.