Impact of COVID-19 pandemic crisis in Italy: comparison of 2020 with non-pharmaceutical measures and 2021 with pervasive vaccination programs

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Research Article

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Abstract

How is the impact of Coronavirus disease 2019 (COVID-19) in Italy in the 2020 (without vaccinations and with non-pharmaceutical interventions) *versus* 2021 (with a vast roll out of COVID-19 vaccination programs) ? Italy is an interesting case study because was one of first European countries to experience in 2020 higher numbers of COVID-19 related infected individuals and deaths and in 2021 has a high share of people vaccinated against COVID-19. This study answers the question with a comparative analysis of the effects of COVID-19 in 2020 and 2021. Data of confirmed cases, hospitalizations, admissions to ICUs and fatality rate for 176 days are analyzed with the Independent Samples *t*-Test that compares the means of two groups concerning values from April to September 2020 (without vaccinations and with non-pharmaceutical measures) and 2021 (with pharmaceutical interventions based on a vast vaccination program). Results suggest that in 2020 and in 2021 the impact of COVID-19 in society is rather similar, except fatality rate (significant level 1%). These findings also reveal that the COVID-19 is driven by seasonal and environmental factors that reduce the negative effects in summer period, regardless vaccination campaign. This study can support appropriate and target policy responses of crisis management for countries to face current and likely future pandemics of similar vital agents.

Introduction And Goal Of This Investigation

The novel Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is the causative viral agent of the Coronavirus disease 2019 (COVID-19), an infectious illness that is generating health and social issues in manifold countries (Anand et al., 2021; Bontempi and Coccia, 2021; Bontempi et al., 2021; Coccia, 2020, 2020a, 2021; Johns Hopkins Center for System Science and Engineering, 2021). The spread and severity of COVID-19 worldwide has supported the development of new drugs, such as different types of vaccines based on viral vector, protein subunit and nucleic acid (cf., Abbasi, 2020; Coccia, 2021a; Cylus et al., 2021; GAVI, 2021; Heaton, 2020; Jalkanen et al., 2021; Jeyanathan et al., 2020; MAYO Clinic, 2021). A fundamental question in COVID-19 pandemic crisis is whether the reduction of COVID-19 pandemic in 2021 is due to administering of vaccines in population or other factors. Manifold studies show the effects of COVID-19 vaccines on population and health system, emphasizing the effectiveness for the security and well-being in society (Cai et al., 2021; Feng and Li, 2021; Rosenberg et al., 2021). However, inconsistencies and ambiguities in the literature and data of time series suggest the need for additional research. The goal of this investigation is a comparative analysis of the dynamics of COVID-19 pandemic between 2020 and 2021 in Italy, considering infected individuals, hospitalizations, ICUs, and fatality rates. This study analyses the impact of COVID-19 in Italy between April-September 2020 (without vaccinations and with non-pharmaceutical interventions) and April-September 2021 (with pharmaceutical interventions based on vaccination programs) to explain, whenever possible, the dynamics and impact of COVID-19 pandemic in society. The results are analyzed to clarify the environmental factors determining the dynamics of this pandemic to support socioeconomic and health policies for policymakers.

Theoretical Background

Because of the rapid spread of COVID-19 worldwide, understanding whether and how the dynamics of COVID-19 pandemic in society changes over time is a crucial aspect to clarify driving factors for controlling, with appropriate health planning, the transmission and effects of novel viral agents in society (Aldila et al., 2021;

Pawelec and McElhaney, 2021). Vaccinations have the potential to keep low basic reproduction number, to relax nonpharmaceutical measures and to support the recovery of socioeconomic systems (cf., Prieto Curiel et al., 2021). Akamatsu et al. (2021) argue that to cope with infectious disease severity that increases considerably, governments have to implement an efficient campaign of vaccinations to reduce infections and mortality in society and avoid the collapse of the healthcare system (cf., Yoshikawa, 2021). Aldila et al. (2021) maintain that higher levels of vaccination can eradicate COVID-19 from the population by achieving, whenever possible, the herd immunity^[1] to protect vulnerable individuals (Anderson et al., 2020; de Vlas and Coffeng, 2021, Randolph and Barreiro, 2020; Redwan, 2021). Ioannidis (2021) suggests a model to assess the benefit of vaccination; in particular, results suggest that if the vaccine efficacy decreases to 0.8, the benefit gets eroded easily with modest risk compensation. Tran et al. (2021) argue in a case study concerning the states of Rhode Islands and Massachusetts that with vaccination coverage higher than >28% and no major changes in non-pharmaceutical measures (social distancing, masking, gathering size, hygiene guidelines, etc.) and virus transmissibility from January to July, a combination of vaccination and population immunity may lead to low or near-zero transmission levels by the second quarter of 2021.

However, other climatological, environmental, demographic, and geographical factors of the total environment can influence the spread of COVID-19 in society (Bashir et al., 2020; Rosario et al., 2020; Sahin, 2020; Sarmadi et al., 2020). Zhong et al. (2018) argue that static meteorological conditions may explain the increase of bacterial communities in the presence of air pollution. Coccia (2020) reveals that, among Italian provincial capitals, the number of infected people was higher in cities having high air pollution, cities located in hinterland zones (i.e., away from the coast), cities having a low wind speed and cities with a lower temperature (cf., Coccia 2020c; 2021b, 2021h). Rosario et al. (2020) also reveal that high wind speed improves the circulation of air and increases the exposure of the novel coronavirus to the solar radiation effects, a factor having a negative correlation in the environmental diffusion of COVID-19. Abraham et al. (2021) suggest that the vital role of climatic variables and seasonality in all kinds of epidemics and pandemics, included COVID-19. Zoran et al., (2021), analyzing COVID-19 waves in Madrid, maintain that air temperature, planetary boundary layer height, and ground level ozone have a significant negative relationship with daily new COVID-19 confirmed cases and deaths. Danon et al. (2021) show that seasonal changes in transmission rate can affect the timing and size of the epidemic potential of COVID-19; in particular, seasonal changes in transmission could shift the timing of the peak into winter, with important implications for healthcare capacity planning.

In this context, a key problem in current COVID-19 pandemic crisis is to examine the evolution of COVID-19 into the same spatial area and period in 2020 and 2021 to explain variations or similarities of the effects in society. This study confronts this problem here by developing a comparative analysis between April-September 2020 (without vaccinations and with non-pharmaceutical interventions) and April-September 2021 (with vaccination programs) in Italy, which was the first European country to experience a rapid increase in confirmed cases and deaths of COVID-19 in 2020 and in 2021 is one of the countries with a widespread plan of vaccination.

The study here can provide critical results to clarify the dynamics of COVID-19 pandemic, environmental behavior and effects of the novel Coronavirus in society. Lessons learned from this study could be of benefit to countries to design effective strategies of healthcare capacity planning to apply in specific period to cope with and/or to prevent future waves of COVID-19 and/or epidemics/pandemics of similar infectious diseases. This study is part of a large body of research directed to explain drivers of transmission dynamics of COVID-19 and

design effective COVID-19 pandemic responses of crisis management (Coccia, 2020, 2020a, 2020b, 2020c, 2021, 2021c, 2021d, 2021e, 2021h, 2022).

[1] Herd immunity indicates that only a share of a population needs to be immune and as a consequence no longer susceptible (by overcoming natural infection or through vaccination) to a viral agent for epidemic control and to stop large outbreaks (Fontanet and Cauchemez, 2020; Rosen et al., 2021).

Materials And Methods

1.1 Research questions

How is the dynamics of the COVID-19 pandemic in summer season of 2020 (without vaccines) and 2021 (with vaccinations)?

Does the behavior of COVID-19 change or not between 2020 (without vaccines) and 2021 (with vaccinations)?

The goal of this study is a comparative analysis of the effects of COVID-19 pandemic between 2020 (*without* vaccinations and with non-pharmaceutical interventions) and 2021 (*with* vaccination programs) in Italy to assess differences or similarities in society (cf., Coccia, 2018).

1.2 Research setting

The research setting here is a case study of Italy, the first European country to experience a rapid increase of COVID-19 related infected individuals and deaths in 2020 (Coccia, 2020, 2021). Moreover, Italy on 27 September 2021 is one of the countries with widespread plan of vaccination having a share of people fully and only partly vaccinated against COVID-19 equal to about 74% (Lab24, 2021; Mathieu et al., 2021; Our World in Data, 2021).

1.3 Period, sample and source

Data of the period from 1st April to 23rd September 2020 are compared to the same period in 2021 in Italy, using daily information based on $N=176$ days in 2020 and $N=176$ days in 2021 for a total of $N=352$ cases for different variables. Source of epidemiological data under study is The Ministry of Health in Italy (Ministero della Salute, 2020).

1.4 Measures

The measures for statistical analyses are:

- *Number of daily COVID-19 infected individuals* is measured with confirmed cases of COVID-19 in population per day.
- *Number of daily COVID-19 swab tests* verifies the positivity to the novel coronavirus (confirmed case) by analyzing specimen of people (LabCorp, 2020).

- *Daily hospitalized people* are the total hospitalized patients with different COVID-19 symptoms and patients in ICUs.
- *Daily admissions to Intensive Care Units (ICUs)* are the number of patients in ICUs for COVID-19.
- *Number of daily COVID-19 deaths* is measured with total deaths per day in society
- *Daily Fatality rate* = ratio of deaths at (t) /confirmed cases at ($t-14$). The time lag of about 14 days from initial symptoms to deaths is based on empirical evidence of some studies (Zhang et al., 2020).

1.5 Data analysis procedure

Firstly, the study calculates the daily contagiousness coefficient of COVID-19 in the period under study of 2020 and 2021, given by:

$$\text{Contagiousness coefficient of COVID - 19 at } t \text{ (CCV)} = \frac{\text{Confirmed cases at } t}{\text{swab tests at } t}$$

This coefficient is used to normalize hospitalization and admissions to ICUs. Moreover, to eliminate from original time series y_t weekly seasonal variation, it is applied the method of moving averages (MM) considering the sub-period of length $r=7$ days (a week), using the following formula for MM7:

$$y'_t = \frac{y_{t-3} + y_{t-2} + y_{t-1} + y_t + y_{t+1} + y_{t+2} + y_{t+3}}{r = 7 \text{ days}}$$

New time series adjusted with averaging process is given by $y_t^* = \sum_t^s y'_t$ that tends to eliminate period to period weakly fluctuations and produces a much smoother series than original observations. Data of daily hospitalization of people and admissions to ICUs are normalized as follows:

$$\text{Daily hospitalization of people normalized} = \frac{\text{daily hospitalization of people (t)}}{\text{MM7 Contagiousness coefficient of COVID - 19 (t - 5)}}$$

$$\text{Daily admission ICUs normalized} = \frac{\text{daily admission ICUs (t)}}{\text{MM7 Contagiousness coefficient of COVID - 19 (t - 5)}}$$

The time lag of about 5 days to normalize these variables is based on an average period from diagnosis (initial symptoms and positivity to swab test) to the hospitalization and recovery in ICUs of COVID-19 patients as explained by specific studies (Faes et al., 2020).

The sample of $N=352$ cases is divided in two sub-samples having similar temporal, healthcare and societal conditions for a structural comparative analysis:

- group 1: data from 1st April to 23rd September 2020, $N=176$
- group 2: data from 1st April to 23rd September 2021, $N=176$

Secondly, data are analyzed with descriptive statistics given by arithmetic mean (M) and Std. error of mean (SEM) for a comparative analysis between two groups just mentioned.

Thirdly, follow-up investigation is the Independent Samples t -Test that compares the means of two independent groups to determine whether there is statistical evidence that the associated population means are significantly different. The assumption of homogeneity of variance in the Independent Samples t Test – i.e., both groups have the same variance – is verified with Levene's Test based on following statistical hypotheses:

$H_0: \sigma_1^2 - \sigma_2^2 = 0$ (population variances of group 1 and 2 are equal)

$H_1: \sigma_1^2 - \sigma_2^2 \neq 0$ (population variances of group 1 and 2 are not equal)

The rejection of the null hypothesis in Levene's Test suggests that variances of the two groups are not equal: i.e., the assumption of homogeneity of variances is violated. If Levene's test indicates that the variances are equal between the two groups (i.e., p -value large), equal variances are assumed. If Levene's test indicates that the variances are not equal between the two groups (i.e., p -value small), the assumption is that equal variances are not assumed.

After that, null hypothesis (H'_0) and alternative hypothesis (H'_1) of the Independent Samples t -Test are:

$H'_0: \mu_1 = \mu_2$, the two-population means are equal in 2020 and 2021

$H'_1: \mu_1 \neq \mu_2$, the two-population means are not equal in 2020 and 2021

Finally, trends of variables under study are analyzed and visualized for a comparative analysis of the impact of COVID-10 pandemic in Italy between 2020 (*without* vaccinations and with non-pharmaceutical interventions) and 2021 (*with* pharmaceutical interventions based on vast roll out of COVID-19 vaccination). In particular, this study also applies a simple regression analysis in which response variables measuring the impact of the COVID-19 on health of people are a linear function of time. The specification of linear relationship is given by a model using the time series y^*_t in 2020 and 2021:

$$\log y^*_t = a + b t + u \quad [1]$$

y^*_t = measures of the impact of COVID-19 pandemic in society using MM7 of time series (Confirmed cases/swab tests, Hospitalization an ICUs)

t = time given by 2020 and 2021 period, as explained before

u = error term

Ordinary Least Squares (OLS) method is applied for estimating the unknown parameters of linear model [1].

Statistical analyses are performed with the Statistics Software SPSSâ version 26.

Results

Table 1 shows that confirmed cases in 2020 is about 2.1%, whereas in 2021 is 2.5%. Number of hospitalizations, ICUs in 2020 has a slightly higher level, whereas fatality rate is lower in 2021 compared to 2021, likely because of a higher number of swab tests in 2021 that have detected more confirmed cases that increase the denominator of the ratio of fatality reducing the total value.

Table 1. Descriptive statistics

Description of variables	April-September 2020		April-September 2021	
	M	Std. Error Mean	M	Std. Error Mean
• Confirmed cases normalized	0.021	0.002	0.0254	0.0012
• Hospitalizations normalized	556.720	94.706	406.0100	46.8410
• ICUs normalized	58.850	11.076	48.0400	5.4400
• Fatality rates	0.073	0.003	0.0146	0.0004

Note: M= arithmetic mean, N=176 days in 2020 and 176 in 2021

Table 2 shows the Independent Samples *t* Test, as follow-up inspection, to assess the significance of the difference of arithmetic mean between groups of 2020 and 2021 under study. The *p*-value of Levene's test is significant, and we have to reject the null hypothesis of Levene's test and conclude that the variance in the groups under study is significantly different (i.e., equal variances are not assumed). Table 2 also shows *t*-test for Equality of Means that provides the results for the actual Independent Samples *t* Test.

Since *p*-value ≥ 0.5 is higher than fixed significance level $\alpha = 0.01$, we can accept the null hypothesis, and conclude that the mean of confirmed cases, hospitalizations of people, and ICUs in 2020 and 2021 is significantly equal: there is not a significant difference in arithmetic mean between 2020 and 2021. Instead, for fatality rates, since *p*-value < 0.001 is less than chosen significance level $\alpha = 0.01$, we can reject the null hypothesis, and conclude that the mean in 2021 and 2021 is significantly different, likely for reasons mentioned for table 1.

Table 2. Independent Samples Test

		Levene's Test for equality of variances		t-test for equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Confirmed cases 2020 vs. 2021	•Equal variances assumed	11.722	0.001	-1.631	350	0.104	-0.004	0.002
	•Equal variances not assumed			-1.631	276.877	0.104	-0.004	0.002
Hospitalizations 2020 vs. 2021	•Equal variances assumed	18.541	0	1.426	350	0.155	150.716	105.657
	•Equal variances not assumed			1.426	255.784	0.155	150.716	105.657
ICUs 2020 vs. 2021	•Equal variances assumed	12.436	0	0.876	350	0.382	10.813	12.340
	•Equal variances not assumed			0.876	254.772	0.382	10.813	12.340
Fatality rates 2020 vs. 2021	•Equal variances assumed	446.728	0	17.812	350	0	0.058	0.003
	•Equal variances not assumed			17.812	180.875	0	0.058	0.003

Table 3 and figures 1-4 confirm, *ictu oculi*, previous results. Simple regression analysis in table 3 shows, in average, a higher reduction in 2020 than year 2021 of the coefficients of regression of response variables under study (p -value= .001).

The coefficient R^2 of regression models indicates that from 24% to 70% of the variation in variables of the COVID-19 can be attributed (linearly) to temporal variable. F -test is significant with p -value <.001.

Conclusion of statistical analyses here is that the dynamics of pandemics in 2020 and 2021 is rather similar, regardless the plan of vaccination implemented by Italy. Results seem to suggest that the negative effects of COVID-19 in Italy are higher in 2021, though vaccination campaign, than 2020 (without vaccination), likely because of delta variant of SARS-CoV-2 that has a higher transmission dynamics (GAVI, 2021).

Table 3. Estimated relationships based on linear model of regression

	Confirmed cases		Hospitalizations	
	2020	2021	2020	2021
Constant α	0.050***	0.066***	1944.93***	2768.46***
Coefficient β	-0.00032***	-0.00015***	-15.69***	-8.93***
Stand. Coeff. β	-0.58	-0.49	-0.64	-0.73
R ²	0.334	0.143	0.41	0.54
<i>F-test</i>	87.25***	55.79***	118.26***	201.25***
	ICUs		Fatality rates	
	2020	2021	2020	2021
Constant α	210.48***	327.21***	0.14***	0.04***
Coefficient β	-1.71***	-1.06***	-0.001***	-0.00009***
Stand. Coeff. β	-0.594	-0.745	-.84	-.78
R ²	0.35	0.55	0.71	0.60
<i>F-test</i>	94.90***	217.30***	416.01***	264.00***

Notes: Explanatory variable: Case sequence (*time*)

Response variables: Hospitalizations normalized, confirmed cases normalized , ICUs normalized, Fatality rates

Significance: ****p*-value<0.001, **p*-value<0.5

Phenomena Expalined Of The Similar Dynamics Of Covid-19 In 2020 And 2021

The results of this study show a comparative analysis of the effects of COVID-19 in 2020 (with non-pharmaceutical interventions) versus 2021 (with vast vaccination programs) in the same socioeconomic system, given by Italy. Results reveal similar dynamics of COVID-19, regardless vaccinations. These results may be interpreted through the lens of theories that explain the critical role of climatic variables and seasonality in all types of epidemics and pandemics based on airborne diseases (Abraham et al., 2021; Dbouk and Drikakis, 2020; lanevski et al., 2019). Manifold studies suggest that the important role of climate on the spread of influenza viruses, such as SARS-CoV-2 (Takagi et al., 2020; Şahin, 2020). In general, meteorological factors (e.g., temperature and humidity) play a well-established role in the seasonal transmission of respiratory viruses and influenza in temperate climates (Chan et al., 2011; Hoogeveen and Hoogeveen, 2021; Roussel et al., 2016). Studies report that the transmission of COVID-19 can be influenced by the variation of environmental factors associated with seasonality (Christophi et al., 2021; Maharaj et al., 2021). In fact, summer seasonality can reduce the spread of the airborne disease of novel coronavirus over time and space and constrain the negative effects in society in the presence of specific conditions of the total environment; in particular, while a higher absolute humidity can support viral transmission (Islam et al., 2021), high solar radiation and high wind speed can mitigate the spread of COVID-19 in society (Coccia, 2021, 2021a; Rosario et al., 2020). Scholars suggest

that the effects of climate on the influenza epidemic are associated with seasonal fluctuations connected with latitude in the North and South Hemisphere (Ianevski et al., 2019; Shaman and Galanti, 2020). Especially, scholars analyze the sensitivity of COVID-19 to meteorological factors to explain how changes in the weather and seasonality may constrain COVID-19 transmission (Kerr et al., 2021). Recent studies point out the strong seasonal factor of COVID-19 (Audi et al., 2020; Moriyama et al., 2020). The study by Liu et al. (2021, p.1ff) shows that the cold season in the Southern Hemisphere countries caused a $59.71 \pm 8.72\%$ increase of total infections, whereas the warm season in the Northern Hemisphere countries contributed to a $46.38 \pm 29.10\%$ reduction.

These results propose that COVID-19 seasonality is more pronounced at higher latitudes, in the presence of larger seasonal amplitudes in environment. Other studies have focused on temperature or humidity effects that might slow down transmission of the novel coronavirus (Karapiperis et al., 2021; Rosario et al., 2020; Runkle et al., 2020). Byun et al. (2021) show that manifold studies suggest an inverse relation between temperature and humidity, and global transmission of SARS-CoV-2. As matter of fact, COVID-19 tends to be temperature-sensitive and, therefore driven by a seasonal viral agent (cf., Engelbrecht and Scholes, 2021). In this context, Karapiperis et al. (2021) demonstrated that UV radiation is strongly associated with incidence rates, rather than mobility, suggesting that UV radiation is a seasonality indicator for COVID-19, irrespective of the initial conditions of the epidemic (cf., Kumar et al., 2021). Many infectious diseases, such as endemic human coronaviruses, can be a seasonally recurrent infectious diseases that vary over time and space (Kronfeld-Schor et al., 2021). Although, a vital relationship between weather seasonality, airborne virus transmission, environmental factors, air pollution and pandemic disease exists over time (Coccia, 2020), Dbouk and Drikakis (2020) maintain that many epidemiologic models do not consider the effects of climate conditions on the transmission dynamics of viruses about airborne diseases. Additionally, Dbouk and Drikakis (2021), applying fluid dynamics simulations, show that weather seasonality can induce two outbreaks of the COVID-19 pandemic worldwide. These two pandemic outbreaks per year are inevitable because they are directly associated with weather seasonality based on temperature, relative humidity, and wind speed of geographical regions.

Hence, the empirical evidence seems to suggest that the novel coronavirus pandemic has a full seasonal cycle, showing a negative correlation of the rate of diffusion with humidity and temperature (Karapiperis et al., 2021): i.e., the SARS-CoV2 transmissibility seems to naturally decrease in summer seasons, regardless vaccinations.

Therefore, many studies-analyzing the role of climate and seasonality of pandemic diseases-have proposed an extension of the family of epidemiologic models with the introduction of parameters associated with seasonality transmission of SARS-CoV-2 and other socioeconomic factors (Batabyal, 2021; Bontempi and Coccia, 2021; Bontempi et al., 2021; Coccia, 2020a).

The proposed explanation here of similar trends of the dynamics of COVID-19 pandemic in 2020 and 2021 based on the factor of seasonality and other environmental factors in the spread of the novel coronavirus is a critical aspect to design and implement appropriate public health interventions and timing of health planning of vaccination and other non-pharmaceutical interventions in society.

Concluding Observations And Limitations

This study reveals, with a comparative analysis between the period April-September 2020 (without vaccinations but applying non-pharmaceutical interventions) and April-September 2021 (with a pervasive roll out of COVID-19 vaccinations) in Italy, that average confirmed cases, hospitalizations of people, and admissions to ICUs is significantly equal, corroborating the seasonal behavior in the total environment of the COVID-19, which decreases in summer season regardless vaccinations[2].

This finding has a critical aspect to clarify transmission dynamics and support appropriate interventions of health policy to cope with outbreaks of current and future infectious diseases. In fact, these results can support the implementation of best practices of public health and policy of new technology[3], considering seasonal factor in the Northern and Southern Hemispheres, in which the COVID-19 and similar infectious diseases unfold mainly over winter-fall period (cf., Coccia, 2021f; Gozzi et al., 2021; Yoshikawa, 2021).

Danon et al. (2021) show that seasonal changes in transmission rate can affect the timing and size of the COVID-19 pandemic, shifting the peak into winter, with important implications for planning the healthcare capacity and vaccinations to cope with infectious diseases[4]. As a matter of fact, Smit et al. (2021) argue that climatic factors would reduce the viral transmission rate in boreal summer and the COVID-19 peak would coincide with the peak of the influenza season, increasing the burden on health systems (cf., Kronfeld-Schor et al., 2021). However, seasonality alone can be a main driver in transmission dynamics of COVID-19 but cannot be a sufficient factor to curb the novel coronavirus transmission that requires multidisciplinary approaches and timely intervention policies of short and long run, a scaled-up health care capacity in the winter seasons, rather than summer period.

Overall, then, this statistical analysis here suggests that the reduction of the dynamics of COVID- seems to be associated with seasonality of the novel coronavirus that reduces the effects in the presence of favorable conditions of summer season that constrain the spread of the airborne disease in society. These conclusions are, of course, tentative. Although this study has provided some interesting, albeit preliminary results, it has several limitations. First, COVID-19 pandemic is still progressing, so data are continually changing over time and space. Second, structure of population and characteristics of patients (e.g., ethnicity, age, sex, and comorbidities) may vary between regions affecting results. Third, there are multiple confounding factors that could have an important role in the spread of COVID-19 pandemic to be further investigated (e.g., institutional aspects, culture, investments in hospital sector, in prevention, in medical personnel, etc.). Finally, the statistical analyses and estimated relationships in this study focus on data in specific period (which were the recent information available in the database) and country having as Mediterranean climate (Italy). Thus, generalizing the results of this research should be done with caution.

To conclude, future research should consider more recent data, when available, and when possible, should examine new time series of variables to provide more dynamic relations of the phenomena under study over time and space. Despite these limitations, the results presented here clearly illustrate the need for more detailed examinations of the relationship between dynamics of COVID-19 and climate factors to better understand transmission dynamics of COVID-19 over time for appropriate policy responses of crisis management at country level.

[2] The reduction in summer of COVID-19 cases is also due to a lower level of pollution and better climate factors (cf., Coccia, 2014, 2020b, 2020c)

[3] For vital role of technology diffusion and evolution see: Calabrese et al., 2005; Coccia, 2012, Coccia, 2016, 2016a; 2017a, 2017c, 2017d, 2019a, 2019b, 2020d, 2020e; Coccia and Finardi, 2012, 2013; Coccia and Watts, 2020, Coccia and Wang, 2015, 2016.

[4] Planning the healthcare capacity of nations depends also on other factors (cf., Coccia, 2005, 2005a, 2005b; 2006, 2008, 2009, 2010, 2015, 2016b, 2017, 2017b, 2018a, 2018b, 2018c, 2018d, 2019, 2019c, 2021g, Coccia and Bellitto, 2018; Coccia and Benati, 2018; Coccia and Cadario, 2014; Coccia and Rolfo, 2010).

Declarations

Declaration of competing interest

The author declares that he is the sole author of this manuscript, and he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figures

Figure 1

Trends of confirmed cases normalized from April to September in 2020 and 2021, Italy Note: log scale on y-axis for better visualization of MM7 values

Figure 2

Trends of hospitalized people normalized from April to September in 2020 and 2021, Italy Note: log scale on y-axis for better visualization of MM7 values

Figure 3

Trends of ICUs normalized from April to September in 2020 and 2021, Italy Note: log scale on y-axis for better visualization of MM7 values

Figure 4

Trends of fatality rate from April to September in 2020 and 2021, Italy Note: log scale on y-axis for better visualization of MM7 values