COVID-19 Pandemic Crisis

Mario Coccia

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Preface

One of the current questions in the contemporary scientific debate is to explain factors determining the diffusion of the Coronavirus Disease 2019 (COVID-19), a new viral infection that is generating a severe acute respiratory syndrome with serious pneumonia to manifold people worldwide that may result in progressive respiratory failure and death. To reduce the number of total deaths and infected individuals of COVID-19, many countries, universities, public and private research organizations have accelerated the scientific research production generating new knowledge about this new Coronavirus disease, but also many people/organizations not involved in research activities sought to provide innovative solutions, especially adopting what they already know, such as current technologies. This on-going accumulation of knowledge, driven by an accelerated velocity of science production on COVID-19 is due to a process of systematic research in labs to generate effective vaccines, new therapies, and new antiviral drugs that can counteract this global public health threat and future epidemics similar to COVID-19.

Current literature in this field of research is rather fragmented and doesn't tell us in a systematic framework the manifold and complex factors involved in transmission dynamics the COVID-19, effects of public policies (such as, lockdown) on public health and economic system and results for improving decision-making of the crisis management of COVID-19 in society.

The goal of this book is to explain some characteristics related to factors determining the transmission dynamics of COVID-19 associated with geography, environment, atmosphere and social structure of cities and regions and effects of public policies applied by governments. In particular, this book, in an interdisciplinary perspective, describes a collection of new researches that can clarify some factors of the spread of COVID-19 in polluted cities extending and effects of containment measures to explain vital relationships that may be helpful for decision making of policymakers in different environments to solve this global health issue or at least reduce its impact in society and future social issues of similar viral agents.

This book is designed for public and private managers and policymakers, as well as general readers that wish to clarify critical aspects of COVID-19 and that wish to expand their knowledge on these areas. I have attempted to minimize the use of extremely complex models, concepts and theories. Studies that I include here are integrated with cases study and empirical analyses based on real contexts of cities and nations, rather than on theoretical models that generate simulations with computer experiments to predict eventual real effects of the dynamics of COVID-19 pandemic in different urban contexts. In order to attain a reasonable depth, this book concentrates on selected topics of particular relevance to problems of COVID-19, and which meet the needs of the intended audience.

The book is divided in four interrelated parts.

1. The first part of this book focuses on environmental, demographic, and geographical factors that influence the spread of COVID-19 in society (Chapter 1-2-3).
2. The second part describes the effects of policy responses of governments to cope with recurring waves of COVID-19 pandemic, focusing on impact in public health, environment and economic system (Chapter 4-5).
3. Part three of the book concentrates on a new approach to assess and predict environmental, demographic, and geographical risk factors that influence the spread of COVID-19 and future epidemics similar to COVID-19 (Chapter 6).
4. The final part of the book explains some general approaches and concepts that can support decision making of crisis management to cope with global pandemic and similar social issues discussed in this book (Chapter 7).

However, no single book could hope to cover adequately all aspects of what is wide and essentially multi-disciplinary field of inquiry, such as infectious diseases, and here it is not the intention to attempt to cover all aspects of COVID-19 pandemic crisis in society. It is regrettable but inevitable therefore that some topics are excluded or given only limited coverage and it is not possible to meet fully the preferences of all readers. I hope that readers dealing with infectious diseases like COVID-19 and other similar viral agents, such as clinicians, managers, policymakers, etc. are able to see this text as a starting point to understand the complex and different factors and processes associated with COVID-19 global pandemic crisis and other similar infectious diseases.

This book's strengths and weaknesses are the responsibility of author.

Dr. Mario Coccia

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13 April 2021

Contents

Introduction

Social scientists for over a century have recognized the complexity of the sources, evolution and impact of infectious diseases in society. The contemporary science has new or relatively unexplored problems that continually emerge and have to explained and/or solved in society, such as Coronavirus disease 2019 (COVID-19): a new viral infection that generates a severe acute respiratory syndrome with serious clinical symptoms given by fever, dry cough, dyspnea, and pneumonia and may result in progressive respiratory failure. The COVID-19 produces minor symptoms in most people, but is also the cause of severe respiratory disorders and deaths in society. This novel bat-origin coronavirus, emerged in China in 2019, is an on-going global health problem that is also generating a socioeconomic crisis and negative world economic outlook projections.

In the presence of novel Coronavirus Disease 2019 (COVID-19), environmental, social and medical sciences have to clarify factors determining the diffusion, how to treat patients, effects of public policies to cope with COVID-19 pandemic crisis, etc. Fundamental questions in this research field are: How to stop transmission dynamics of COVID-19 in a short period of time? What is the best strategy to reduce transmission dynamics: does apply a general lockdown, a partial lockdown and interventions to support herd immunity to cope with both infectious disease and socioeconomic issues? How to reduce the impact on public health and economic systems? How to measure risk factors of exposure of specific areas infectious diseases to prevent negative effects of future epidemics similar to COVID-19? And so on. These questions are some of scientific issues that have been inadequately addressed in social studies, yet they offer exciting entry points into the current discussion of these research fields of COVID-19 pandemic. As a matter of fact, understanding the prime factors of transmission dynamics of COVID-19, effects of public policies applied by governments and other problems of this novel Coronavirus are crucial aspects for explaining possible relationships underlying the temporal and spatial diffusion of this viral infectivity. In particular, new results and new knowledge are basic to discover new drugs, to treat patients and design an effective strategy to prevent future epidemics similar to COVID-19 that generates health and socioeconomic issues for nations and globally (Coccia, 2020, 2020a, b, c).

What is already known on these topics is based on some studies from different disciplines. Factors determining the diffusion of epidemics similar to COVID-19 are due to manifold elements, in addition to human-to-human transmission, given by: *General factors* that are the same for all locations and associated with innate biological characteristics of the viruses, incubation time, effects on infected and susceptible people, etc. *Specific factors* that are different for each location and even for each individual, such us level of air pollution of cities, meteorological conditions of specific location, season, density of urban areas, economic wealth, cultural characteristics (religious habits, food culture, etc.), organization and efficiency of healthcare sector, facilities and equipment in health sector, immune system of people, average age of population, sex of people, etc. (Coccia, 2020). The diffusion of COVID-19 and other similar infectious diseases is also due to more infected individuals that arrive in international locations before control measures are applied, generating numerous epidemic chains with new outbreaks in different nations worldwide Currently, as people with the COVID-19 infection arrive in countries or regions with low ongoing transmission, efforts should be done to stop transmission, prevent potential outbreaks and to avoid new waves of COVID-19 epidemic (European Centre for Disease Prevention and Control, 2020, 2020a). Wells *et al*. (2020) argue that at the very early stage of the epidemic, reduction in the rate of exportation could delay the importation of cases into cities or nations unaffected by the COVID-19, to gain time to coordinate an appropriate public health response. After that, rapid contact tracing is basic within the epicentre and within and between importation cities to limit human-to-human transmission outside of outbreak countries, also applying appropriate isolation of cases (Wells *et al*., 2020). The case of severe acute respiratory syndrome outbreak in 2003 started in southern China was able to be controlled through tracing contacts of cases because the majority of transmission occurred after symptom onset. These interventions also play a critical role in response to outbreaks where onset of symptoms and infectiousness are concurrent, such as Ebola virus disease (Swanson *et al*., 2018; WHO, 2020), MERS (Kang *et al*., 2016, Public Health England, 2019) and other viral diseases

(Hoang *et al.*, 2019; European Centre for Disease Prevention and Control. 2020a). Kucharski, *et al.* (2020) claim that the isolation of cases and contact tracing can be less effective for COVID-19 because infectiousness starts before the onset of symptoms. Hellewell *et al.* (2020) show that effective contact tracing and case isolation are enough to control a new outbreak of COVID-19 within three months, but the probability of control decreases with long delays from symptom onset to isolation that increase transmission before symptoms. In the presence of COVID19 outbreaks, it is crucial to understand the determinants of the transmission dynamics of this new infectious disease for designing strategies to stop or reduce diffusion, empowering health policy with economic, social and environmental policies.

This book focuses on new studies that investigate the association between infected people and environmental, demographic and geographical factors that can explain transmission dynamics over time, and provide insights into the environmental situation to prevent and apply, *a priori*, appropriate control measures. In particular, studies presented here can explain, whenever possible, factors determining the accelerated viral infectivity in specific regions to guide policymakers to prevent future epidemics similar to COVID-19. A socioeconomic strategy to prevent future epidemics similar to the COVID-19 is also the reduction of air pollution with fruitful environmental and health effect by a perspective of sustainable development, de-industrializing polluting activities in the geographical development of current capitalism. De-industrialization of polluting industries and sustainable development impose often huge social costs in the short term on people, households, and families but they have long-run benefits for human societies. Studies show that public and environmental health policy interventions are necessary and have the potential to reduce morbidity and mortality across

Europe. In fact, the improvements in air quality have been accompanied by demonstrable benefits to human health. Guo *et al.* (2019) argue that in recent years, haze pollution is a serious environmental problem affecting cities, proposing implications for urban planning to improve public respiratory health.

Hence, it is important to reinforce evidence related to air pollution and inter-related factors of the transmission dynamics of virus similar to COVID-19, and helps policy makers to develop proactive regulations for the control of environment, air pollution, polluting industrialization and prevention of the diffusion of viral infectivity.

What this book adds to current studies is that transmission dynamics of COVID-19 may be also given by the mechanism of air pollution-to-human transmission that in addition to human-to-human transmission seems to have accelerated diffusion of epidemics in countries. Moreover, studies presented here show that an accurate comparison of the first and second wave of COVID-19 pandemic suggests how the first one seems to have had a stronger impact on public health, environment and economy. In addition, government responses to cope with the first wave of COVID-19 pandemic, based on national lockdown and quarantine, seem to have lightly constrained the diffusion of COVID-19 but a main indirect positive effect on public health is due to the reduction of concentrations of pollutants that improves air quality. In addition, health policy based on a long period of lockdown during the first wave of COVID-19 pandemic has induced a severe contraction of real GDP growth % in 2020 and likely also 2021. In this context, countries with the on-going COVID-19 pandemic have showed an uncertain governance and an unrealistic optimism about their low vulnerability that new waves of this pandemic cannot hit them. Although the severe impact on public health of the first wave of COVID-19 pandemic, many countries have shown still a low capability of national planning for crisis management adopting ambiguous, delayed and uncertain policy responses in the presence of recurring waves of COVID-19 pandemic crisis. In general, it seems that countries have not used in comprehensive way the process of institutional learning and lessons learned of the effects of first wave of COVID-19 pandemic in society for supporting effective and timely critical decisions to cope with similar problematic situations generated by a new pandemic waves.

In this context it is more and more necessary to provide new knowledge and findings to support policy makers and reduce their bounded rationality to support effective and timely policy responses in the presence of new waves of COVID-19 pandemic and similar epidemics of new viral agents.

The purpose of this book is to provide a collection of new studies to clarify some of the topics just mentioned, focusing on critical aspects of COVID-19 in a interdisciplinarity perspective. The chapters of the book provide results focused on mainly Italy but can be easily generalized in other geo-economic contexts.

In particular, the *first chapter* has two goals. The first is to explain the main factors determining the diffusion of COVID-19 that is generating a high level of deaths. The second is to suggest a strategy to cope with future epidemic threats of accelerated viral infectivity in society. It analyses Italy that was the first European country to experience a rapid increase in confirmed cases and deaths of the novel Coronavirus disease (COVID-19). This study explains how COVID-19 transmitted so rapidly in northern Italy, analysing the underlying relationships between infected people and environmental, demographic, and geographical factors that influenced its spread. This study analyses data on COVID-19 cases alongside environmental data. This study finds out that cities with little wind, high humidity and frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — had higher numbers of COVID-19 related infected individuals and deaths. Overall, then, results here suggest that that geo-environmental factors may have accelerated the spread of COVID-19 in Northern Italian cities, leading to a higher number of infected individuals and deaths.

The *second chapter* endeavours to explain how wind speed can affect the diffusion of COVID-19 pandemic. The statistical analysis, based on data from Italy, suggests that high wind speed can reduce air pollution commingled with viral agents and as a consequence reduce infected individuals of COVID-19; moreover, results reveal that polluted cities with low wind speed have a greater number of infected individuals and total deaths also because of bad air quality. This study suggests the important role of atmospheric pollution and atmospheric circulation in the transmission dynamics of the novel Coronavirus to support appropriate environmental policy to reduce concentration of pollutants in the atmosphere, improving air quality and human health mainly in urban areas.

The *third chapter* investigates the relation between diffusion of COVID-19 and wind resources to provide insights on how sustainable policies for energy production can improve ecosystem, reduce environmental pollution, enhance public health and prevent future infectious diseases. Results reveal that cities in regions with high wind energy production have a lower number of infected individuals of COVID-19, whereas polluted cities with less clean production and low production of energy from sustainable resources (e.g., wind) have higher numbers of infected individuals and deaths. These findings underscore the importance of sustainable energy production to support an ecosystem that protects human health and reduces the associated social welfare loss because of the COVID-19 pandemic and future similar infectious diseases.

The *fourth chapter* analyses first and second wave of COVID-19 pandemic in one of largest European countries, Italy, to show how the first wave of COVID-19 pandemic had a high negative effect on public health that reduced intensity with the summer season and with containment policies; second wave of the COVID-19 pandemic, from August 2020, has increasing confirmed cases but general impact in society seems to be of a lower intensity. This study can support best practices of crisis management to cope with future recurring waves the COVID-19 pandemic and similar epidemics.

The *fifth chapter* analyses impact of COVID-19 pandemic on public health according to public policies applied by governments and directed to longer and shorter period of national lockdown during the first wave of COVID-19. Results show that. a) countries with shorter period of lockdown have a variation of confirmed cases/population (%) higher than countries with longer period of lockdown; b) countries with shorter period of lockdown have average fatality rate lower than countries with longer period of lockdown, whereas variation of fatality rate suggests a higher reduction in countries with longer period of lockdown. However, the study reveals that the impact of longer period of national lockdown, as policy response of governments against COVID-19 pandemic, seems to generate rather ambiguous effects on public health; however, longer period of lockdown to cope with COVID-19 pandemic has a higher negative impact on economic growth of countries in terms of contraction of gross domestic product (GDP) growth. Lessons learned can be important to design effective public responses for future waves of the COVID-19 and future epidemics similar to the COVID-19 to induce benefits of public policies for public health without deteriorating structural indicators of the economic system.

The final part of the book explains some approaches to prevent future epidemics similar to COVID-19 and support appropriate policy responses and strategies in contexts of crisis management.

Chapter six suggests a new index that measures the environmental risk of exposure of cities to future waves of COVID-19 pandemic and epidemics of similar vital agents. The proposed index combines environmental, socioeconomic and health risk factors of cities to assess their vulnerability to the diffusion of infectious diseases. The statistical evidence seems in general to support the predictive results of the index in assessing the risk of exposure of cities to the spread of infectious diseases. The metrics here can be important to help policymakers in decision making to constrain new waves of the COVID-19 and/or diffusion of new infectious diseases similar to COVID-19 with appropriate control measures on environment and socioeconomic system.

To conclude, the final *Chapter seven* explains some approaches related to support decision making for crisis management to cope with issues discussed in this book. This chapter provides a simple description related to techniques of decision support in different environments/conditions and how that process is influenced by manifold social, economic and/or technical factors; ultimately introduce the approach of improvisation that can be used to guide and improve decision-making to cope with unforeseen and new events, rapid changes, turbulent environment and/or specific situations of emergency.

Overall, then, the studies presented in this book show that evolution and effects of novel infectious diseases are due to manifold factors. Social studies, like the present book, are more and more a vital research field that can complement studies of biology and medicine in contexts of interdisciplinary perspective that can explain critical relationships underlying infectious diseases in interaction with environment and society and how novel diseases affect economy and society.

This book endeavours to clarify these challenges that can help policy makers to develop proactive regulations for the control of environment, air pollution, polluting industrialization for a sustainable environment that reduces risk factors associated with future epidemics similar to the COVID-19.

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1 How do environmental, demographic, and geographical factors influence the spread of COVID-19?

Introduction

This chapter has two goals. The first is to explain the main factors determining the diffusion of COVID-19 that is generating a high level of deaths. The second is to suggest a strategy to cope with future epidemic threats with of accelerated viral infectivity in society.

Coronavirus disease 2019 (COVID-19) is viral infection that generates a severe acute respiratory syndrome with serious clinical symptoms given by fever, dry cough, dyspnea, and pneumonia and may result in progressive respiratory failure and death. Kucharski *et al.* (2020) argue that COVID-19 transmission declined in Wuhan (China) during late January, 2020 (WHO, 2019, 2020, 2020a; nCoV-2019 Data Working Group, 2020). However, as more infected individuals arrive in international locations before control measures are applied, numerous epidemic chains have led to new outbreaks in different nations worldwide (Xu & Kraemer Moritz, 2020; Wang *et al.*, 2020; Wu *et al.*, 2020). An outbreak of COVID-19 has led to more than 13,900 confirmed deaths in Italy and more than 51,000 deaths worldwide as of April 1st, 2020 (Johns Hopkins Center for System Science and Engineering, 2020; cf., Dong *et al.*, 2020). Understanding the prime factors of transmission dynamics of COVID-19 in Italy, having the highest number of deaths worldwide, is crucial for explaining possible relationships underlying the temporal and spatial aspects of the diffusion of this viral infectivity. Results here are basic to design a strategy to prevent future epidemics similar to COVID-19 that generates health and socioeconomic issues for nations and globally.

Currently, as people with the COVID-19 infection arrive in countries or regions with low ongoing transmission, efforts should be done to stop transmission, prevent potential outbreaks and to avoid second and subsequent waves of a COVID-19 epidemic (European Centre for Disease Prevention and Control, 2020; Quilty & Clifford, 2020; Wells *et al.*, 2020). Wells *et al.* (2020) argue that at the very early stage of the epidemic, reduction in the rate of exportation could delay the importation of cases into cities or nations unaffected by the COVID-19, to gain time to coordinate an appropriate public health response. After that, rapid contact tracing is basic within the epicentre and within and between importation cities to limit human-to-human transmission outside of outbreak countries, also applying appropriate isolation of cases (Wells *et al.*, 2020). The case of severe acute respiratory syndrome outbreak in 2003 started in southern China was able to be controlled through tracing contacts of cases because the majority of transmission occurred after symptom onset (Glasser *et al.*, 2011). These interventions also play a critical role in response to outbreaks where onset of symptoms and infectiousness are concurrent, such as Ebola virus disease (WHO, 2020b; Swanson *et al.*, 2018), MERS (Public Health England, 2019; Kang *et al.*, 2016) and other viral diseases (Hoang *et al.*, 2019; European Centre for Disease Prevention and Control. 2020a). Kucharski, *et al.* (2020) claim that the isolation of cases and contact tracing can be less effective for COVID-19 because infectiousness starts before the onset of symptoms (cf., Fraser *et al.*, 2004; Peak *et al.*, 2017). Hellewell *et al.* (2020) show that effective contact tracing and case isolation is enough to control a new outbreak of COVID-19 within 3 months, but the probability of control decreases with long delays from symptom onset to isolation that increase transmission before symptoms. However, it is unclear if these efforts will achieve the control of transmission of COVID-19. In the presence of COVID19 outbreaks, it is crucial to understand the determinants of the transmission dynamics of this viral infectious disease for designing strategies to stop or reduce diffusion, empowering health policy with economic, social and environmental policies. This study focuses on statistical analyses of association between infected people and environmental, demographic and geographical factors that can explain transmission dynamics over time, and provide insights into the environmental situation to prevent and apply, *a priori*, appropriate control measures (Camacho, *et al.*, 2015; Funk *et al.*, 2017; Riley *et al.*, 2003). In particular, this study here can explain, whenever possible, factors determining the accelerated viral infectivity in specific regions to guide policymakers to prevent future epidemics similar to COVID-19 (Cooper *et al.*, 2006; Kucharski *et al.*, 2015). However, there are several challenges to such studies, particularly in real time. Sources may be biased, incomplete, or only capture certain aspects of the on-going outbreak dynamics.

Data and study design

The complex problem of viral infectivity of COVID-19 is analysed here in a perspective of reductionist approach, considering the geo-environmental and demographic factors that we study to explain the relationships supporting the transmission dynamics (cf., Linstone, 1999). In addition, the investigation of the causes of the accelerated diffusion of viral infectivity is done with a philosophical approach *sensu* the philosopher Vico (Flint, 1884). In particular, the method of inquiry is also based on Kantian approach in which theoretical framework and empirical data complement each other and are inseparable. In this case the truth on this phenomenon, transmission dynamics of COVID-19, is a result of synthesis (Churchman, 1971).

Data and their sources

This study focuses on N=55 Italian cities that are provincial capitals. Sources of data are The Ministry of Health in Italy for epidemiological data (Ministero della Salute, 2020), Legambiente (2019) for data of air pollution deriving from the Regional Agencies for Environmental Protection in Italy, il Meteo (2020) for data of weather trend based on meteorological stations of Italian province capitals, The Italian National Institute of Statistics for density of population concerning cities under study (ISTAT, 2020).

Measures

The unit of analysis is main Italian provincial cities. In a perspective of reductionism approach for statistical analysis and decision making, this study focuses on the following measures.

- Pollution: total days exceeding the limits set for PM_{10} (particulate matter 10 micrometres or less in diameter) or for ozone in the 55 Italian provincial capitals over 2018. This measure is stable over time and the strategy of using the year 2018, before the COVID-19 outbreak in Italy, is to include the health effects of exposures to pollutants, such as airborne particulate matter and ozone (Brunekreef *et al.*, 2002). In fact, days of air pollution within Italian cities are a main factor that has affected health of population and environment (Legambiente, 2019).

- Diffusion of COVID19. Number of infected from 17 March, 2020 to April 2020 (Ministero della Salute, 2020). Infected are detected with COVID-19 tests according to following criteria:
  - Have fever or lower respiratory symptoms (cough, shortness of breath) and close contact with a confirmed COVID-19 case within the past 14 days; OR
  - Have fever and lower respiratory symptoms (cough, shortness of breath) and a negative rapid flu test
- Meteorological indicators are: average temperature in °C, Moisture %, wind km/h, days of rain and fog from 1st February to 1 April, 2020 (il Meteo, 2020).
- Interpersonal contact rates: a proxy here considers the density of cities (individual /km^2) in 2019 (ISTAT, 2020).

i.

ii.2.3. Data analysis and procedure

This study analyses a database of *N*=55 Italian provincial capitals, considering variables in 2018-2019-2020 to explain the relationships between diffusion of COVID19, demographic, geographical and environmental variables.

Firstly, preliminary analyses of variables are descriptive statistics based on mean, std. deviation, skewness and kurtosis to assess the normality of distributions and, if necessary to fix distributions of variables with a *log*-transformation.

Statistical analyses are also done categorizing Italian provincial capitals (*N*=55) in groups as follows:

- Hinterland cities
- Coastal cities

Categorization in:

- Windy cities
- Not windy cities

Categorization in:

- Cities of North Italy
- Cities of Central-South Italy

Categorization in:

- Cities with >100 days per year exceeding the limits set for PM_{10} or for ozone
- Cities with <100 days per year exceeding the limits set for PM_{10} or for ozone

Categorization in:

- Cities with ≤1000 inhabitant/km^2
- Cities with > 1000 inhabitant/km^2

Categorization in:

- Cities with ≤500 inhabitant/km^2
- Cities with 500-1500 inhabitant/km^2
- Cities with >1500 inhabitants/km^2

Secondly, the bivariate and partial correlation verifies relationships (or associations) between variables understudy, and measures the degree of association. After that the null hypothesis (H_0) and alternative hypothesis (H_1) of the significance test for correlation is computed, considering two-tailed significance test.

Thirdly, the analysis considers the relation between independent and dependent variables. In particular, the dependent variable (number of infected people across Italian provincial capitals) is a linear function of a single explanatory variable given by total days of exceeding the limits set for PM_{10} across Italian province capitals. Dependent variables have in general *a lag of 1 years* in comparison with explanatory variables to consider temporal effects of air pollution predictor on environment and population in the presence of viral infectivity by COVID19 in specific cities of Italy.

The specification of the linear relationship is a *log-log* model is:

$$\log y_t = \alpha + \beta \log x_{t-1} + u \qquad (1)$$

α is a constant; β= coefficient of regression; u= error term

y = dependent variable is number of infected individuals in cities

x =explanatory variable is a measure of air pollution, given by total days of exceeding the limits set for PM_{10} or ozone in cities

This study extends the analysis with a multiple regression model to assess how different indicators can affect diffusion of COVID-19. The specification of the linear relationship is also a *log-log* model as follows:

$$\log y_t = \alpha + \beta_1 \log x_{1,t-1} + \beta_2 \log x_{2,t-1} + u \qquad (2)$$

y = dependent variable is number of infected individuals in cities

x_1 =explanatory variable is a measure of air pollution, given by total days of exceeding the limits set for PM_{10} or ozone in cities

x_2 = density of cities, inhabitants /km^2

In addition, equation [2] is performed using data of infected at t=17th March, 2020 in the starting phase of growth of the outbreak in Italy, and the at $t+16days$= 1st April, 2020 in the phase of maturity of viral infectivity during lockdown and quarantine to assess the magnitude of two explanatory variables in the transmission dynamics of COVID-19. The estimation of equation [2] is also performed using hierarchical multiple regression, a variant of the basic multiple regression procedure that allows to specify a fixed order of entry for variables in order to control for the effects of covariates or to test the effects of certain predictors independent of the influence of others. The R^2 changes are important to assess the predictive role of additional variables. The adjusted R-square and standard error of the estimate are useful as comparative measures to assess results between models. The *F*-test evaluates if the regression model is better than using only the mean of the dependent variable. If the *F* value is very small (e.g., 0.001), then the independent variables reliably predict the dependent variable.

Moreover, the linear relationship is also specified with a quadratic model as follows:

$$y_t = \alpha + \beta\, x_{t-1} + \beta\, (x_{t-1})^2 + u \qquad (3)$$

the goal is to apply an optimization approach, to calculate the minimum of equation [3] that suggests the maximum number of days in which cities can exceed the limits set for PM_{10}. or ozone. Beyond this critical estimated limit, there are environmental inconsistencies of air pollution associated with meteorological conditions that can trigger a take-off of viral infectivity with damages for health of population and economic system (cf., Coccia, 2017c, 2017d). The max number of days in which cities can exceed the limit set for air pollution that minimizes the number of people infected, before the take-off of epidemic curve, can also suggest implications of proactive strategies and critical decision to cope with future epidemics similar to COVID-19 in society. Ordinary Least Squares (OLS) method is applied for estimating the unknown parameters of relations in linear regression models [1-3]. Statistical analyses are performed with the Statistics Software SPSS® version 26.

Results

Descriptive statistics of variables in *log* scale, based on

Italian province capitals (N=55), have normal distribution to apply appropriate parametric analyses.

Table 1. *Descriptive statistics of Hinterland and Coastal Italian province capitals*

	Days exceeding imits set for PM_{10} or ozone 2018	Infected 17th March 2020	Infected 1st April 2020	Density inhabitants/km² 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020	Rain Days Feb-Mar 2020	Fog Days Feb-Mar 2020
Hinterland cities N=45									
Mean	80.40	497.00	1929.69	1480.11	9.11	68.31	8.02	4.81	4.14
Std. Deviation	41.66	767.19	2265.86	1524.25	2.20	7.68	3.69	2.38	3.13
Coastal cities N=10									
Mean	59.40	171.30	715.80	1332.80	10.61	74.40	11.73	5.10	3.25
Std. Deviation	38.61	164.96	522.67	2463.04	2.20	7.38	2.60	2.71	3.68

Table 1 shows that hinterland cities have and average higher level of infected individuals than coastal cities. Hinterland cities have also a higher air pollution (average days per years) than coastal cities, in a context of meteorological factors of lower average temperature, lower average wind speed, lower rain days and lower level of moisture % than coastal cities.

Table 2. *Descriptive statistics of windy and not windy of Italian province capitals*

	Days exceeding limits set for PM_{10} or ozone 2018	Infected 17th March 2020	Infected 1st April 2020	Density inhabitants/km² 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020	Rain Days Feb-Mar 2020	Fog Days Feb-Mar 2020
Low windy cities N=41									
Mean	84.32	536.20	2036.15	1517.41	9.05	68.23	7.30	4.56	4.18
Std. Deviation	43.31	792.84	2333.72	1569.70	2.12	7.50	2.77	2.33	2.94
High windy cities N=14									
Mean	53.93	149.57	750.86	1265.64	10.36	72.89	12.77	5.75	3.39
Std. Deviation	25.87	153.55	640.02	2108.31	2.43	8.37	3.46	2.56	4.00

Table 2 shows that cities with low intensity of wind speed (7.3km/h) have and average higher level of infected individuals than windy cities (average of 12.77km/h). Cities with lower intensity of wind speed have also a higher level of air pollution (average days per years), in a meteorological context of lower average temperature, lower rain days, lower level of moisture % and a higher average days of fog.

Table 3. *Descriptive statistics of Northern and Central-Southern Italian province capitals*

	Days exceeding limits set for PM_{10} or ozone 2018	Infected 17th March 2020	Infected 1st April 2020	Density inhabitants/km² 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020	Rain Days Feb-Mar 2020	Fog Days Feb-Mar 2020
Norther cities N=45									
Mean	80.51	515.60	1968.42	1448.00	9.05	69.40	7.89	4.80	4.31
Std. Deviation	42.67	759.18	2230.43	1538.10	1.97	7.61	3.15	2.42	3.06
Central-Southern cities N=10									
Mean	58.90	87.60	541.50	1477.30	10.88	69.50	12.31	5.15	2.50
Std. Deviation	32.36	129.98	735.21	2424.50	2.92	9.64	4.44	2.52	3.65

Table 3 shows that cities in the central and southern part of Italy have, during the COVID-19 outbreak, a lower number of infected than cities in North Italy. This result is in an environment with lower air pollution (average days per years), higher average temperature, higher average wind speed, higher rain days and lower level of moisture %.

Table 4. *Descriptive statistics of Italian provincial capitals according to days exceeding the limits set for PM_{10}*

	Days exceeding	Infected 17th	Infected 1st April	Density inhabitants/	Temp °C	Moisture	Wind km/h	Rain Days	Fog Days

	limits set for PM_{10} or ozone 2018	March 2020	2020	km² 2019	Feb-Mar 2020	% Feb-Mar 2020	Feb-Mar 2020	Feb-Mar 2020	Feb-Mar 2020
Cities with >100days exceeding limits set for PM_{10} *N=20*									
Mean	125.25	881.70	3124.75	1981.40	9.19	71.30	7.67	4.80	4.88
Std. Deviation	13.40	1010.97	2905.18	1988.67	1.46	7.63	2.86	2.57	2.65
Cities with <100days exceeding limits set for PM_{10} *N=35*									
Mean	48.77	184.11	899.97	1151.57	9.49	68.34	9.28	4.90	3.47
Std. Deviation	21.37	202.76	708.32	1466.28	2.62	7.99	4.15	2.37	3.44

Table 4 confirms previous results considering cities with >100days exceeding limits set for PM_{10} or ozone: they have, *versus* cities with less than 100 days, a very high level of infected individuals, in an environment of higher average density of population, lower average intensity of wind speed, lower average temperature with higher average moisture % and days of fog.

Table 5. *Descriptive statistics of Italian provincial capitals according to density per km² (2 categories)*

	Days exceeding limits set for PM_{10} or ozone 2018	Infected 17th March 2020	Infected 1st April 2020	Density inhabitants/km² 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020	Rain Days Feb-Mar 2020	Fog Days Feb-Mar 2020
Cities with ≤1000 inhabitant/km² *N=30*									
Mean	64.37	248.37	960.97	510.77	10.01	69.61	9.28	4.08	3.75
Std. Deviation	39.25	386.95	951.26	282.11	1.95	10.30	4.41	2.37	3.40
Cities with >1000 inhabitant/km² *N=25*									
Mean	91.24	665.08	2606.60	2584.40	8.63	69.19	7.99	5.80	4.26
Std. Deviation	40.24	919.70	2717.57	2000.63	2.40	3.59	2.79	2.17	3.03

Table 6. *Descriptive statistics of Italian provincial capitals according to density per km² (3 categories)*

	Days exceeding limits set for	Infected 7th March 2020	Infected 1st April 2020	Density nhabitants/km² 2019	Temp °C Feb-	Moisture % Feb-Mar	Wind km/h Feb-	Rain Days Feb-	Fog Days Feb-

	PM_{10} or ozone 2018				Mar 2020	2020	Mar 2020	Mar 2020	Mar 2020
Cities with <1000 inhabitant/km^2 *N=17*									
Mean	52.82	116.12	567.12	312.76	9.88	71.12	9.52	4.44	4.41
Std. Deviation	36.87	128.13	466.49	161.34	2.12	8.91	5.73	2.79	3.79
Cities with 500-1000 inhabitant/km^2 *N=22*									
Mean	84.32	430.91	1519.50	951.32	9.04	68.50	8.37	4.34	3.75
Std. Deviation	37.28	476.29	1018.07	277.77	2.65	9.17	2.33	2.06	2.99
Cities with >1000 inhabitant/km^2 *N=16*									
Mean	91.19	789.00	3182.75	3355.44	9.33	68.86	8.26	6.03	3.84
Std. Deviation	43.29	1103.03	3239.96	2151.27	1.81	4.32	2.79	2.19	3.03

Tables 5-6 show results considering categorization of cities per density of population/km^2. Results reveal that average number of infected individuals increases with average density of people/km^2, but with an arithmetic growth, in comparison to geometric growth of number of infected individuals with other categorizations of cities. These findings suggest that density of population per km^2 is important for transmission dynamics but other factors may support acceleration of viral infectivity by COVID-19 rather than high probability of interpersonal contacts in cities.

In short, results suggest that among Italian province capitals:

- Number of infected people is HIGHER in: Cities with >100days exceeding limits set for PM_{10} or ozone, located in hinterland zones having a low average intensity of wind speed and lower temperature in °C.

Table 7. *Correlation*

N=55	*Log* Days exceeding limits set for PM_{10} or ozone	*Log* Density inhabitants/km^2 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020

	2018				
Log Infected 17 March, 2020					
Pearson Correlation	.643**	.484**	-.117	.005	–.377**
Sig. (2-tailed)	.001	.001	.397	.970	.005
N=55	Days exceeding limits set for PM_{10} or ozone 2018	Density inhabitants/km^2 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020
Log Infected 1 April, 2020					
Pearson Correlation	.620**	.552**	–0.247	0.049	–0.281*
Sig. (2-tailed)	0.001	0.001	0.069	0.720	0.038

Note: **. Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Table 7 shows association between variables on 17th March and 1st April, 2020: a correlation higher than 62% (*p*-value<.001) is between air pollution and infected individuals, a lower coefficient of correlation is between density of population and infected individuals (r=48-55%, *p*-value<.001). Results also show a negative correlation between number of infected individuals and intensity of wind speed among cities (r= –28 to –38%, *p*-value <0.05): this effect is due to the role of wind speed that cleans air from pollutants that are associated with transmission dynamics of viral infectivity.

Table 8. *Partial Correlation*

Control Variables Temp °C Moisture % Wind km/h Feb-Mar 2020	*Pearson Correlation*	*Log* Infected 17 March, 2020	*Log* Infected 1 April , 2020
	Log Days exceeding limits set for PM_{10} or ozone 2018	0.607	.602
	Sig. (2-tailed)	.001	.001
	N	50	50

Table 8 confirms the high correlation between air pollution and infected individuals on 17th March and 1 April, 2020, controlling meteorological factors of cities under study (r>60%, *p*-value<.001).

Table 9. *Partial Correlation*

Control Variables *Log* Density inhabitants/km^2 2019	*Pearson Correlation*	*Log* Infected 17 March, 2020	*Log* Infected 1 April, 2020
	Log Days exceeding limits set for PM_{10} or ozone 2018	0.542	.496
	Sig. (2-tailed)	.001	.001
	N	52	52
Control Variables *Log* Days exceeding limits set for PM_{10} or ozone 2018	*Pearson Correlation*	Log Infected 17 March, 2020	Log Infected 1 April, 2020
	Log Density inhabitants/km^2 2019	0.279	.385
	Sig. (2-tailed)	.041	.004
	N	50	50

Partial correlation in table 9 suggests that controlling density of population on 17th march and 1st April 2020, number of infected people is associated with air pollution (r≥50%, p-value<.001), whereas, controlling air pollution the correlation between density of population in cities and infected individuals is lower (r=27-38%, p-value<.001). The reduction of r between infected individuals and air pollution from 17th March to 1st April, and the increase of the association between infected people and density of people in cities over the same time period, controlling mutual variables, suggests that that air pollution in cities seems to be a more important factor in the initial phase of transmission dynamics of COVID-19 (i.e., 17th March, 2020). In the phase of the maturity of transmission dynamics (1st April, 2020), with lockdown that reduces air pollution, the role of air pollution reduces intensity whereas human-to-human transmission increases.

Table 10. *Parametric estimates of the relationship of Log Infected 17 March and 1 April on Log Days exceeding limits set for PM_{10} and Log Density inhabitants/km^2 2019 (hierarchical regression)*

	Model 1A	Model 2A,		Model 1B	Model 2B,

	Step 1: Air pollution	*Step 2: Interpersonal contacts*			*Step 1: Air pollution*	*Step 2: Interpersonal contacts*	
	log Days exceeding limits set for PM_{10}, 2018	*log* Days exceeding limits set for PM_{10}, 2018	*Log* Density inhabitants/km^2 2019		*log* Days exceeding limits set for PM_{10}, 2018	*log* Days exceeding limits set for PM_{10}, 2018	*Log* Density inhabitants/km^2 2019
log infected 17th March, 2020				*log* infected 1st April, 2020			
Constant α	-1.168		–2.168	Constant α	2.171**		1.089
(St. Err.)	(1.053)		(1.127)	(St. Err.)	(.827)		(.851)
Coefficient β 1	1.526***		1.266***	Coefficient β 1	1.129***		.847***
(St. Err.)	(0.250)		(.272)	(St. Err.)	(.196)		(.206)
Coefficient β 2			.309*	Coefficient β 2			.335**
(St. Err.)			(.148)	(St. Err.)			(.111)
F	37.342***b		22.059***c	*F*	33.158***b		23.604***c
R^2	0.413		0.459	R^2	.385		.476
ΔR^2.	0.413		0.046	ΔR^2.	.385		.091
ΔF	37.342***		4.388*	ΔF	33.158***		9.028**

Notes: *** *p*-value<0.001; ** *p*-value<0.01; * *p*-value<0.05; b= predictors: *log* Days exceeding limits set for PM_{10}; c= predictors: *log* Days exceeding limits set for PM_{10}, 2018 year; *Log* Density inhabitants/km^2 2019

These findings are confirmed with hierarchical regression that also reveals how air pollution in cities seems to be a driving factor of transmission dynamics in the growing phase of CIVID-19 (17th March, 2020). In the phase of the maturity of transmission dynamics (1st April, 2020), the determinant of air pollution is important to support infected population but reduces intensity, whereas the factor of human-to-human transmission increases, *ceteris paribus* (Table 10). This result reveals that transmissions dynamics of COVID-19 is due to human-to-human transmission but the factor of air pollution-to-human transmission of viral infectivity supports a substantial growth.

Table 11. *Parametric estimates of the relationship of Log Infected 1st April,2020 on Log Density inhabitants/km² 2019, considering the groups of cities with days exceeding limits set for PM10 or ozone*

	Model cities with <100 days exceeding limits set for PM_{10} or ozone, 2018		Model cities with >100 days exceeding limits set for PM_{10} or ozone, 2018
↓DEPENDENT VARIABLE	*Log* Density inhabitants/km^2 2019	↓DEPENDENT VARIABLE	*Log* Density inhabitants/km^2 2019

log infected		*log* infected	
1 April, 2020		1 April, 2020	
Constant α	4.501	Constant α	1.425
(St. Err.)	(.801)	(St. Err.)	(1.624)
Coefficient $\beta 1$	0.303*	Coefficient $\beta 1$	0.856***
(St. Err.)	(0.122)	(St. Err.)	(0.223)
R^2 (St. Err. of Estimate)	0.158 (.828)	R^2 (St. Err. of Estimate)	0.450(.803)
F	6.207*	*F*	14.714***

Note: Explanatory variable: *Log* Density inhabitants/km² in 2019; *** *p*-value<0.001; * *p*-value<0.05

Table 11 shows results of the transmission dynamics of COVID-19 considering the interpersonal contacts, measured with density of population in cities understudy. In short, results suggest that density of population explains the number of infected individuals, increasing the probability of human-to-human transmission. However, if we decompose the sample to consider the cities with ≤100 days exceeding limits set for PM_{10} or ozone and with >100 days exceeding limits set for PM_{10} or ozone, then the expected increase of number of infected individuals is higher in cities having more than 100 days exceeding limits set for PM_{10} or ozone. In particular,

- Cities with ≤100 days exceeding limits set for PM_{10}, an increase of 1% in density of population, it increases the expected number of infected by about 0.30%
- Cities with >100 days exceeding limits set for PM_{10}, an increase of 1% in density of population, it increases the expected number of infected by about 1.43%!

The statistical output of table 11 is schematically summarized as follows:

	Cities with ≤100 days exceeding limits set for PM_{10}	Cities with >100 days exceeding limits set for PM_{10}
Density of population	0.30 (p<0.05)	1.43 (p<0.001)
F	6.207 (p<0.05)	14.714 (p<0.001)
R^2	15.8%	45%

In short, the coefficient of regression in cities with >100 days exceeding limits set for PM_{10} is much bigger than the coefficient in cities with ≤100 days exceeding limits set for PM_{10}, suggesting that air pollution-to-human transmission is definitely important to explain the transmission dynamics of COVID-19. The policy implications here are clear: COVID-19 has reduced transmission dynamics on population in the presence of lower level of air pollution and specific environments with lower intensity of wind speed. Hence, the effect of accelerated transmission dynamics of COVID-19 cannot be explained without accounting for the level of air pollution and geo-environmental conditions of the cities.

Table 12. *Parametric estimates of the relationship of Infected 1st April, 2020 on days exceeding limits set for PM_{10} (simple regression analysis, quadratic model)*

Response variable: Infected 1 April, 2020				
Explanatory variable	B	St. Err.	R^2 (St. Err. of the Estimate)	*F* (sign.)
Days exceeding limits set for PM_{10}	–35.32	32.26	0.38 (1693.91)	15.89(0.001)
(Days exceeding limits set for PM_{10}) ^{2}	0.39*	0.194		
Constant	1438.81	1080.89		

Note: * *p*-value=0.057

A main question for environmental policy is: What is the maximum number of days in which cities can exceed the limits set for PM_{10} or ozone per year, before that the combination between air pollution and meteorological condition triggers a take-off of viral infectivity (epidemic diffusion) with damages for health of population and economy in society?

The function based on table 12 is:

$y = 1438.808–35.322\,x+0.393\,x^2$

y = number of infected individuals 1st April, 2020

x= days exceeding limits of PM_{10} or ozone in Italian provincial capitals

The minimization is performed imposing first derivative equal to zero.

$Dy / x = y' = -35.322 + 0.786x = 0$

$x = 35.32/0.786 = 44.94 \sim 45$ *days* exceeding limits of PM_{10} or ozone in Italian provincial capitals.

This finding suggests that the max number of days in which Italian provincial capitals can exceed per year the limits set for PM_{10} (particulate matter 10 micrometres or less in diameter) or for ozone, considering the meteorological condition is about 45 days. Beyond this critical point, the analytical and geometrical output suggests that environmental inconsistencies because of the combination between air pollution and meteorological conditions trigger a take-off of viral infectivity (epidemic diffusion) with damages for health of population and economy in society.

Discussion

Statistical analyses for *N*=55 Italian provincial capitals confirm the significant association between high diffusion of viral infectivity and air pollution. Studies show that the diffusion of viral infectivity depends on the interplay between host factors and the environment (Neu & Mainou, 2020). In this context, it is critical to understand how air quality can affect viral dissemination at national and global level (Das & Horton, 2017). Many ecological studies have examined the association between the incidence of invasive pneumococcal disease and respiratory virus circulation and various climatic factors (McCullers, 2006; Jansen *et al.*, 2008). These studies show that in temperate climates, the epidemiology of invasive pneumococcal disease has a peak incidence in winter months (Dowell *et al.*, 2003; Kim *et al.*, 1996; Talbot *et al.* 2005). Brunekreef & Holgate (2002) argue that, in addition to climate factors, the health effects of air pollution have been subject to intense investigations in recent years. Air pollution is ubiquitous in manifold urban areas worldwide of developed and developing nations. Air pollution has gaseous components and particulate matter (PM). The former includes ozone (O_3), volatile organic compounds (VOCs), carbon monoxide (CO) and nitrogen oxides (NO_x) that generate inflammatory stimuli on the respiratory tract (Glencross *et al.,* 2020). Of these pollutants, PM has a complex composition that includes metals, elemental carbon and organic carbon (both in hydrocarbons and peptides), sulphates and nitrates, etc. (Ghio *et al.,* 2012; Wooding *et al.,* 2019).

Advanced countries, such as in Europe, have more and more smog because of an unexpected temperature inversion, which trap emissions from the city's coal-burning heating stoves and diesel powered buses near ground-level in winter. The ambient pollution mixes with moisture in the air to form a thick, foul-smelling fog that affect the health of people in the city (Wang *et al.,* 2016; Bell *et al.,* 2004). The exposure to pollutants, such as airborne particulate matter and ozone, generates respiratory and cardiovascular diseases with increases in mortality and hospital admissions (cf., Langrish & Mills, 2014). Wei *et al.* (2020) analyse the effect of heavy aerosol pollution in northern China–characterized by long-duration, high $PM_{2.5}$ concentrations and wide geographical coverage– that impacts on environmental ecology, climate change and public health (cf., Liu *et al.,* 2017, 2018; Jin *et al.,* 2017). The biological components of air pollutants and bio aerosols also include bacteria, viruses, pollens, fungi, and animal/plant fragments (Després *et al.,* 2012; Fröhlich-Nowoisky *et al.,* 2016; Smets *et al.,* 2016). Studies show that during heavy aerosol pollution in Beijing (China), 50%-70% of bacterial aerosols are in sub micrometre particles, 0.56-1 mm (Zhang *et al.,* 2019; cf., Zhang *et al.,* 2016). As bacteria size typically ranges from 0.5 to 2.0 mm (Després *et al.,* 2012), they can form clumps or attach to particles and transport regionally between terrestrial, aquatic, atmospheric and artificial ecosystems (Smets *et al.,* 2016). Moreover, because of regional bio aerosol transportation, harmful microbial components, bacterial aerosols have dangerous implications on human health and also plantation (cf., Van Leuken *et al.,* 2016). Harmful bio aerosol components–including pathogens, antibiotic-resistant bacteria, and endotoxins–can cause severe respiratory and cardiovascular diseases in society (Charmi *et al.,* 2018). In fact, the concentration of microbes, pathogens and toxic components significantly increases during polluted days, compared to no polluted days (Liu *et al.,* 2018). In addition, airborne bacterial community structure and concentration varies with pollutant concentration, which may be related to bacterial sources and multiplication in the air (Zhang *et al.,* 2019). Studies also indicate that microbial community composition, concentration, and bioactivity are significantly affected by particle concentration (Liu *et al.,* 2018). To put it differently, the atmospheric particulate matter harbours more microbes during polluted days than sunny or clean days (Wei *et al.,* 2016). These studies can explain one of the driving factors of higher viral infectivity of COVID-19 in the industrialized regions of Nord Italy, rather than other part of Italy (Tables 1-6). In fact, viable bio aerosol particles and high microbial concentration in particulate matter play their non-negligible role during air pollution and transmission of viral infectivity (Zhang *et al.,* 2019). For instance, airborne bacteria in $PM_{2.5}$ from the Beijing-Tianjin-Hebei regions in China revealed that air pollutants are main factors in shaping bacterial community structure (Gao *et al.,* 2017). Xie *et al.* (2018) indicate that total bacteria concentration is higher in moderately polluted air than in clean or heavily polluted air. Liu *et al.* (2018) show that bacterial concentration is low in moderately or heavily pollution in $PM_{2.5}$ and PM_{10}, whereas the pathogenic bacteria concentration is very high in heavy and moderate pollution.

Sun *et al.* (2018) study bacterial community during low and high particulate matter (PM) pollution and find out that predominant species varied with PM concentration. In general, bio aerosol concentrations are influenced by complex factors, such as emission sources, terrain, meteorological conditions and other climate factors (Zhai *et al.,* 2018). Wei *et al.* (2020) also investigate the differences between inland and coastal cities in China (Jinan and Weihai, respectively) to explain the influence of topography, meteorological conditions and geophysical factors on bio aerosol. Results suggest that from clean days to severely polluted days, bacterial community structure is influenced by bacterial adaptation to pollutants, chemical composition of pollutants and meteorological conditions (cf., Sun *et al.,* 2018). Moreover, certain bacteria from Proteobacteria and Deinococcus-Thermus have high tolerance towards environmental stresses and can adapt to extreme environments. As a matter of fact, bacilli can survive to harsh environments by forming spores. Moreover, certain bacteria with protective mechanisms can survive in highly polluted environments, while other bacteria cannot withstand such extreme conditions. In particular, bacteria in the atmosphere to survive must withstand and adapt to ultraviolet exposure, reduced nutrient availability, desiccation, extreme temperatures and other factors. In addition, in the presence of accumulated airborne pollutants, more microorganisms might be attached to particulate matter. Thus, in heavy or severe air pollution, highly toxic pollutants in $PM_{2.5}$ and PM_{10} may inhibit microbial growth. Numerous studies also indicate the role of meteorological conditions in pollution development that creates appropriate conditions for microbial community structure and abundance, and viral infectivity (Jones & Harrison, 2004). Zhong *et al.* (2018) argue that static meteorological conditions may explain the increase of $PM_{2.5}$. In general, bacterial communities during aerosol pollution are influenced by bacterial adaptive mechanisms, particle composition, and meteorological conditions. The particles could also act as carriers, which have complex adsorption and toxicity effects on bacteria (Wei *et al.,* 2020). Certain particle components are also available as nutrition for bacteria and the toxic effect dominates in heavy pollution. The differences in bacterial adaptability towards airborne pollutants cause bacterial survival or death for different species. Groulx *et al.* (2018) argue that microorganisms, such as bacteria and fungi in addition to other biological matter like endotoxins and spores comingle with particulate matter (PM) air pollutants. Hence, microorganisms may be influenced by interactions with ambient particles leading to the inhibition or enhancement of viability and environmental stability (e.g., tolerance to variation in seasonality, temperature, humidity, etc.). Moreover, Groulx *et al.* (2018) claim that in the case of microbial agents of communicable disease, such as viruses, the potential for interactions with pollution may have public health implications. Thus, the variation in bacterial community structure is related to different pollution intensities. Wei *et al.* (2020) show that Staphylococcus increased with $PM_{2.5}$ and became the most abundant bacteria in moderate pollution. In heavy or severe pollution, bacteria, which are adaptable to harsh environments, increase. In moderate pollution, the $PM_{2.5}$ might harbour abundant bacteria, especially genera containing opportunistic pathogens. Therefore, effective measures should control health risks caused by bio aerosols during air pollution, especially for immunocompromised, elderly and other fragile individuals. This may explain the high mortality of certain individuals having previous pathologies because of COVID-19 in Italy that has the mortality rate (the percentage of deaths compared to the total of those who tested positive for COVID-19) of about

80% in individuals aged > 70 years with comorbidities as of April 1st, 2020 (Istituto Superiore Sanità, 2020; cf., WHO, 2020c). Papi *et al.* (2006) also indicate that chronic obstructive pulmonary disease (COPD) was significantly exacerbated by respiratory viral infections that cause reduction of forced expiratory volume in *1s* (FEV1) and airway inflammation (cf., Gorse *et al.*, 2006). Ko *et al.* (2007) report that the most prevalent viruses detected during acute exacerbations of COPD in Hong Kong were the influenza A virus and coronavirus. They indicate that among patients with a mean age of more than 75 years, mean FEV1 was 40% of predicted normal and the FEV1/FVC (forced vital capacity) ratio was reduced to 58% of normal. De Serres *et al.* (2009) also suggested that the influenza virus frequently causes acute exacerbations of asthma and COPD. Moreover, the study by Wei *et al.* (2020) argues that air pollution in coastal city Weihai in China was slightly lower than the inland city of Jinan. This study supports our results that the viral infectivity by COVID-19 is higher in hinterland cities rather than coastal cities in Italy. Wei *et al.* (2020, p.9) also suggest that different air quality strategies should be applied in inland and coastal cities: coastal cities need start bio aerosol risk alarm during moderate pollution when severe pollution occurs in inland cities.

Other studies have reported associations between air pollution and reduced lung function, increased hospital admissions, increased respiratory symptoms and high asthma medication use (Simoni *et al.*, 2015; Jalaludin *et al.*, 2004). In this context, the interaction between climate factors, air pollution and increased morbidity and mortality of people and children from respiratory diseases is a main health issue in society (Darrow *et al.*, 2014). Asthma is a disease that has been associated with exposure to traffic-related air pollution and tobacco smoke (Liao, 2011). Many studies show that exposure to traffic-related outdoor air pollutants (e.g., particulate matter PM_{10} with an aerodynamic diameter ≤10 μm, nitrogen dioxide NO_2, carbon monoxide CO, sulfur dioxide SO_2, and ozone O_3) increases the risk of asthma or asthma-like symptoms (Shankardass *et al.,* 2009; Weinmayr *et al.,* 2010). Especially, current evidence indicates that PM_{10} increases cough, lower respiratory symptoms and lower peak expiratory flow (Ward & Ayres, 2004; Nel, 2005). Weinmayr *et al.* (2010) provide strong evidence that PM_{10} may be an aggravating factor of asthma in children. Furthermore, asthma symptoms are exacerbated by air pollutants, such as diesel exhaust, PM_{10}, NO_2, SO_2, and O_3 and respiratory virus, such as adenovirus, influenza, parainfluenza and respiratory syncytial virus (Jaspers *et al.,* 2005; Murdoch & Jennings, 2009; Murphy *et al.,* 2000; Wong *et al.,* 2009). The study by Liao *et al.* (2011) confirms that exacerbations of asthma have been associated with bacterial and viral respiratory tract infections and air pollution. Some studies have focused on the effect of meteorology and air pollution on acute viral respiratory infections and viral bronchiolitis (a disease linked to seasonal changes in respiratory viruses) in the first years of life (Nenna *et al.,* 2017; Ségala *et al.,* 2008; Vandini *et al.,* 2013, 2015). Carugno *et al.* (2018) analyse respiratory syncytial virus (RSV), the primary cause of acute lower respiratory infections in children: bronchiolitis. Results suggest that seasonal weather conditions and concentration of air pollutants seem to influence RSV-related bronchiolitis epidemics in Italian urban areas. In fact, airborne particulate matter (PM) may influence the children's immune system and foster the spread of RSV infection. This study also shows a correlation between short- and medium-term PM_{10} exposures and increased risk of hospitalization due to RSV bronchiolitis among infants. In short, manifold environmental factors–such as air pollution levels, circulation of respiratory viruses and colder temperatures–induce in longer periods of time spent indoors with higher opportunities for diffusion of infections between people. In fact, in Italy the high diffusion of viral infectivity by COVID-19 in North of Italy is in winter period (February-March, 2020). Studies also show that air pollution is higher during winter months and it has been associated with increased hospitalizations for respiratory diseases (Ko *et al.*, 2007a; Medina-Ramón *et al.*, 2006). Moreover, oscillations in temperature and humidity may lead to changes in the respiratory epithelium which increased susceptibility to infection (Deal *et al.*, 1980). Murdoch & Jennings (2009) correlate the incidence rate of invasive pneumococcal disease (IPD) with fluctuations in respiratory virus activity and environmental factors in New Zealand, showing how incidence rates of IPD are associated with the increased activity of some respiratory viruses and air pollution. Another side effect of air pollution exposure is the association with the incidence of mumps. Hao *et al.* (2019) explore the effects of short-term exposure to air pollution on the incidence of mumps and show that exposure to NO_2 and SO_2 is significantly associated with higher risk of developing mumps. Instead, Yang *et al.* (2020) analyse the relationship between exposure to ambient air pollution and hand, foot, and mouth diseases (in short, HFMDs). Results show that the exposure of people to SO_2, NO_2, O_3, PM_{10} and $PM_{2.5}$ is associated with HFMDs. Moreover, the effect of air pollution in the cold season is higher than in the warm season. Shepherd & Mullins (2019) have also analysed the relationship between arthritis diagnosis in those over 50 and exposure to extreme air pollution in utero or infancy. Results link early-life air pollution exposure to later-life arthritis diagnoses, and suggest a particularly strong link for Rheumatoid arthritis (RA)[1]. Sheperd & Mullins (2019) also

[1] Rheumatoid arthritis is a chronic inflammatory disorder in which the

argue that exposure to smog and air pollution in the first year of life is associated with a higher incidence of arthritis later in life. These findings are important to explain complex relationships between people, meteorological conditions, air pollution and viral infectivity because millions of people continue to be exposed to episodes of extreme air pollution each year in cities around the world.

Air pollution, immune system and genetic damages

The composition of ambient particulate matter (PM) varies both geographically and seasonally because of the mix of sources at any location across time and space. A vast literature shows short-term effects of air pollution on health, but air pollution affects morbidity also in the long run (Brunekreef & Holgate, 2002). The mechanism of damages of air pollution on health can be explained as follows. Air pollutants exert their own specific individual toxic effects on the respiratory and cardiovascular systems of people; in addition, ozone, oxides of nitrogen, and suspended particulates have a common property of being potent oxidants, either through direct effects on lipids and proteins or indirectly through the activation intracellular oxidant pathways (Rahman & MacNee, 2000). Animal and human in-vitro and in-vivo exposure studies have demonstrated the powerful oxidant capacity of inhaled ozone with activation of stress signalling pathways in epithelial cells (Bayram *et al.*, 2001) and resident alveolar inflammatory cells (Mochitate *et al.*, 2001). Lewtas (2007) shows in human studies that exposures to combustion emissions and ambient fine particulate air pollution are associated with genetic

body's immune system attacks its joints, and is one of the most common autoimmune diseases (Cooper & Stroehla, 2003). Moreover, rheumatoid arthritis is a major cause of disability that reduces patient's lifespan by 15-20% from the onset of the illness (Myllykangas-Luosujäarvi *et al.*, 1995; cf., Chang *et al.*, 2016; De Roos *et al.*, 2014; Farhat *et al.*, 2011; Jung *et al.*, 2017).

damages. Long-term epidemiologic studies report an increased risk of all causes of mortality, cardiopulmonary mortality, and lung cancer mortality associated with increasing exposures to air pollution (cf., Coccia, 2012, 2014; Coccia & Wang, 2015). Although there is substantial evidence that polycyclic aromatic hydrocarbons or substituted polycyclic aromatic hydrocarbons may be causative agents in cancer and reproductive effects, an increasing number of studies–investigating cardiopulmonary and cardiovascular effects–shows potential causative agents from air pollution combustion sources.

About the respiratory activity, the adult lung inhales approximately 10-11,000 L of air per day, positioning the respiratory epithelium for exposure to high volumes of pathogenic and environmental insults. In fact, respiratory mucosa is adapted to facilitate gaseous exchange and respond to environmental insults efficiently, with minimal damage to host tissue. The respiratory mucosa consists of respiratory tract lining fluids; bronchial and alveolar epithelial cells; tissue resident immune cells such as alveolar macrophages (AM), dendritic cells, innate lymphoid cells and granulocytes; as well as adaptive memory T and B lymphocytes. In health, the immune system responds effectively to infections and neoplastic cells, with a response tailored to the insult, but must tolerate (i.e., not respond harmfully to) the healthy body and benign environmental influences. A well-functioning immune system is vital for a healthy body. Inadequate and excessive immune responses generate diverse pathologies, such as serious infections, metastatic malignancies and auto-immune conditions (Glencross *et al.*, 2020). In particular, immune system consists of multiple types of immune cell that act together to generate (or fail to generate) immune responses. In this context, the explanation of relationships between ambient pollutants and immune system is vital to explain how pollution causes disease, and how pathology can be removed. Glencross *et al.* (2020) show that air pollutants can affect different immune cell types, such as particle-clearing macrophages, inflammatory neutrophils, dendritic cells that orchestrate adaptive immune responses and lymphocytes that enact those responses. In general, air pollutants stimulate pro-inflammatory immune responses across multiple classes of immune cell. Air pollution can enhance T helper lymphocyte type 2 and T helper lymphocyte type 17 adaptive immune responses, as seen in allergy and asthma, and dysregulate anti-viral immune responses. In particular, the association between high ambient pollution and exacerbations of asthma and chronic obstructive pulmonary disease (COPD) is consistent with immunological mechanisms. In fact, diseases can result from inadequate responses to infectious microbes allowing fulminant infections, inappropriate/excessive immune responses to microbes leading to more (collateral) damages than the microbe itself, and inappropriate immune responses to self/environment, such as seems to be in the case of COVID-19. Glencross *et al.* (2020) also discuss evidence that air pollution can cause disease by perturbing multicellular immune responses. Studies confirm associations between elevated ambient particulate matter and worsening of lung function in patients with COPD (Bloemsma *et al.,* 2021), between COPD exacerbations and both ambient particulate matter and ambient pollutant gasses (Li *et al.,* 2016) and similarly for asthma exacerbations with high concentration of ambient pollutants (Orellano *et al.,* 2017, Zheng *et al.,* 2015). In short, the associations between ambient pollution and airways exacerbations are stronger than associations with development of chronic airways diseases. Glencross *et al.* (2020) also argue that ambient pollutants can directly trigger cellular signalling pathways, and both cell culture studies and animal models have shown profound effects of air pollutants on every type of immune cell studied. In addition to the general pro-inflammatory nature of these effects, many of studies suggest an action of air pollution to augment Th2 immune responses and perturb antimicrobial immune responses. This mechanism also explains the association between high air pollution and increased exacerbations of asthma – a disease characterized by an underlying Th2 immuno-pathology in the airways with severe viral-induced exacerbations. Moreover, as inhaled air pollution deposits primarily on the respiratory mucosa, potential strategies to reduce such effects may be based on vitamin D supplementation. Studies show that plasma levels of vitamin D, activated by ultraviolet B, are significantly higher in summer and fall than winter and spring, in a latitude-dependent manner (Barger-Lux & Heaney, 2002). Since the temperature and hour of sun are dependent upon the latitude of population residence and influenced by urban/rural residence, Oh *et al.* (2010) argue that adequate activated vitamin D levels are also associated with diminished cancer risk and mortality (Lim *et al.*, 2006; Grant, 2002). For instance, breast cancer incidence correlates inversely with the levels of serum vitamin D and ultraviolet B exposure, which are the highest intensity in summer season. These relationships of vitamin D and cancer risk are not limited to breast cancer, but are also relevant to colon, prostate, endometrial, ovarian, and lung cancers (Zhou *et al.*, 2005).

In the context of this study and considering the negative effects of air pollution on human health and transmission dynamics of viruses, summer season may have twofold effects to reduce diffusion of viral infectivity:

1) hot and sunny weather increases temperature and improves environment that can reduce air pollution, typically of winter period, and as result alleviate transmission of viral infectivity by COVID-19 (Ko *et al.*,

2007a; Medina-Ramón *et al.*, 2006; Wei *et al*, 2020; Dowell *et al.*, 2003; Kim *et al.*, 1996; Talbot *et al.* 2005);

2) sunny days and summer season induce in population a higher production of vitamin D that reinforces and improves the function of immune system to cope with viral infectivity of COVID-19.

Overall, then, statistical analysis, supported by relevant studies in these research topics, reveals that accelerated transmissions dynamics of COVID-19 is also to air pollution-to-human transmission in addition to human-to-human transmission.

Strategies to prevent future epidemics similar to Covid-19

At the end of 2019, medical professionals in Wuhan (China) were treating cases of pneumonia cases that had an unknown source (Li *et al.*, 2020; Zhu & Xie, 2020; Chan *et al.*, 2020; Backer *et al.*, 2020). Days later, researchers confirmed the illnesses were caused by a new coronavirus (COVID-19). By January 23, 2020, Chinese authorities had shut down transportation going into and out of Wuhan, as well as local businesses, in order to reduce the spread of viral infectivity (Centers for Disease Control and Prevention, 2020; Public Health England. 2020; Manuell & Cukor, 2011). It was the first in the modern history of several quarantines set up in China and other countries around the world to cope with transmission dynamics of COVID-19. Quarantine is the separation and restriction of movement of people who have potentially been exposed to a contagious disease to ascertain if they become unwell, in order to reduce the risk of them infecting others (Brooks *et al.*, 2019). In short, quarantine can generate a strong reduction of the transmission of viral infectivity. In the presence of COVID-19 outbreak in North Italy, Italian government has applied the quarantine and lockdown from 11 March, 2020 to 13 April, 2020 for all Italy, adding also some holidays thereafter. In fact, Italy was not able to prevent this complex problem of epidemics and has applied quarantine as a recovery strategy to lessen the health and socioeconomic damages caused by COVID-19. Millions of people have been quarantined for the first time in Italy and is one of the largest actions in the history of Italy. In addition, Italy applied non-pharmaceutical interventions based on physical distancing, school and store closures, workplace distancing, to avoid crowded places, similarly to the COVID-19 outbreak in Wuhan (cf., Prem *et al.,* 2020). The benefits to support these measures until April, 2020 are aimed at delaying and reducing the height of epidemic peak, affording health-care systems more time to expand and respond to this emergency and, as a result reducing the final size of COVID-19 epidemic. In general, non-pharmaceutical interventions are important factors to reduce the epidemic peak and the acute pressure on the health-care system (Prem *et al.,* 2020; Fong *et al.,* 2020). However, Brooks *et al.* (2019) report: "negative psychological effects of quarantine including post-traumatic stress symptoms, confusion, and anger. Stressors included longer quarantine duration, infection fears, frustration, boredom, inadequate supplies, inadequate information, financial loss, and stigma. Some researchers have suggested long-lasting effects. In situations where quarantine is deemed necessary, officials should quarantine individuals for no longer than required, provide clear rationale for quarantine and information about protocols, and ensure sufficient supplies are provided. Appeals to altruism by reminding the public about the benefits of quarantine to wider society can be favourable".

This strategy, of course, does not prevent future epidemics similar to the COVID-19 and it does not protect regions from future viral threats. Nations, alike Italy, have to apply *proactive strategies* that anticipate these potential problems and works to prevent them, reducing the health and economic impact in society.

Suggested proactive strategies to prevent future epidemics similar to COVID-19

Daszak *et al.* (2020) argue that to prevent the next epidemic and pandemic similar to COVID-19, research and investment of nations should focus on:

1) surveillance among wildlife to identify the high-risk pathogens they carry

2) surveillance among people who have contact with wildlife to identify early spillover events

3) improvement of market biosecurity regarding the wildlife trade.

In addition, high surveillance and proper biosafety procedures in public and private institutes of virology that study viruses and new viruses to avoid that may be accidentally spread in surrounding environments with damages for population and vegetation. In this context, international collaboration among scientists is basic to address these risks, support decisions of policymakers to prevent future pandemic creating potential huge socioeconomic issues worldwide (cf., Coccia & Wang, 2016)[2]. In fact, following the COVID-19 outbreak, The Economist Intelligence Unit (EIU) points out that the global economy may contract of about by 2.2% and Italy by -7% of real GDP growth % in 2020 (EIU, 2020). Italy and other advanced countries should introduce organizational, product and process innovations to cope with future viral threats, such as the expansion of hospital capacity and testing capabilities, to reduce diagnostic and health system delays also using artificial intelligence, and as a consequence new ICT

[2] Socioeconomic shocks can lead to a general increase of prices, high public debts, high unemployment, income inequality and as a consequence violent behaviour (Coccia, 2016, 2017, 2017a).

technologies for alleviating and/or eliminating effective interactions between infectious and susceptible individuals, and finally of course to develop effective vaccines and antivirals that can counteract future global public health threat in the presence of new epidemics similar to COVID-19 (Chen *et al,* 2020; Wilder-Smith *et al.,* 2020; Riou & Althaus, 2020; Yao *et al.,* 2020; cf., Coccia, 2015, 2017, 2019, 2020)[3].

This study here shows that geo-environmental factors of accelerated diffusion of COVID-19 are also likely associated with high air pollution and specific meteorological conditions (low wind speed, etc.) of North Italy and other Norther Italian regions that favour the transmission dynamics of viral infectivity. North Italy is one of the European regions with the highest motorization rate and polluting industrialization (cf., Legambiente, 2019). In 2018 in 55 provincial capitals the daily limits for PM_{10} or ozone were exceeded (i.e., 35 days for PM_{10} and 25 for ozone). In 24 of the 55 Italian province capitals, the limit was exceeded for both parameters, with negative effects on population that had to breathe polluted air for about four months in the year with subsequent health problems. In fact, the cities that last year passed the higher number of polluted days are Brescia

[3] For additional studies about science and technology, cf., Coccia, 1999, 2003, 2005, 2005a, 2005b, 2005c, 2006, 2008, 2009, 2010, 2010a, 2010b, 2010c, 2011, 2012, 2012a, 2012b, 2012c, 2012d, 2013, 2014, 2014a, 2014b, 2014c, 2014d, 2014e, 2014f; 2015, 2015a, 2015b, 2015c; 2016, 2016a, 2016b, 2017, 2017a, 2017b, 2017c, 2017d, 2017e, 2017f, 2017g; 2018, 2018a, 2018b, 2018c, 2018d, 2018e, 2018f, 2018g, 2018h, 2018i, 2018l, 2018m, 2018n; 2019, 2019a, 2019b, 2019c, 2019d, 2019e, 2019f, 2019g, 2019h, 2019i, 2019l, 2019m, 2019n, 2019o, 2019p; Coccia, 2020, 2020a, 2020b, 2020c, 2020d, 2020e, 2020f, 2020g, 2020h, 2020i, 2020l, 2020m, 2020n, 2020o, 2020p, 2020q; Coccia and Bellitto, 2020; Coccia and Benati, 2018, Coccia and Bozeman, 2016; Coccia et al., 2015; Coccia and Finardi, 2012, 2013; Coccia et al., 2012; Coccia and Rolfo, 2002, 2008, 2009; Coccia and Wang, 2015, 2016; Coccia and Watts, 2020.

with 150 days (47 for the PM_{10} and 103 for the ozone), followed by Lodi with 149 (78 for the PM_{10} and 71 for the ozone),–these are two cities with severe COVID-19 outbreak–, Monza (140), Venice (139), Alessandria (136), Milan (135), Turin (134), Padua (130), Bergamo and Cremona (127) and Rovigo (121). These provincial capitals of the River Po area in Italy have exceeded at least one of the two limits just mentioned. The first city not located in the Po valley is Frosinone (Lazio region of the central part of Italy) with 116 days of exceedance (83 for the PM_{10} and 33 for the ozone), followed by Genoa with 103 days, Avellino a city close to Naples in South Italy (Campania region with 89 days: 46 for PM_{10} and 43 for ozone) and Terni with 86 (respectively 49 and 37 days for the two pollutants). Many cities in Italy are affected by air pollution and smog because of traffic, domestic heating, industries and agricultural practices and with private cars that continue to be by far the most used means of transportation (more than 39 million cars in 2019). In fact, a major source of emissions of nitrogen oxides into the atmosphere is the combustion of fossil fuels from stationary sources (heating, power generation) and motor vehicles. In ambient conditions, nitric oxide is rapidly transformed into nitrogen dioxide by atmospheric oxidants such as ozone (cf., Brunekreef & Holgate, 2002). In Italy, the first COVID-19 outbreak has been found in Codogno, a small city of the Lodi area, close to Milan. Although local lockdown as red zone on February 25, 2020, the Regional Agency for Environmental Protection showed that concentrations of PM_{10} beyond the limits in almost all of Lombardy region including the red zone (i.e., 82 mm/m^3 of air measured in Codogno). The day after, February 26, 2020, the mistral wind and then the north wind swept the entire Po valley, bringing to Lombardy region a substantial reduction in the average daily concentrations of PM_{10}, which almost everywhere were lower than 50 micrograms of particulate matter/m^3 of air.

Hence, high concentration of nitrogen dioxide, a noxious gas, particulate air pollutants emitted by motor vehicles, power plants, and industrial facilities in North Italy seems to be a platform to support diffusion of viral infectivity (Groulx *et al.,* 2018), increase hospitalizations for respiratory virus bronchiolitis (cf., Carugno *et al.,* 2018; Nenna *et al.,* 2017), increase asthma incidence (Liao *et al.,* 2011) and damage to the immune system of people (Glencross *et al.,* 2020). Transmission dynamics of COVID-19 has found in air pollution and meteorological conditions of North Italy an appropriate environment and population to carry out an accelerated diffusion that is generation more than 13,000 deaths and a huge number of hospitalizations in a short period of time.

An *indirect effect* of quarantine and lockdown in Italy is the strong reduction of airborne Nitrogen Dioxide Plummets and PM_{10} over Norther of Italy. The maps by ESA (2020) show concentrations of nitrogen dioxide NO_2 values across Italy before the quarantine and lockdown in February, 2020 and during the quarantine and lockdown in March, 2020. The reduction in NO_2 pollution is apparent in all North Italy (Po Valley). Hence, the measures taken to cope with the COVID-19 outbreak (closure of schools and the reduction of traffic), particularly restrictive in the first phase on the regions of Northern Italy, have allowed a drastic reduction of concentrations of fine particulate matter, nitrogen dioxide and other polluting substances on the Po Valley. For instance, in Piedmont, one of the regions of North Italy also having a high COVID-19 diffusion, the concentration of air pollution since the beginning of March, 2020 has ever exceeded the limit values of PM_{10} and has always remained below 50μg / m^3 everywhere. Overall, then, the indirect effect of quarantine and lockdown of Italy and other

European countries has reduced in a short time NO_2 and air pollution, improving the quality of environment that may reduce, associated with quarantine, physical distancing and other inter-related factors, the transmission dynamics of COVID-19. A study by Zhang *et al.* (2019a) shows that with the implementation of air policy in China, from 2013 to 2017, fine particle ($PM_{2.5}$) concentrations have significant declined nationwide with health benefits. Now, the danger is that after the quarantine and lockdown, the industrial activity of industrialized regions in Italy has to resume at an intense pace of production and in next winter-fall season 2020-2021 there may be again the environmental and meteorological conditions that can lead to diffusion of viral infectivity of COVID-19 and/or other dangerous viruses. Of course, non-physical distancing and other long-run factors play a critical part in mitigating transmission dynamics of future epidemic similar to COVID-19, in particular when measures of physical distancing, school and store closures, workplace distancing, prohibition for crowded places are relaxed. The suggested strategy that regions of North Italy has to apply, considering their geographical locations and meteorological conditions with a high density of polluting industrialization, is to avoid to overcome the limits set of PM_{10} and other pollutants, following more and more a sustainable pathways of growth. *One of the findings here suggests that the max number of days per year that Italian provincial capitals can exceed the limits set for PM_{10} (particulate matter 10 micrometres or less in diameter) or for ozone, considering the meteorological condition has to be less than 50 days. After this critical point, the study suggests that environmental inconsistencies because of the combination between air pollution and meteorological conditions trigger a take-off of viral infectivity (epidemic diffusion) with damages for health of population and economy in society.* Italy must design and set up necessary measures to drastically reduce the concentrations of pollution present and improve air quality in cities. Italy not has to respect Legislative Decree 155/2010 that establishes a maximum number of 35 days / year with concentrations higher than 50 μg / m^3. As a matter of fact, the quarantine and other non-pharmaceutical interventions can reduce the impact of viral infectivity in the short term, but to prevent future epidemics similar to COVID-19, Italy and advanced nations have more and more to sustain a sustainable growth. The environmental policy has to be associated with sustainable technologies that reduce air pollution improving the quality of air and environment for population to cope with future viral threats (cf., Coccia, 2005, 2006, 2018; Coccia & Watts, 2020)[4]. Italy must support, more and more, sustainable mobility as engine of socioeconomic change and redesign cities for people using an urban planning that improves public respiratory health. Moreover, in the presence of the association between air pollution, climate [5] and viral infectivity. Italy and other advanced nations have to immediately reduce the motorization rate of polluting machines with a transition to new electric vehicles, generating a revolution in society. It is basic to encourage sustainable mobility, by enhancing local, urban and commuter public transport with electric vehicles and creating vast Low Emission Zones within cities. Italy has to launch a real sustainable growth roadmap with the aim of complete zero emissions in all socioeconomic system. Some studies done in the past show the causality of the reduction

4 cf. for dynamics of technological and economic change in society the studies by Coccia (2005a, 2005b, 2008, 2008, 2009, 2015a, 2017e, 2017f, 2017g, 2018a, 2019a, 2019b, 2019c, 2019d; Coccia and Finardi, 2012; Coccia and Rolfo, 2008).

5 Some studies show that in addition to human-to-human contact, ambient temperature is an important factor in the transmission and survival of coronaviruses (Zhu *et al.*, 2020) as well as temperature variation and humidity may also be important factors affecting the COVID-19 mortality (Ma *et al.*, 2020).

of air pollution on health benefits. For instance, Pope (1989) describes the case of a labour dispute that shut down a large steel mill in the Utah Valley for 14 months in 1987. Toxicological studies of particulate matter collected before, during, and after the strike, in the Utah Valley case, provide strong evidence of a causal relation between exposure to ambient particulate matter and mortality and morbidity. Ambient particulate matter concentrations as well as respiratory hospital admissions were clearly decreased during the strike, increasing to prestrike levels after the dispute ended (Pope, 1989; cf., the reduction of mortality described by Pope, 1996). Another example includes the reductions in acute-care visits and hospital admissions for asthma in Atlanta (GA, USA), in conjunction with reduced air pollution due to traffic restrictions taken during the 2000 Olympic games (Friedman, 2001).

Concluding remarks

The intensity of human interactions with Earth systems has accelerated in recent decades, because of urban development, population growth, industrialization, deforestation, construction of dams, etc., with changes in physical, biological, and chemical processes in soils and waters. In particular, human activity, driven by a high level of world population that is about eight billion (U.S. Census Bureau 2020), has induced changes to Earth's surface, cryosphere, ecosystems, and climate that are now so great and rapid, advancing the geological epoch of Anthropocene (Crutzen & Stoermer, 2000; Foley *et al.*, 2013). The beginning of the Anthropocene at around 1780 AD marks the beginning of immense rises in human population and carbon emissions as well as atmospheric CO^2 levels (Ellis *et al.*, 2013). The scale of carbon emissions associated with industrial activity is leading to a rise in atmospheric greenhouse gases at a rate unprecedented and gradual rise in carbon dioxide (Glikson, 2013; Coccia, 2014a). In this era of Anthropocene, the health effects of air pollution have been subject to intense study in recent years. Exposure to airborne particulate matter and ozone has main health effects associated with increases in mortality and hospital admissions for respiratory and cardiovascular diseases (Kampa & Castanas, 2008; Hoek *et al.*, 2013). The idea that air pollution episodes have a detrimental effect on health is now rarely contested, and acute exposures to high concentrations of air pollutants exacerbate cardiopulmonary disorders in human population worldwide (Langrish & Mills, 2014).

This study shows that factors determining the diffusion of epidemics similar to COVID-19 are due to manifold elements, in addition to human-to-human transmission, given by:

1. *General factors* that are the same for all locations and associated with innate biological characteristics of the viruses, incubation time, effects on infected and susceptible people, etc.

2. *Specific factors* that are different for each location and even for each individual, such us level of air pollution over time and space, meteorological conditions of specific location, season, density of areas, economic wealth, cultural characteristics (religious habits, food culture, etc.), organization and efficiency of healthcare sector, facilities and equipment in health sector, immune system of people, average age of population, sex of people, etc.

The main results of the study here, based on case study of COVID-19 outbreak in Italy, are:

- The acceleration of transmission dynamics of COVID-19 in North Italy has a high association with air pollution of cities measured with days of exceeding the limits set for PM10 or ozone
- Cities having more than 100 days of air pollution (exceeding the limits set for PM_{10}), they have a very high

average number of infected individual (about 3,100 infected), whereas cities having less than 100 days of air pollution, they have a lower average number of infected (about 900 infected individuals)

- Hinterland cities with higher number of average days exceeding the limits set for PM_{10} have a very high number of infected people on 1st April, 2020 (arithmetic mean is about 2,000 infected, with average polluted days more than 80), than coastal cities also having days of exceeding the limits set for PM10 or ozone (arithmetic mean about 700 infected, with average polluted days about 60). In fact, coastal cities have an average higher intensity of wind speed (about 12 km/h) than hinterland cities (8 km/h) and statistical analysis reveals a negative coefficient correlation between number of infected and intensity of wind speed (r= –28 to –38%, p-value <0.05): in fact, wind speed and other elements clean air from pollutants that are associated with transmission dynamics of viral infectivity.
- Air pollution in cities under study seems to be a more important predictor in the initial phase of transmission dynamics (on 17th March 2020, $b_1 = 1.27$, $p<0.001$) than human-to-human transmission ($b_2 = 0.31$, $p<0.05$). In the second phase of the transmission dynamics of viral infectivity, air pollution reduces intensity (on 1st April, 2020 $b'_1 = .85$, $p<0.001$) also because of indirect effect of lockdown and human-to-human transmission slightly increases ($b'_2 = 0.34$, $p<0.01$): *This result reveals that accelerated transmissions dynamics of COVID-19 is due to mainly air pollution-to-human transmission in addition to human-to-human transmission.*
- To minimize future epidemics similar to COVID-19, the max number of days per year in which Italian provincial capitals can exceed the limits set for PM_{10} (particulate matter 10 micrometres or less in diameter) or for ozone, considering their meteorological conditions, is about 45 days.

Hence, high concentration of nitrogen dioxide, a noxious gas, particulate air pollutants emitted by motor vehicles, power plants, and industrial facilities in North Italy seems to be a platform to support diffusion of viral infectivity (Groulx *et al.,* 2018), increase hospitalizations for respiratory virus bronchiolitis (cf., Carugno et al., 2018; Nenna *et al.,* 2017), increase asthma incidence (Liao *et al.,* 2011) and damage to the immune system of people (Glencross *et al.,* 2020). Beelen *et al.* (2013) report the need to draw attention to the continuing effects of air pollution on health. A socioeconomic strategy to prevent future epidemics similar to the COVID-19 is also the reduction of pollution with fruitful environmental and health effect by the rationalization of manufacturing industry in a perspective of sustainable development, de-industrializing polluting activities in the geographical development of current capitalism. De-industrialization of polluting industries and sustainable development impose often huge social costs in the short term on people, households, and families but they have long-run benefits for human societies. Studies show that public and environmental health policy interventions are necessary and have the potential to reduce morbidity and mortality across Europe (cf., Raaschou-Nielsen *et al.,* 2013). In fact, the improvements in air quality have been accompanied by demonstrable benefits to human health. Pope *et al.* (2009) reported that $PM_{2.5}$ concentrations fell by a third from the early 1980s to the late 1990s across major US metropolitan areas, with each 10 $\mu g/m^3$ reduction associated with an increase in life expectancy of 0.61 years. Because of health problems of polluting industrialization, Wei *et al.* (2020) suggest different air pollution regulations in regions having varied geographical and climatic conditions, and different bio aerosol pollution. In particular, Wei *et al.* (2020) suggest that different air quality strategies should be applied in inland and coastal cities, e.g., coastal cities also need start bio aerosol risk alarm during moderate pollution when severe pollution occurs in inland cities. Guo *et al.* (2019) argue that in recent years, haze pollution is a serious environmental problem affecting cities, proposing implications for urban planning to improve public respiratory health. In short, the long-term benefits of sustainable economic development are basic for the improvement of environment, atmosphere, air quality and especially health of populations (Blackaby, 1978; Bluestone & Harrison, 1982; Pike, 2009).

Overall, the, these findings here are consistent with correlational studies and indicate that health effects of air pollution exposure can span decades and extend beyond cardiopulmonary systems affecting diffusion of epidemics similar to COVID-19. Hence, it is important to reinforce evidence related to air pollution and inter-related factors of the transmission dynamics of virus similar to COVID-19, and helps policy makers to develop proactive regulations for the control of environment, air pollution, polluting industrialization and prevention of the diffusion of viral infectivity. The complex problem of epidemic threats has to be treated with an approach of dissolution: it means to redesign the strategies and protocols to cope with future epidemics in such way as to eliminate the conditions that caused accelerated diffusion of COVID-19, thus enabling advanced nations to do better in the future than the best it can do today (Ackoff & Rovin, 2003, pp. 9-10; Bundy *et al.*, 2017). This study revels interesting results of transmission dynamics of COVID-19 given by the mechanism of air pollution-to-human transmission that in addition to human-to-human transmission seems to have accelerated diffusion of epidemics in Italy. However, these conclusions are tentative. There are several challenges to such studies, particularly in real time. Sources may be incomplete, or only capture certain aspects of the on-going outbreak dynamics;

there is need for much more research in to the relations between viral infectivity, air pollution, meteorological factors and other determinants, when the COVID-19 outbreak is over. Overall, then, in the presence of polluting industrialization of cities and air pollution -to-human transmission of viral infectivity, this study must conclude that a comprehensive strategy to prevent future epidemics similar to COVID-19 has also to be designed in environmental and socioeconomic terms, that is in terms of sustainability science and environmental science, and not only in terms of biology, healthcare and health sector

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2 How does atmospheric circulation affect the diffusion of COVID-19 in polluted cities?

Introduction

The contemporary environmental and sustainability debate is based on new or relatively unexplored topics continually emerging. This study provides an investigation for the exploration of causes, consequences and policy responses linked to diffusion of Coronavirus disease 2019 in a context of environmental and sustainability science.

The Coronavirus disease 2019 (COVID-19) is due to a new virus called Severe Acute Respiratory Syndrome CoronaVirus-2 (SARS-CoV-2) that produces minor symptoms inmost people, but is also the cause of death of many individuals (Ogen, 2020; Dantas *et al.*, 2020). This Coronavirus Disease, started in China in 2019, is an on-going global problem for human health that is generating a socioeconomic crisis and negative world economic outlook projections (Saadat *et al.*, 2020). Manifold studies suggest a possible relation between air pollution and diffusion of COVID-19 infection with severe respiratory disorders (Fattorini & Regoli, 2020; Frontera *et al.*, 2020; Wang & Su, 2020). Scholars also state that high levels of air pollution can increase the lethality of COVID-19 infection (Contini & Costabile, 2020). Conticini *et al.* (2020) argue that population living in regions with high levels of pollutant has also a high probability to develop respiratory disorders because of infective agents. In fact, the highest level of COVID-19 infection is in the USA, Spain, Italy, UK, Russia, China, France, etc. having in some regions a very high level of particulate compounds in the atmosphere (Frontera *et al*, 2020). Studies confirm correlations between exposure to air pollution, diffusion and virulence of SARS-CoV-2 within regions with population having a high incidence of respiratory disorders, such as chronic obstructive pulmonary disease (COPD) and Lung Cancer (Fattorini & Regoli, 2020). Ogen (2020, p.4) finds that high NO_2 concentrations in the atmosphere, associated with downwards airflows, cause of NO_2 buildup close to the surface and prevent the dispersion of air pollution, increasing mortality of COVID-19, such as in Italy, Belgium, etc. In particular, this geographical structure of regions associated with specific atmospheric conditions prevents the dispersion of particulate compounds, which are one of the factors of a high incidence of respiratory disorders and inflammation in population of some European areas, such as Norther Italy. In short, the exposure of air pollution and poor air quality can be a driver of high rate of mortality of Coronavirus infection, such as in Italy (13.91%), Spain (11.8%), UK (14.73%), Belgium (16.38%), etc. (cf., Center for System Science and Engineering at Johns Hopkins, 2020). The study by van Doremalen *et al.* (2020) revels that in China viral particles of SARS-CoV-2 may be suspended in the air for various minutes and this result can explain the high total number of infected people and deaths of COVID-19 infection in the USA, Spain, Russia, France, Brazil, Turkey, Iran, etc. (cf., Center for System Science and Engineering at Johns Hopkins, 2020). In general, these studies suggest the hypothesis that the atmosphere having a high level of air pollutants, associated with certain climatological factors, may support a longer permanence of viral particles in the air, fostering a diffusion based on mechanisms of air pollution-to-human transmission in addition to human-to-human transmission (Frontera et al., 2020). In order to extend the investigation of these critical aspects in the development of COVID-19 outbreaks worldwide, in the atmospheric environment with high levels of particulate compounds and specific climatological conditions, the goal of this study is to analyze the relation between infected people, wind speed in the atmosphere and air pollution that can explain some critical relationships determining the diffusion of COVID-19 infection and negative impact in environment and human health. This study has the potential to support long-run environmental policy directed to mitigation strategies of emissions and depositions of gaseous and particulate compounds in the atmosphere for reducing and/or preventing the diffusion of future epidemics similar to COVID-19 infection.

Study design

Data sources and research setting

This study focuses fifty-five (*N*=55) cities that are provincial capitals in Italy, one of the countries with the highest number of deaths of COVID-19 infection: more than 30,900 units at 12May, 2020 (cf., Lab24, 2020). Epidemiological data are from Ministero della Salute (2020); data of air pollution are from Regional Agencies for Environmental Protection in Italy (cf., Legambiente, 2019); climatological information are based on meteorological stations in Italian provinces (il Meteo, 2020); and finally, data of the density of population are from the Italian National Institute of Statistics (ISTAT, 2020).

Measurements

- *Air pollution and particulate compounds emissions*. Total days exceeding the limits set for PM_{10} or for ozone in2018 per Italian provincial capitals. Days of air pollution are a main factor that affects atmosphere, environment and human health. Moreover, 2018 as baseline year for air pollution data, it separates out the effects of COVID-19 infection.
- *Diffusion of COVID-19 infection.* Number of infected individuals on March-April, 2020
- *Atmospheric circulation.* Average wind speed km/h on February-March 2020
- *Interpersonal contact rates*. Population density of cities (individual /km^2) in 2019

Primary data analysis and statistics

Descriptive statistics is performed categorizing Italian provincial capitals in groups, considering:

- *Atmospheric circulation - wind speed*
  - Cities with *high wind speed in the atmosphere* (>9 km/h)
  - cities with *low wind speed in the atmosphere* (≤9 km/h)
- *Air pollution and particulate compounds emissions in the atmosphere*
  - Cities with *high air pollution and particulate compounds emissions* in the atmosphere (with >100 days per year exceeding the limits set for PM_{10} or for ozone)
  - Cities with *low air pollution and particulate compounds emissions* in the atmosphere (≤100 days per year exceeding the limits set for PM_{10} or for ozone)

Correlation and regression analyses verifies relationships between variables understudy. Regression analysis considers that the number of infected people across Italian provincial capitals (dependent variable *y*) is a linear function of the explanatory variable of total days exceeding the limits set for PM_{10} (explanatory variable *x*).

The specification of linear relationship is a *log-log* model:

$$log\ y_t = \alpha + \beta log\ x_{t-1} + u \quad (1)$$

α is a constant; β= coefficient of regression; *u*= error term

The estimation of equation [1] is performed using a categorization of cities according to *wind speed in the atmosphere*. An alternative model [1] applies as explanatory variable the density of population per km^2 considering groups of cities with *high* or *low air pollution and particulate compounds emissions in the atmosphere*.

Ordinary Least Squares (OLS) method is applied for estimating the unknown parameters of linear models [1]. Statistical analyses are performed with the Statistics Software SPSS® version 24.

Statistical analyses

Table 1 shows that cities in regions with *low* wind speed in the atmosphere have a higher level of days of air pollution and particulate compounds emissions than cities with a *high* wind speed in the atmosphere (about 88polluted days *vs.*65 polluted days exceeding PM_{10} or ozone per year).

Table 1. *Descriptive statistics of Italian province capitals according to atmospheric circulation - wind speed*

		Days exceeding limits set for PM_{10} or ozone 2018	Infected Individuals 19h March 2020	Infected Individuals 6th April 2020	Infected Individuals 26th April 2020	Density inhabitants /km² 2019	Wind km/h Feb-Mar 2020	Temperature °C Feb-Mar 2020
Cities in regions with high wind speed in the atmosphere (> 9 km/h)	Arithmetic Mean	64.85	252.48	1198.52	1826.19	1153.85	11.12	9.82
N=27	Std. Error of Mean	6.93	40.91	176.32	290.02	303.74	0.58	0.54
		Days exceeding limits set for PM_{10} or ozone 2018	Infected Individuals 19h March 2020	Infected Individuals 6th April 2020	Infected Individuals 26th April 2020	Density inhabitants /km² 2019	Wind km/h Feb-Mar 2020	Temperature °C Feb-Mar 2020
Cities in regions with low wind speed in the atmosphere (≤ 9 km/h)	Arithmetic Mean	87.89	850.32	2731.64	3963.86	1742.11	6.35	8.97
N=28	Std. Error of Mean	8.32	209.62	565.33	830.65	340.18	0.55	0.27

This preliminary result suggests that high intensity of wind speed in the atmosphere improves the dispersion of gaseous and particulate matters, and as a consequence, it mitigates, i.e. reduces, diffusion of COVID-19 infection in environment and society. In order to confirm this result, table 2 considers*air pollution and particulate compounds emissions in the atmosphere*of cities: especially, cities with high *air pollution and particulate compounds emissions in the atmosphere* (>100 days exceeding limits set for PM_{10} or ozone per year) and low wind speed, they have a very high level of infected individualsin March and April 2020, in an environment with high average density of population.

Table 2. *Descriptive statistics of Italian provincial capitals according to air pollution and particulate compounds emissions in the atmosphere*

Cities with high air pollution and particulate compounds	Days exceeding	Infected Individuals	Infected Individuals	Infected Individuals	Density inhabitants/km²	Wind km/h	Temperature °C

emissions in the atmosphere: >*100days* exceeding limits set for PM_{10} *N=20*	limits set for PM_{10} or ozone 2018	19h March 2020	6th April 2020	26th April 2020	2019	Feb-Mar 2020	Feb-Mar 2020
Arithmetic Mean	125.25	1102.00	3575.15	5293.10	1981.40	7.67	9.19
Std. Error of Mean	3.00	270.41	714.93	1036.63	444.68	0.64	0.33
Cities with low air pollution and particulate compounds emissions in the atmosphere: ≤*100days* exceeding limits set for PM_{10} *N=35*	Days exceeding limits set for PM_{10} or ozone 2018	Infected Individuals 19h March 2020	Infected Individuals 6th April 2020	Infected Individuals 26th April 2020	Density inhabitants/km² 2019	Wind km/h Feb-Mar 2020	Temperature °C Feb-Mar 2020
Arithmetic Mean	48.77	245.31	1066.94	1555.23	1151.57	9.28	9.49
Std. Error of Mean	3.61	42.80	134.26	219.44	247.85	0.70	0.44

Table 3. *Bivariate Correlation*

	Cities in regions with high wind speed in the atmosphere (> 9 km/h)	*Cities in regions withlow high wind speed in the atmosphere (≤9 km/h)*
	Log Days exceeding limits set for PM_{10} or ozone 2018	*Log* Days exceeding limits set for PM_{10} or ozone 2018
Log Infected Individuals 19th March, 2020 Pearson Correlation	.68**	.51**
Log Infected individuals 6th April, 2020 Pearson Correlation	.88**	.96**
Log Infected individuals 26th April, 2020 Pearson Correlation	.80**	.93**

Note: **. Correlation is significant at the 0.01 level (2-tailed)

Table 3 showsthat cities of regions with high and low wind speed, they have a high positive correlation (*p-value*<.01) betweenair pollution and particulate compounds emissions in the atmosphere and infected individualsof COVID-19 in March and April 2020.

Table 4. *Parametric estimates of the relationship of Log Infected individuals on Log Air pollution and particulate compounds emissions in the atmosphereconsidering the groups of cities with high or low wind*

speed

↓DEPENDENT VARIABLE	*Cities in regions low wind speed in the atmosphere (≤9 km/h)* Explanatory variable: *Log* Days exceeding limits set for PM_{10} or ozone 2018	↓DEPENDENT VARIABLE	*Cities in regions high wind speed in the atmosphere (≤9 km/h)* Explanatory variable: *Log* Days exceeding limits set for PM_{10} or ozone 2018
*log*infected 6th April, 2020		*log*infected 6th April, 2020	
Constant α	3.62**	Constant α	2.14*
(St. Err.)	(1.26)	(St. Err.)	(1.05)
Coefficient $\beta 1$	.88**	Coefficient $\beta 1$	1.14***
(St. Err.)	(.29)	(St. Err.)	(..26)
R^2 (St. Err. of Estimate)	.26 (.92)	R^2 (St. Err. of Estimate)	.44(.74)
F	9.28**	*F*	16.27***

Note: Explanatory variable: *log* Days exceeding limits set for PM_{10} or ozone 2018; dependent variable *log* infected individuals; *** *p*-value<0.001; ** *p*-value<0.01; * *p*-value<0.05

Table 4 suggests that air pollution and particulate compounds emissions in the atmosphere explain the number of infected individuals of COVID-19. In particular,

- cities with *low* wind speed in the atmosphere, an increase of 1% of air pollution and particulate compounds emissions, measured with days exceeding limits set for PM_{10}, it increases the expected number of infected COVID-19 by about 0.88% (P<.01).
- cities with *high* wind speed in the atmosphere, an increase of 1% of air pollution and particulate compounds emissions, measured with days exceeding limits set for PM_{10}, it increases the expected number of infected COVID-19 by about 0.14% (P<.001).

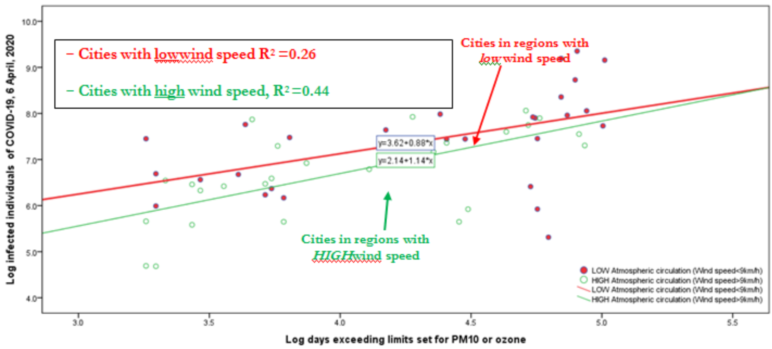

Figure 1. *Regression lines of Log Infected Individuals on Log Air pollution and particulate compounds emissions in the atmosphere according to wind speed of cities.*

Note: This result suggests that diffusion of COVID-19 infection is higher in cities with low wind speed and moderate air pollution and particulate compounds emissions in the atmosphere. In order to confirm this result, table 6 considers cities with a high and low polluting industrialization.

Figure 1. shows a visual representation of regression lines that cities with low atmospheric circulation - wind speed, initially, they have a high number of total infected individuals driven by a moderate air pollution and particulate compounds emissions in the atmosphere.

Table 5. *Parametric estimates of the relationship of Log Infected individuals on Log Density inhabitants/km² 2019, considering the groups of cities with high and low air pollution and particulate compounds emissions in the atmosphere*

	Cities with *low* air pollution and particulate compounds emissions		Cities with *high*air pollution and particulate compounds emissions
↓DEPENDENT VARIABLE	*Explanatory variable:* *Log* Density inhabitants/km² 2019	↓DEPENDENT VARIABLE	*Explanatory variable:* *Log* Density inhabitants/km² 2019
*log*infected 6th April, 2020		*log*infected 6th April, 2020	
Constant α	4.62***	Constant α	1.61
(St. Err.)	(.76)	(St. Err.)	(1.52)
Coefficient β 1	.32**	Coefficient β 1	.85***
(St. Err.)	(.12)	(St. Err.)	(.21)
R^2 (St. Err. of	.18 (.78)	R^2 (St. Err. of	.48 (.75)

Estimate)		Estimate)	
F	7.42**	*F*	16.63***

Note: Explanatory variable: *log* Density inhabitants/km² in 2019; dependent variable *log* infected individuals; *** *p*-value<0.001; ** *p*-value<0.01; * *p*-value<0.05

Table 5 reveal that:

- *in cities with low air pollution and particulate compounds emissions in the atmosphere,* an increase of 1% of the density of population, it increases the expected number of infected individuals with COVID-19 by about 0.31% (*p-value*=.01)
- *in cities with high air pollution and particulate compounds emissions in the atmosphere,* an increase of 1% of the density of population, it increases the expected number of infected individuals by about 85% ($P<.001$).

Figure 2 shows regression lines on 6th April 2020, in the middle phase of COVID-19 outbreak in Italy: regions with an atmosphere rich of air pollutants, associated with a climatological factor of low wind speed, can support a *stronger* of diffusion of COVID-19 infection.

In addition, if we consider regions with high/low air pollution and particulate compounds emissions in the atmosphere, using arithmetic mean of days exceeding limits set for PM_{10} or ozone of cities, the percentage of infected individuals and total deaths, weighted with population of these regions, reveals that about 74.50% of infected individuals and about 81% of total deaths in Italy because of COVID-19 infection are in regions with high air pollution and particulate compounds emissions in the atmosphere, cities located in hinterland zones (i.e. away from the coast, mostly those bordering large urban conurbations, such as Bergamo, Brescia and Cremona close to Milan in Lombardy region of North-West Italy), cities also having a low average intensity of wind speed and cities with a lower temperature.

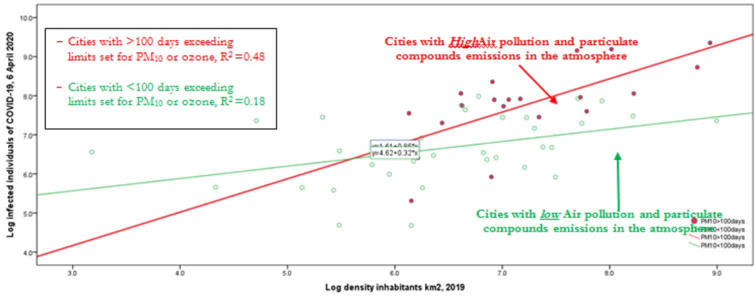

Figure 2. *Regression line of Log Infected people on Log population density inhabitants, considering the groups of cities with high or low air pollution and particulate compounds emissions in the atmosphere. Note: This result reveals that diffusion of COVID-19 is higher in cities with high Air pollution and particulate compounds emissions in the atmosphere*

Discussion

The current pandemic of Coronavirus disease and future epidemics similar to COVID-19 cannot be solved *only* with research and practice of medicine, immunology and microbiology but *also* with the development of environmental policy to reduce emission of particulate compounds, improving air quality and ecosystem. These findings here provide valuable insight into atmospheric-environmental factors that may accelerate the diffusion of COVID-19 and similar viral agents. The main results of the study, based on case study of COVID-19 outbreak in Italy, are *cities with little wind, and frequently high levels of air pollution and particulate compounds emissions in the atmosphere — exceeding safe levels of ozone or particulate matter — had higher numbers of COVID-19 related deaths.*

Considering the result just mentioned, the fundamental question is:

- *what is the link between diffusion of COVID-19 infection, air pollution and particulate compounds emissions in the atmosphere and low atmospheric circulation with low wind speed?*

Results suggest that, among Italian provincial capitals, the number of infected people is higher in cities with air pollution and particulate compounds emissions in the atmosphere, cities located in hinterland zones (i.e. away from the coast), cities having a low average intensity of wind speed and cities with a lower temperature. In particular, in hinterland cities (mostly those bordering large urban conurbations, such as Bergamo, Brescia, Lodi, close to Milan in Lombardy region of North Italy) with a high levels of air pollution and particulate compounds emissions in the atmosphere, coupled with low wind speed in the atmosphere, the average number of infected people in April 2020 more than doubled that of more windy cities. Therefore, cities in regions, with an atmosphere having a high intensity of wind speed, sustains clean days from air pollution and particulate compounds emissions, which current studies suggest is one of the drivers of the diffusion of Coronavirus infection. As a matter of fact, cities in hinterland zones (i.e. away from the coast) of Northern Italy with high air pollution and particulate compounds emissions, also having a low wind speed, have a stagnation of air pollution and particulate compounds in the atmosphere that can support diffusion of COVID-19 infection (Contini & Costabile, 2020; Conticini *et al.*, 2020; Fattorini & Regoli, 2020). The implications for an environmental policy are clear: *COVID-19 outbreak has low diffusion in cities of regions with low air pollution and particulate compounds emissions and atmosphere with a high circulation given by wind speed.* Northern Italian regions and in particular hinterland cities, covered by the study, considering the structure of the atmosphere with low circulation given by low wind speed over time and space, as a consequence, in future should *applyan environmental policy based on strategies of mitigation of air pollution and particulate compounds emissions,* so that the accelerated transmission dynamics of infections similar to COVID-19 re not triggered.

In order to reinforce these conclusions with a perspective of environmental policies, Xu *et al.* (2020) found out the effect of moisture on explosive growth in fine particulate matter (PM), and propose a new approach for the simulation of fine PM growth and dissipation in ambient air. In particular, winds significantly aid the dissipation of fine PM, and high concentrations of fine PM only persisted for a very short time and dissipated after several hours. The role of climatological factors, such as wind speed and direction, temperature, and humidity are critical for urban ventilation and the pollutant concentration in the streets of cities (Yuan *et al.*, 2019). Hence, cities and regions should consider the benefit of a high atmospheric circulation with high wind speed wind that can increase the dispersion of air pollution and particulate compounds emissions and, as a consequence, reduce diffusion of viral infectivity with main public health benefits, as well as cities have to consider a pollution industrialization in areas with low wind speed that can increase stagnation of the air in the atmosphere with potential problems for public health in the presence of viral agents. Gu *et al.* (2020) argue that a strategy to enhance air quality in cities is improving urban ventilation: the ability of an urban area to dilute pollutants and heat by improving the exchange of air between areas within and above the urban canopy. Of course, urban ventilation is a function of a manifold urban geometry parameters, e.g., frontal area density, and plan area density and the aspect ratio of the urban morphology (Gu *et al.*, 2020). Studies show that variations of building height have beneficial effects in terms of breathability levels, whereas larger aspect ratios of urban canyons can lead to high levels of pollutant concentrations inside the streets of cities. Hence, cities located in hinterland zones of the northern Italian region with low wind speed have an urban climatology and aspects of urban and regional topography that sustain the stagnation of air pollution and particulate compounds that can support the spread of viral infectivity in fall and winter season. These regions have to design environmental and industrial policies to reduce the level of air pollutants directed to reduce polluting industrialization and support a sustainable production with benefits for air quality and human health (Wang & Zhu, 2020). In fact, health and economic benefits associated with national and local reduction of air pollution are now rarely contested. Cui *et al.* (2020), based on a study in China, show that where reductions in ambient air pollution have avoided more than 2,300 premature deaths and more than 15,80 related morbidity cases in 2017, with a total of about US$ 318 million in economic benefits. In addition, these scholars argue that reduction of $PM_{2.5}$ concentrations to 15 μg/m^3 would result in reductions of 70% in total $PM_{2.5}$-related non-accidental mortality and 95% in total $PM_{2.5}$-related morbidity, with economic benefits of more than US$ 1,289.5 million. In short, environmental policies that improve air quality and reduce air pollution generate significant health, social and economic benefits in the ecosystem.

Overall, then, in order to prevent epidemics similar to COVID-19 and other infection, nations have, more and more, to apply an environmental and sustainable policy and technologies directed to reduce air pollution that improvespublic health of population and mitigates the negative effects of airborne viral diseases[1]. A comprehensive

[1] For studies about the interaction between science, technology and innovation, their sources, evolution, diffusion and impact on socioeconomic systems, see: Cavallo et al., 2014; Coccia, 1999, 2001, 2004, 2005, 2005a, b, c, 2006, 2007, 2008, 2009, 2009a,b,c; 2010, 2010a,b; 2012, 2012a,b; 2013; 2014, 2014a, b, c,d; 2015, 2015a, b; 2016, 2016a; 2017, 2017a, b, c, d, e, f, g, 2018, 2018a, b, c, d, e, f, g, h, i; 2019, 2019a, b, c, d, e, f, g, h, i, l, m; Coccia, 2020a, b, c, d, e, f, g, h, i, l, m, n, o, p, q; Coccia and Bellitto, 2018, Coccia and Cadario, 2018; Coccia et al., 2015; Coccia and Finardi, 2012, 2013; Coccia et al., 2012; Coccia and Rolfo, 2008, 2009, 2010, 2013; Coccia and Wang, 2015, 2016; Coccia and Watts, 2020.

environmental policy for a sustainable development has to consider the urban climatology and atmosphere of regions with the study of climatic properties of urban areas and support a better air quality (Gu *et al.*, 2020; Wang & Zhu, 2020).

Conclusions

The concentration in specific areas of a combination of atmosphere with low wind, specific urban climatology of hinterland cities, high Air pollution and particulate compounds emissions, aspects of regional topography and physical geography sustains, in fall and winter season, the stagnation of air pollution that has supported the spread of COVID-19 infection and likely in future of other infections(cf., Contini & Costabile, 2020; Conticini *et al.*, 2020; Fattorini & Regoli, 2020). New findings here show that geo-environmental and atmospheric factors of hinterland zones with low wind may have accelerated the spread of COVID-19 in northern Italian cities, leading to a higher numbers of COVID-19 related infected individuals and deaths.

However, these conclusions are of course tentative because there are several challenges to such studies, particularly in real time because the sources can only capture certain aspects of the on-going complex relations between air pollution and particulate compounds emissions, atmospheric composition and impact, and diffusion of viral infectivity in ecosystem. This study therefore encourages further investigations on these aspects of the diffusion of COVID-19 outbreaks in regions that have a specific atmosphere composition and impact on environment to design appropriate environmental policies that are also main public health measure to reduce air pollution and control the spread of infection similar to COVID-19 (Ou *et al.*, 2020). In short, in the presence of high air pollution and particulate compounds emissions and low wind speed in the atmosphere that can support diffusion of epidemics in environment, this study must conclude that a comprehensive strategy to prevent future epidemics similar to COVID-19 has also to be designed in terms of environmental science to improve air quality and human health.

To conclude, a proactive environmental strategy to help cope with future epidemics should concentrate on reducing levels of air pollution in hinterland and polluted cities. Therefore, such a strategy needs to take into account socioeconomic and environmental factors of affected regions, not only factors related to biology and medicine.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationshipsthat could have appeared to influence the work reportedin this paper.No funding was received for this study.

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3 Low numbers of COVID-19 related infected individuals in regions having wind resources and energy: A case study

Introduction

The contemporary environmental and sustainability debate has new or relatively unexplored topics that continually emerge in science. This study provides an investigation for the exploration of causes, consequences and sustainable policy responses linked to diffusion of Coronavirus disease 2019 in a context of environmental and sustainability science.

The Coronavirus disease 2019 (COVID-19) produces minor symptoms in most people, but is also the cause of severe respiratory disorders and death of many individuals worldwide (Ogen, 2020; Dantas *et al.*, 2020). The Coronavirus infection, started in China in 2019, is an on-going global health problem that is generating a socioeconomic crisis and negative world economic outlook projections (Saadat *et al.*, 2020). Manifold studies suggest a possible relation between air pollution and particulate compounds emissions and diffusion of COVID-19 infection (Fattorini & Regoli, 2020; Frontera *et al.*, 2020). Scholars also state that high level of air pollution can increase viral infectivity and lethality of COVID-19 infection (Contini & Costabile, 2020). Conticini *et al.* (2020) argue that population living in regions with high levels of particulate compounds emissions has also a high probability to develop respiratory disorders because of infective agents. In fact, the highest level of COVID-19 infection is in the USA, Spain, Italy, UK, Russia, China, Brazil, France, etc. that are countries having in some regions a very high level of air pollution (Coccia, 2020; Frontera *et al*, 2020). Studies confirm correlations between exposure to air pollution, diffusion and virulence of the SARS-CoV-2 within regions with population having a high incidence of respiratory disorders, such as chronic obstructive pulmonary disease (COPD) and Lung Cancer (Fattorini & Regoli, 2020; Coccia, 2014, 2015). Lewtas (2007) shows that exposures to combustion emissions and ambient fine particulate air pollution are associated with genetic damages. Long-term epidemiologic studies report an increased risk of all causes of mortality, cardiopulmonary mortality, and lung cancer mortality associated with increasing exposures to air pollution (cf., Coccia & Wang, 2015). Ogen (2020, p.4) finds that high NO_2 concentrations associated with downwards airflows cause of NO_2 buildup close to the surface. This geographical aspect of regions, associated with specific atmospheric conditions of low wind, prevents the dispersion of air pollutants, which are one of the factors of a high incidence of respiratory disorders and inflammation in population of some European regions, such as Norther Italy. In short, the exposure of air pollution, associated with Coronavirus infection, can be a driver of high rate of mortality in Italy (14.06%), Spain (11.90%), UK (14.37%), Belgium (16.40%), France (15.32%), etc. (cf., Center for System Science and Engineering at Johns Hopkins, 2020).

The study by van Doremalen *et al.* (2020) revels that in China viral particles of SARS-CoV-2 may be suspended in the air for various minutes and this result can explain the high total number of infected people and deaths of COVID-19 infection in the USA, Spain, Russia, France, Italy, Brazil, Turkey, Iran, etc. (cf., Center for System Science and Engineering at Johns Hopkins, 2020). In general, these studies suggest the hypothesis that the atmosphere having a high level of air pollutant, associated with certain climatological factors, may support a longer permanence of viral particles in the air, fostering a diffusion of COVID-19 infection based on mechanisms of air pollution-to-human transmission in addition to human-to-human transmission (Frontera *et al.*, 2020). In order to extend the investigation of these critical aspects in the development of COVID-19 outbreaks worldwide, in the presence of polluting industrialization, the goal of this study is to analyze the relation between infected people, air pollution, wind speed and inter-related renewable wind energy production that can explain some critical relationships determining the diffusion of COVID-19 and negative effect in environment and public health. This study has the potential to support long-run sustainable policy directed to foster a cleaner production for reducing and/or preventing the diffusion of future epidemics similar to COVID-19 infection.

Methods and research techniques

Data, sources and research setting

This study focuses on fifty-five (*N*=55) cities that are provincial capitals in Italy, one of the countries with the highest number of deaths of COVID-19 infection: more than 31,360 units at 15 May, 2020 (cf., Lab24, 2020). Epidemiological data of COVID-19 infection are from Ministero della Salute (2020); data of polluting industrialization, air pollution and particulate compounds emissions are from Regional Agencies for Environmental Protection in Italy (cf., Legambiente, 2019); climatological information are based on meteorological stations in Italian provinces (il Meteo, 2020); data of the density of population are from the Italian National Institute of Statistics (ISTAT, 2020) and finally, data concerning the production of wind energy per Italian regions are from Italian Transmission Operator called Terna (2020).

Measurements

- *Polluting industrialization and particulate compounds emissions.* Total days exceeding the limits set for PM_{10} or for ozone in 2018 per Italian provincial capitals. Days of air pollution and particulate compounds emissions are a main factor that affects environment and public health. Moreover, 2018 as baseline year for air pollution and particulate compounds emissions data, it separates out the effects of COVID-19 infection.
- *Diffusion of COVID-19 infection.* Number of infected individuals on March-April, 2020
- *Climatological information.* Average wind speed km/h on February-March 2020
- *Indicators of interpersonal contact rates*. Population density of cities (individual / km^2) in 2019
- *Production of renewable wind energy*. Power in MW of overall wind farms in all regions at January 2020

Primary data analysis and statistics

Descriptive statistics is performed categorizing Italian provincial capitals in groups, considering:

- *Renewable wind energy production*
  - cities with *high wind energy production* (seven regions in Italy have 94% of national production of wing energy)
  - cities with *low wind energy production* (regions that have 6% of national production of wing energy)

- *Polluting industrialization with and particulate compounds emissions*
  - Cities with *high polluting industrialization* (> 100 days per year exceeding the limits set for PM_{10} or for ozone)
  - Cities with *low polluting industrialization* (≤ 100 days per year exceeding the limits set for PM_{10} or for ozone)

Correlation and regression analyses verifies relationships between variables understudy. Regression analysis considers the number of infected people across Italian provincial capitals (variable y) as a linear function of the explanatory variable of total days exceeding the limits set for PM_{10} (variable x).

The specification of linear relationship is a *log-log* model:

$$log\ y_t = \alpha + \beta\ log\ x_{t-1} + u \quad (1)$$

α is a constant; β= coefficient of regression; u = error term

An alternative model [1] applies as explanatory variable the density of population per km^2 considering groups of cities with *high* or *low* level of polluting industrialization and particulate compounds emissions.

The estimation of equation [1] is also performed using a categorization of cities according to level of polluting industrialization and their location in regions with high and low intensity of wind energy production. Ordinary Least Squares (OLS) method is applied for estimating the unknown parameters of linear models [1]. Statistical analyses are performed with the Statistics Software SPSS® version 24.

Findings

The wind energy production in Italy is in Table 1 per regions.

Table 1. *Wind energy production in Italy per regions, January 2020*

Italian Regions	Number wind farms	Power [MW]
Abruzzo	47	264.2
Basilicata	1413	1300.1
Calabria	418	1125.8
Campania	619	1734.6
Emilia Romagna	72	44.9
Friuli Venezia Giulia	5	0.0
Lazio	69	70.9
Liguria	33	56.8
Lombardia	10	0.0
Marche	51	19.2
Molise	79	375.9
Piemonte	18	23.8
Puglia	1176	2570.1
Sardegna	595	1105.3
Sicilia	884	1904.1
Toscana	126	143.0
Trentino Alto Adige	10	0.4
Umbria	25	2.1
Valle d'Aosta	5	2.6
Veneto	18	13.4

Source: Terna (2020).

Table 1 shows that seven regions in Italy (Molise, Puglia, Calabria, Basilicata, Campania, Sicilia and Sardegna) have the 94% of total wind energy production. These regions have at least over 1 GW of power, with the leadership of Puglia region (South-East Italy) having 2.5 GW. Italy had in January 2020 about 5,645 wind farms with almost 7,000 wind turbines of various power sizes. In particular, above 10 MW of power there are 313 plants for a total power of just over 9 GW (i.e., 9.07 GW). The most relevant power class ranges from 20 to 200 kW, with 3,956 systems having a total power of approximately 234 MW. As just mentioned, Puglia has the largest share of wind power installed in Italy: 24.8% of the total with 92 plants above 10 MW of power. Results of Italian province capitals, categorized in two groups belonging to regions with *high* or *low* wind energy production, suggest that cities in regions with a *high* production of wind energy (94% of total) have a very *low* number of infected individuals with COVID-19 infection (in March and April 2020), whereas cities located in regions with a low intensity of wind energy production (6% of total) have a very high number of infected individuals (Table 2).

Table 2. *Descriptive statistics of Italian province capitals according to intensity of wind energy production*

Cities in regions with 94% of wind energy production N=5	Days exceeding limits set for PM_{10} or ozone 2018	Infected Individuals 17th March 2020	Infected Individuals 7th April 2020	Infected Individuals 27th April 2020	Density inhabitants/km² 2019	Wind km/h Feb-Mar 2020
Mean	48.00	59.80	505.60	708.20	2129.00	14.60
Std. Deviation	30.27	90.84	646.12	949.19	3384.10	5.45
Cities in regions with 6% of wind energy production N=50						
Mean	79.44	475.58	2119.68	3067.67	1385.76	8.10
Std. Deviation	41.70	731.11	2450.71	3406.67	1489.31	3.08

Table 2 also shows that cities in regions with low production of wind energy (6% of total) have a higher level of polluting industrialization than cities with a high production of wind energy (about 70 polluted days *vs.* 48 polluted days exceeding PM_{10} or ozone per year). This preliminary result suggests that regions with a high intensity of wind-based renewable energy and low polluting industrialization have also a low diffusion of COVID-19 infection in society. In order to confirm this result, table 3 considers polluting industrialization of cities: especially, cities with high polluting industrialization and particulate compounds emissions (>100 days exceeding limits set for PM_{10} or ozone per year) and low production of wind energy, they have a very high level of infected individuals in March and April 2020, in an environment with high average density of population and low average intensity of wind speed.

Table 3. *Descriptive statistics of Italian provincial capitals according to polluting industrialization and particulate compounds emissions*

Cities with high polluting industrialization: >*100days* exceeding limits set for PM_{10} *N=20*	Days exceeding limits set for PM_{10} or ozone 2018	Infected Individuals 17th March 2020	Infected Individuals 7th April 2020	Infected Individuals 27th April 2020	Density inhabitants/km² 2019	Wind km/h Feb-Mar 2020
Mean	125.25	881.70	3650.00	4838.05	1981.40	7.67
Std. Deviation	13.40	1010.97	3238.82	4549.41	1988.67	2.86
Cities with low polluting industrialization: <*100days* exceeding limits set for PM_{10} *N=35*						
Mean	48.77	184.11	1014.63	1637.21	1151.57	9.28
Std. Deviation	21.37	202.76	768.91	1292.26	1466.28	4.15

Table 4. *Correlation*

	Cities in regions with 94% of wind energy production	*Cities in regions with 6% of wind energy production*
	Log Days exceeding limits set for PM_{10} or ozone 2018	*Log* Days exceeding limits set for PM_{10} or ozone 2018
Log Infected Individuals 17th March, 2020 Pearson Correlation	.81	.69**
Log Infected individuals 7th April, 2020 Pearson Correlation	.74	.55**
Log Infected individuals 27th April, 2020 Pearson Correlation	.69	.36**

Note: **. Correlation is significant at the 0.01 level (2-tailed)

Table 4 shows that cities of regions with less than 6% of wind energy production, they have a high positive correlation between polluting industrialization and infected individuals of COVID-19 infection at 17th March (r=.69, p-value<.01), 7th April (r=.55, p-value<.01) and 27th April, 2020 (r=.36, p-value<.01). In regions with a high intensity of wind production, results are not significant.

Table 5. *Parametric estimates of the relationship of Log Infected individuals on Log polluting industrialization considering the groups of cities in regions with high or low production of wind energy*

	Cities in regions with 94% of wind energy production		*Cities in regions with 6% of wind energy production*
↓DEPENDENT VARIABLE	*Explanatory variable:* *Log* Days exceeding limits set for PM_{10} or ozone 2018	↓DEPENDENT VARIABLE	*Explanatory variable:* *Log* Days exceeding limits set for PM_{10} or ozone 2018
log infected 7th April, 2020		*log* infected 7th April, 2020	
Constant α	.70	Constant α	3.39***
(St. Err.)	(2.64)	(St. Err.)	(.85)
Coefficient $\beta 1$	1.34	Coefficient $\beta 1$	.92***
(St. Err.)	(.70)	(St. Err.)	(.20)
R^2 (St. Err. of Estimate)	.55 (.86)	R^2 (St. Err. of Estimate)	.31 (.82)
F	3.65	*F*	21.28***

Note: Explanatory variable: *log* Days exceeding limits set for PM_{10} or ozone 2018; dependent variable *log* infected individuals. *** *p*-value<0.001

Table 5 suggests that polluting industrialization, in areas with low production of wind energy, explains the number of infected individuals of COVID-19. In particular,

- cities in regions with 94% of wind energy production have not significant results because of low number of cases in sample
- instead, in cities of regions with 6% of wind energy production, an increase of 1% of polluting industrialization, measured with days exceeding limits set for PM_{10}, it increases the expected number of infected by about 0.92% (P<.001).

Figure 1 shows a visual representation of regression lines: cities having a higher production of renewable energy tend to have a low number of total infected individuals driven by polluting industrialization.

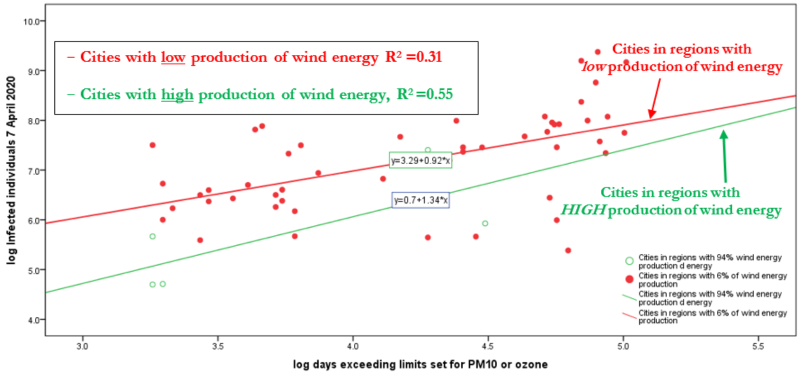

Figure 1. *Regression lines of Log Infected Individuals on Log polluting industrialization according to production of wind energy of cities.*
Note: *This result suggests that diffusion of COVID-19 infection increases with polluting industrialization in regions having low production of wind energy, i.e., with a less sustainable production.*

In order to confirm this findings, table 6 considers cities with a high and low polluting industrialization.

Table 6. *Parametric estimates of the relationship of Log Infected individuals on Log Density inhabitants/km² 2019, considering the groups of cities with high and low polluting industrialization*

	Cities with *low* polluting industrialization		Cities with *high* polluting industrialization
↓DEPENDENT VARIABLE	*Explanatory variable:* *Log* Density inhabitants/km² 2019	↓DEPENDENT VARIABLE	*Explanatory variable:* *Log* Density inhabitants/km² 2019
log infected 7th April, 2020		*log* infected 7th April, 2020	
Constant α	4.976	Constant α	1.670
(St. Err.)	(.786)	(St. Err.)	(1.491)
Coefficient $\beta\,1$	.252*	Coefficient $\beta\,1$	.849***
(St. Err.)	(.120)	(St. Err.)	(.205)
R^2 (St. Err. of Estimate)	.119	R^2 (St. Err. of Estimate)	.488
F	17.168***	*F*	4.457*

Note: Explanatory variable: *log* Density inhabitants/km² in 2019; dependent variable *log* infected individuals. *** *p*-value<0.001; ** *p*-value<0.01; * *p*-value<0.05.

Table 6 reveal that *in cities with low polluting industrialization and low particulate compounds emissions*, an increase of 1% of the density of population, it increases the expected number of infected individuals by about 0.25% (*P*=.042); whereas, *in cities with high polluting industrialization*, an increase of 1% of the density of population, it increases the expected number of infected individuals by about 85% (*P*<.001). Figure 2 shows regression lines on 7th April 2020, in the middle phase of COVID-19 outbreak in Italy: regions with a polluting industrialization generating an atmosphere rich of air pollutants that associated with a climate factor of low wind speed support a stronger of diffusion of COVID-19 infection.

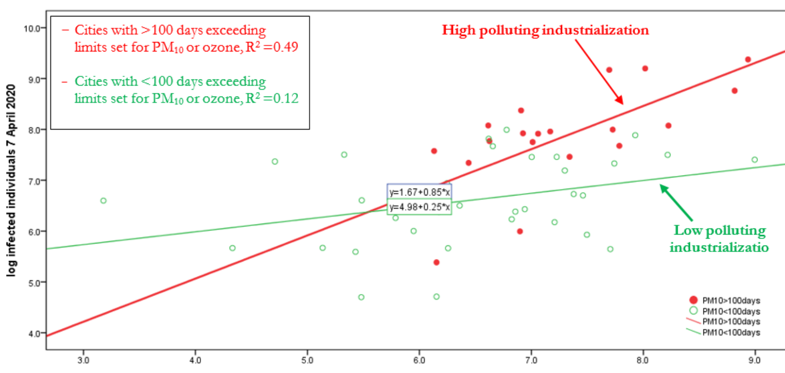

Figure 2. *Regression line of Log Infected people on Log population density inhabitants, considering the groups of cities with high or low polluting industrialization*

Note: *This result reveals that diffusion of COVID-19 is higher in cities with high polluting industrialization*

In addition, if we consider regions with high/low air pollution and particulate compounds emissions, using arithmetic mean of days exceeding limits set for PM_{10} or ozone of cities, the percentage of infected individuals and total deaths, weighted with population of these regions, reveals that about 74.50% of infected individuals and about 81% of total death in Italy because of COVID-19 infection are in regions with high air pollution and polluting industrialization and with low production of the renewable energy based on wind resource.

Discussion and observations

This new study finds that geo-environmental factors may have accelerated the spread of COVID-19 in northern Italian cities, leading to a higher number of infected individuals and deaths. This study analyzed data on COVID-19 cases alongside environmental and wind energy data. It found that cities with little wind and frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — had higher numbers of COVID-19 related infected individuals and deaths. These findings suggest that the current pandemic of Coronavirus disease and future epidemics similar to COVID-19 cannot be solved *only* with research and practice in medicine, immunology and microbiology but *also* with the development of industrial instruments directed to a sustainable and cleaner production (Coccia, 2019). These findings here provide valuable insight into geo-environmental and industrial factors that may accelerate the diffusion of COVID-19 and similar viral agents. The main results of the study, based on case study of COVID-19 outbreak in Italy, are:

- The diffusion of COVID-19 in Italy has a high association with high polluting industrialization in cities
- Cities having a high production of wind energy, associated with low polluting industrialization, have a low diffusion of COVID-19 infection and a lower number of total deaths.

Considering the results just mentioned, the question is:

what is the link between diffusion of COVID-19 infection, polluting industrialization and renewable wind energy in specific regions?

Results suggest that, among Italian provincial capitals, the number of infected people is higher in cities with polluting industrialization, cities located in hinterland zones (i.e. away from the coast), cities having a low average intensity of wind speed and cities with a lower temperature. In hinterland cities (mostly those bordering large urban conurbations, such as Bergamo, Brescia, Lodi, close to Milan in Lombardy region of North West Italy etc.) with a high polluting industrialization, coupled with low wind speed and wind energy production, the average number of infected people in April 2020 more than doubled that of more windy cities with renewable energy production. Therefore, cities in regions with a high production of wind energy in Italy, they also have a low polluting industrialization, low air pollution and particulate compounds emissions., in an environment with a high intensity of wind speed that sustains clean days from air pollution, particulate compounds emissions that current studies suggest the higher diffusion of Coronavirus infection (Fattorini & Regoli, 2020). As a matter of fact, cities with high polluting industrialization, mainly in Northern Italy (also having a low wind speed and as a consequence low wind energy production), have a stagnation of air pollution in the atmosphere that can support diffusion of COVID-19 infection (Contini & Costabile, 2020; Conticini *et al.*, 2020). The implications for a sustainable policy are clear: *COVID-19 outbreak has low diffusion in regions with low polluting industrialization and high production of renewable (wind) energy.* Northern Italian region covered by the study, as a consequence, in future should reduce pollution industrialization and particulate compounds emissions, so that the accelerated transmission dynamics of COVID-19 viral infectivity are not triggered.

In order to reinforce these conclusions with a perspective of sustainable policies, Xu *et al.* (2020) found out the effect of moisture on explosive growth in fine particulate matter (PM), and propose a new approach for the simulation of fine PM growth and dissipation in ambient air. In particular, winds significantly aid the dissipation of fine PM, and high concentrations of fine PM only persisted for a very short time and dissipated after several hours. The role of climatological factors, such as wind speed and direction, temperature, and humidity are critical for urban ventilation and the pollutant concentration in the streets of cities (Yuan *et al.* 2019). Considering the benefit of wind as resource that can reduce air pollution and as a consequence viral infectivity with main public health benefits, Gu *et al.* (2020) argue that a strategy to enhance air quality in cities is improving urban ventilation: the ability of an urban area to dilute pollutants and heat by improving the exchange of air between areas within and above the urban canopy. Of course, urban ventilation is a function of a manifold urban geometry characteristics, e.g., frontal and plan area density, and the aspect ratio of urban morphology.

Studies show that variations of building height have beneficial effects in terms of breathability levels, whereas larger aspect ratios of urban canyons can lead to high levels of pollutant concentrations inside the streets of cities. Hence, cities located in hinterland zones of the Northern Italian region with low wind speed have an urban climatology and aspects of urban and regional topography that sustain the stagnation of air pollution that can support the spread of viral infectivity in fall and winter season. Hence, these regions have to reduce the level of particulate compounds emissions applying long-run sustainable polices directed to reduce polluting industrialization and support the production of renewable energy (Wang & Zhu, 2020). In fact, health and economic benefits associated with national and local reduction of air pollution are now rarely contested. Cui *et al.* (2020), based on a study in China, show that where reductions in ambient air pollution and particulate compounds emissions have avoided more than 2,300 premature deaths and more than 15,80 related morbidity cases in 2017, with a total of about US$ 318 million in economic benefits. In addition, these scholars argue that reduction of $PM_{2.5}$ concentrations to 15 μg/m^3 would result in reductions of 70% in total $PM_{2.5}$-related non-accidental mortality and 95% in total $PM_{2.5}$-related morbidity, with economic benefits of more than US$ 1,289.5 million. In short, sustainable policies that reduce air pollution and particulate compounds emissions generate significant environmental, public health, social and economic benefits. This study suggests that in order to prevent epidemics similar to COVID-19 and other infections, nations have to apply a sustainable policy directed to reduce air pollution that affects public health and amplifies the negative effects of airborne viral diseases. In addition, the policy for a sustainable development has to consider the urban climatology with the study of climatic properties of urban areas (Gu *et al.,* 2020) and support renewable energy, such as wind resource, that create the environmental conditions for the reduction of air pollution on trans-regional level (Wang & Zhu, 2020). Moreover, high surveillance and proper biosafety procedures in public and private institutes of virology that study viruses and new viruses to avoid that may be accidentally spread in surrounding environments with damages for population and vegetation. In this context, international collaboration among scientists is basic to address these risks, support decisions of policymakers to prevent future pandemic creating potential huge socioeconomic issues worldwide (cf., Coccia & Wang, 2016; Coccia, 2020a)[1]. In fact, following the COVID-19 outbreak, The Economist Intelligence Unit (EIU) points out that the global economy may contract of about by 2.2% and Italy by -7% of real GDP growth % in 2020 (EIU, 2020). Italy and other advanced countries should introduce organizational, product and process innovations to cope with future viral threats, such as the expansion of hospital capacity and testing capabilities, to reduce diagnostic and health system delays also using artificial intelligence, and as a consequence new ICT technologies for alleviating

[1] Socioeconomic shocks can lead to a general increase of prices, high public debts, high unemployment, income inequality and as a consequence violent behavior (Coccia, 2016, 2017, 2017a).

and/or eliminating effective interactions between infectious and susceptible individuals, and finally of course to develop effective vaccines and antivirals that can counteract future global public health threat in the presence of new epidemics similar to COVID-19 (Chen *et al*, 2020; Wilder-Smith *et al*., 2020; Riou & Althaus, 2020; Yao *et al*., 2020; cf., Coccia, 2005, 2009, 2015a, 2017b, 2018, 2019a, 2020b; Coccia & Watts, 2020)[2]. In short, the concentration in specific areas of a combination of climate with low wind, a specific urban climatology of hinterland cities, high polluting industrialization, aspects of regional topography and physical geography sustains, in fall and winter season, the stagnation of air pollution and particulate compounds emissions that seems to have supported the spread of COVID-19 infection (cf., Contini & Costabile, 2020; Conticini *et al*., 2020; Fattorini & Regoli, 2020). New findings here show that geo-environmental factors may have accelerated the spread of COVID-19 in northern Italian cities, leading to a higher number of infected individuals and deaths.

[2] For studies about the interaction between science, technology and innovation, their sources, evolution, diffusion and impact on socioeconomic systems, see: Cavallo *et al*., 2014; Coccia, 1999, 2001, 2004, 2005, 2005a, b, c, 2006, 2007, 2008, 2009, 2009a,b,c; 2010, 2010a,b; 2012, 2012a,b; 2013; 2014, 2014a, b, c,d; 2015, 2015a, b; 2016, 2016a; 2017, 2017a, b, c, d, e, f, g, 2018, 2018a, b, c, d, e, f, g, h, i; 2019, 2019a, b, c, d, e, f, g, h, i, l, m; Coccia, 2020a, b, c, d, e, f, g, h, i, l, m, n, o, p, q; ;Coccia and Bellitto, 2018, Coccia and Cadario, 2018; Coccia et al., 2015; Coccia and Finardi, 2012, 2013; Coccia et al., 2012; Coccia and Rolfo, 2008, 2009, 2010, 2013; Coccia and Wang, 2015, 2016; Coccia and Watts, 2020.

Concluding remarks

The results here also suggested that, among Italian provincial capitals, the number of infected people was higher in cities with >100 days per year exceeding limits set for PM10 or ozone, cities located in hinterland zones (i.e. away from the coast), cities having a low average intensity of wind energy production and cities with a lower temperature. In hinterland cities (mostly those bordering large urban conurbations) with a high number of days exceeding PM10 and ozone limits, coupled with low wind speed, the average number of infected people in April more than doubled. These findings provide valuable insight into geo-environmental and industrial factors that may accelerate the diffusion of COVID-19 and similar viral agents. In this context, a proactive strategy to help cope with future epidemics should concentrate on reducing levels of air pollution in hinterland and polluted cities.

However, these conclusions are of course tentative because there are several challenges to such studies, particularly in real time because the sources can only capture certain aspects of the on-going complex relations between polluting industrialization, diffusion of viral infectivity and other resources of economic systems. This study therefore encourages further investigations on these aspects of the diffusion of COVID-19 outbreaks in highly industrialized areas to design appropriate sustainable policies that can provide lung-run public health measures to reduce air pollution and control the spread of infection similar to COVID-19 (Ou *et al.*, 2020). Overall, then, in the presence of high polluting industrialization and low renewable energy production of regions that can support diffusion of epidemics in environment with high level of air pollution and particulate compounds emissions, this study has to suggest that a comprehensive strategy to prevent future epidemics similar to COVID-19 must be designed in terms of sustainability science with a high incidence of cleaner production in socioeconomic systems.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No funding was received for this study.

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4 Recurring waves of COVID-19 pandemic with different effects in public health

Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the strain of novel coronavirus that causes Coronavirus disease 2019 (COVID-19) with high numbers of COVID-19 related infected individuals and deaths in society (Coccia, 2020; Zhang *et al.,*, 2020). In this context, the main goal of this study is to analyze the first and second wave of the COVID-19 pandemic to compare the effects on public health in terms of confirmed cases, fatality rates and admission at Intensive Care Units. This study is important to explain the impact of COVID-19 pandemic to design effective policy responses for constraining the effects on public health and economic systems of on-going and future waves of the COVID-19 and similar epidemics.

What is already known on these topics is based on some studies from different disciplines. Glass (2020) analyses four large countries in Europe and the USA with a proposed model and results reveal that policy responses based on limited containment measures can generate an impact of the second wave of COVID-19 pandemic on public health higher than the first one: "The results indicate that relaxations took effect in terms of increasing numbers of cases with dates ranging from early June in some countries to mid-July in other countries. For the European countries, results suggest relaxations ranging from 31% to 57% are underway and if current trends continue unchecked could lead to significant second waves that last longer than the corresponding earlier waves. In the case of the US, where the number of cases has already peaked for a second time, an extended version of the model suggests that the level of transmission may now be similar to that after the first peak". Bontempi (2020) argues that from September 2020, Europe has to cope with the appearance of a COVID-19 second wave. The Italy situation compared with other large European countries (e.g., France, Germany, UK, and Spain) seems to show a lower impact on public health likely due to containment measures applied in the first wave of COVID-19 pandemic (cf., Atalan, 2020; Prem *et al.*,, 2020). Cacciapaglia *et al.* (2020) apply the *Epidemic Renormalisation Group* approach to COVID-19 pandemic, using data of the first wave, to simulate the transmission dynamics of this novel infectious disease as well as the diffusion across different European countries. Results of simulation model suggest that the peak of the second wave can be roughly between July 2020 and January 2021. In particular, the timing of the peak can be estimated considering different non-pharmaceutical measures of containment and mitigation and in addition: "The sensitivity of the second peak prognosis on the value of the infection rates gives a clear indication that social distancing measures and responsible individual behavior can have a strong effect if implemented early on" (Cacciapaglia *et al.*,, 2020). Instead, Renardy *et al.*, (2020) apply a model based on discrete and stochastic network in a case study of Washtenaw County in Michigan (USA) to forecast the second wave of the COVID-19 pandemic. Results show that a delay of reopening does not reduce the total impact of the second peak of confirmed cases, but only delays it. However, simulations of the model reveal that a reduction of casual contacts between people can both delay and reduce the peak of the second wave of COVID-19 pandemic. Gatto *et al.,* (2020), based on their transmission model, argue that restriction to mobility and human interactions can reduce transmission dynamics of the COVID-19 pandemic by about 45%. Other studies show that specific places have a high risk to be COVID-19 outbreaks, acting as *suprspreaders* (Chang *et al.,* 2020). In particular, model by Chang *et al.* (2020), using cell phone data, predicts that a small minority of points of interest (called, POIs), such as restaurants and religious establishments, account for a large majority of infections; as a consequence, restricting maximum occupancy at each POI is more effective than uniformly reducing mobility. Moreover, higher infection rates among disadvantaged racial and socioeconomic people are due to their behavior of visiting more crowded and higher-risk places (Chang *et al.,* 2020). In this context, countries and regions can apply timely containment and mitigation measures, such as personal protective equipment, school closing, cancellation of public/private events, restrictions on mass gatherings in public and private places, restriction on internal mobility and international travel, etc. to reduce the threats of accelerated diffusion of the waves of COVID-19 pandemic and similar viral agents in society (Petherick *et al.,* 2020). Chu *et al.* (2020) also point out that mitigation measures based on social distancing and the use of facemasks seem to be effective to reduce the risk factors of transmission of the novel coronavirus. Instead, van Weert (2020) states that in the presence of a shortage of personal protective equipment, social distancing is a vital control measure to reduce the transmission dynamics of the COVID-19 pandemic in society (cf., Islam, 2020).

However, studies just mentioned are mainly based on models that generate simulations with computer experiments to predict eventual real effects of the dynamics of COVID-19 pandemic in different urban contexts. *What is hardly known in these research topics* is, using current data of COVID-19 pandemic, to explain whether the evolution of the second wave of the COVID-19 is generating an impact on public health higher or lower than first pandemic wave. The study here proposes an empirical analysis based on available data to explain the evolutionary dynamics of the second wave of COVID-19 compared to first one to design effective strategies of crisis management to cope with recurring waves of COVID-19 pandemic and future epidemics of new viral agents[1].

Study design

Data collection

The paper here is based on a case study of Italy that was the first large European country to experience a rapid increase in COVID-19 confirmed cases and deaths from March 2020. This study focuses on evolution of the first and second wave of COVID-19 pandemic in Italy. The end of the first wave of COVID-19 is detected here considering the

[1] For additional readings of these topics, see For studies about the interaction between science, technology and innovation, their sources, evolution, diffusion and impact on socioeconomic systems, see: Cavallo et al., 2014; Coccia, 1999, 2001, 2004, 2005, 2005a, b, c, 2006, 2007, 2008, 2009, 2009a,b,c; 2010, 2010a,b; 2012, 2012a,b; 2013; 2014, 2014a, b, c,d; 2015, 2015a, b; 2016, 2016a; 2017, 2017a, b, c, d, e, f, g, 2018, 2018a, b, c, d, e, f, g, h, i; 2019, 2019a, b, c, d, e, f, g, h, i, l, m; Coccia, 2020a, b, c, d, e, f, g, h, i, l, m, n, o, p, q, r; Coccia and Bellitto, 2018, Coccia and Cadario, 2018; Coccia et al., 2015; Coccia and Finardi, 2012, 2013; Coccia et al., 2012; Coccia and Rolfo, 2008, 2009, 2010, 2013, Coccia and Watts, 2020.

minimum number of confirmed cases from February 2020 onwards, which is the 31 July 2020;after this date, confirmed cases begin to increase and this study considers the starting of the second wave of COVID-19 pandemic in Italy, i.e., 1st August 2020. In particular, this study considers data for 105 days from the starting of each wave for a comparable framework of analysis:

- *First wave of COVID-19* from 24thFebruary, considering *N*=105 days
- *Second wave of COVID-19* from 1st August 2020 onwards, also considering *N*=105 days

In the context of first wave of COVID-19 pandemic, the containment measures of national lockdown and quarantine in Italy started on 8th March 2020 and ended on 18thMay 2020 (Governo Italiano, 2020). In addition, Italy is located in the North hemisphere of the globe and the summer season started on 20-21 June 2020 and ended 23 September 2020, for a period of 92 days of warmer temperatures. This period is important for current study because some papers suggest that hot weather can reduce the viral infectivity of COVID-19: "high temperatures damage the virus lipid layer decreasing its stability and infection potential and may even cause virus inactivation, therefore lowering the transmission rate" (Rosario Denes *et al.*, 2020, p. 4).

In the context of second wave of COVID-19, Italian government on 3 November 2020 applied different containment measures according to the impact of COVID-19 in regions in terms of level of admission to Intensive Care Units (ICUs) and other factors of health sector: *red* regions with full lockdown based on restrictions to individual mobility and closure of schools and public/private events; *orange* regions with a partial lockdown, and *yellow* regions in which people mainly have to wear protective mask against droplets of the coronavirus into the air and respect social distancing (cf., Chaudhry *et al.*, 2020; Coccia, 2020f; Islam, 2020).

Data of the COVID-19 pandemic under study here are:

- daily confirmed cases
- daily deaths
- daily admission to Intensive Care Units (ICUs)
- daily swabs

Period under study is from 24 February to November 2020 and source of data is the Ministero della Salute (2020) in Italy.

Variables

Dynamics of the first and second wave of the COVID-19 pandemic in Italy is measured by:

- *Daily confirmed cases standardized* = ratio of confirmed cases (t) / swab test (t-2). The lag of about 2 days from swab test to the result of positivity to the novel coronavirus (confirmed case) is based on average time of laboratories to deliver results of the COVID-19 swab test that is roughly 1-2 days from the date of specimen pickup (LabCorp, 2020).
- *Daily admission to ICUs standardized* = ratio of admission to ICUs (t) / confirmed cases at (t-5). The lag of about 5 days from initial symptoms, positivity to swab test to the hospitalization and recovery in ICUs of patients is based on average time from diagnosis to hospitalization as explained by specific studies (Faes *et al*., 2020).
- *Daily Fatality rate* = ratio of deaths at (t) /confirmed cases at (t-14). The lag of about 14 days from initial symptoms to deaths is based on empirical evidence of some studies (Zhang *et al*., 2020).

Methods of statistical analysis

Firstly, data are analyzed with descriptive statistics, comparing arithmetic mean of measures just mentioned between first and second wave of the COVID-19pandemic in Italy.

Secondly, each measure is represented in graphs comparing trends of the 1st wave and 2nd wave of COVID-19 pandemic, inserting the specific measure on *y*-axis (e.g., fatality rates) and temporal unit on *x*-ax is given by progressive numbers, in which the number 1 indicates the starting of the pandemic wave (i.e., 24th February for 1st wave and 1st August for 2nd wave), the number two is the second day of COVID-19 pandemic wave, and so on. Moreover, the three indicators are also compared within the 1st and 2nd wave to have a comparative analysis of the overall evolutionary dynamics of COVID-19 pandemic (cf., Coccia & Benati, 2018).

Thirdly, the study explores relationships between variables with correlation analysis and test of association. This study extends the analysis with a regression model based on a linear relationship in which variables measuring the impact of the COVID-19 on public health are linear function of time (days from starting of the pandemic wave for a period of 105 days). The specification of linear relationship is given by a semi-log model:

$$\log y_t = \alpha + \beta t + u \qquad (1)$$

y= measures of the impact of COVID-19 pandemic in society: Daily fatality rate, Daily admission to ICUs, Daily confirmed cases

t= time given by progressive numbers representing days of the first and second wave of COVID-19 pandemic

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 SPSS® version 26.

Results

Impact of the COVID-19 pandemic on public health comparing 1st and 2ndwave

Table 1. *Descriptive statistics of variables measuring the impact on public health of waves of COVID-19 pandemic*

	1 W Fatality rates	2 W Fatality rates	1 W Admission to ICUs	2 W Admission to ICUs	1W Confirmed cases	2W Confirmed cases
Mean	0.242	0.019	0.877	0.126	0.089	0.047
Std. Error of Mean	0.034	0.001	0.027	0.004	0.009	0.005

Note: W=wave; *N*= 105 days from the starting of the wave of COVID-19 pandemic; Fatality rate = ratio of deaths at (t) /confirmed cases at (t-14); Admission to ICUs = ratio of admission to ICUs (t) / confirmed cases at (t-5); Confirmed cases = ratio of confirmed cases (t) / swab test (t-2).

First wave of COVID-19 pandemic shows from February 2020 onwards an average fatality rate of about 24%, whereas second wave of COVID-19–for the same number of 105 days from the starting in August 2020–indicates an average fatality rate of about 1.9%. Comparative analysis of the average admission to Intensive Care Units (ICUs) shows an 87.7% in the first wave and about 13% in the second one. Instead, standardized confirmed cases with swab tests show that it is about 9% in the first pandemic wave of COVID-19 and roughly 5% in the second one (Table 1). Figures 1-2-3 show the trend of variables just mentioned confirming, *ictu oculi,* that the impact of the first wave of COVID-19 pandemic in Italy on public health has been stronger than second one in the first 105 days of the evolution of this pandemic.

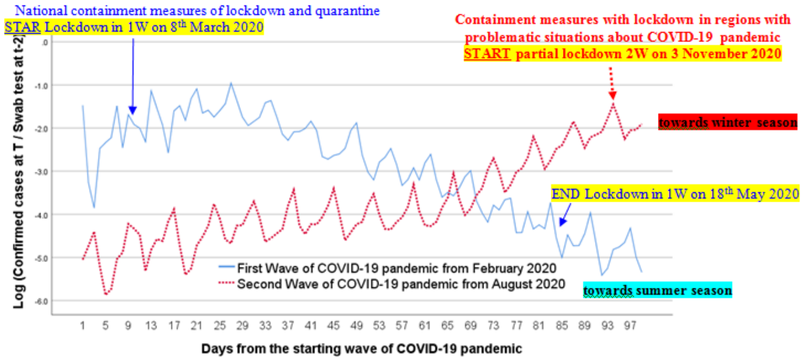

Figure 1. *Trend of confirmed cases of the first and second wave(W) of COVID-19pandemic in Italy, first 105 days*

However, Figure 1 of confirmed cases reveals a growing trend for second pandemic wave, whereas the first one has a declining trend also because of lockdown and quarantine and the progression of COVID-19 pandemic towards summer season when the novel coronavirus seems to have a seasonality with natural reduction of transmission for better weather conditions (e.g., hot temperatures) and also low levels of air pollution for containment measures applied (cf., Coccia, 2020, 2020a, 2020b; Rosario Dentes *et al.*, 2020).

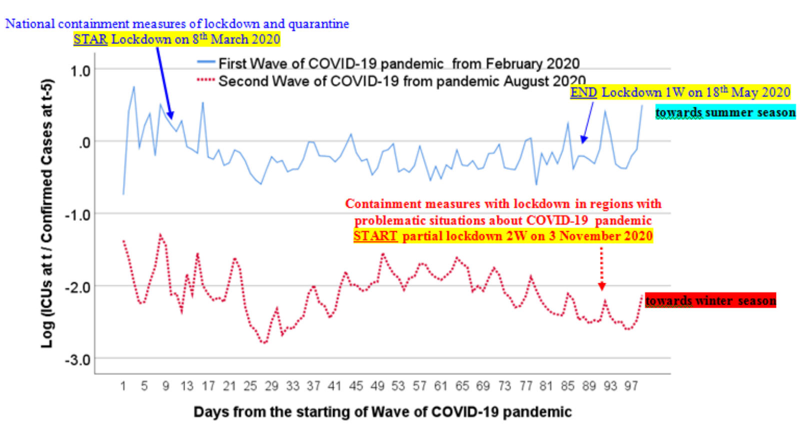

Figure 2. *Trend of ICUs of the first and second wave (W) of COVID-19 in Italy, first 105 days*

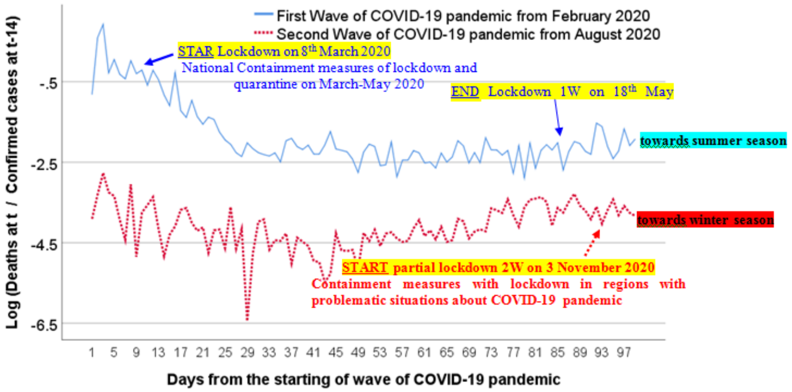

Figure 3. *Trend of fatality rate of the first and second wave(W) of COVID-19 in Italy, first 105 days*

Figure 2 shows trends of admission to ICUs: the second wave has an intensity lower than first pandemic wave and both waves seem to have stable dynamics. Instead, figure 3 shows trends of fatality rates: second pandemic wave has a low magnitude over time, suggesting a low impact on public health until November 2020.

Table 2. *Bivariate correlation of indicators in the First Wave of COVID-19 pandemic*

	Fatality rates	Admission to ICUs	Confirmed cases
Fatality rates	1		
Admission to ICUs	0.664**	1	
Confirmed cases	0.236*	-0.218*	1

Note: Values in *log* scale; ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed); Fatality rate = ratio of deaths at (t) /confirmed cases at (t-14); Admission to ICUs = ratio of admission to ICUs (t) / confirmed cases at (t-5); Confirmed cases = ratio of confirmed cases (t) / swab test (t-2); *N*=105 observations form starting of the wave in February 2020.

Table 2 shows bivariate correlation analysis of variables under study in the first wave of COVID-19 pandemic: fatality rates have a high positive association with admission to ICUs (r=.66, p-value <.01), and a lower positive association of the coefficient of correlation is between fatality rates and confirmed cases (r=.24, p-value <.05), whereas correlation between ICUs and confirmed cases is negative (r= –.22, p-value <.05). Table 2 seems to show that many infected individuals died as well as a lot of patients in ICUs likely because of low knowledge of the pathology and evolution of COVID-19 in patients, and lack of appropriate ther apies and low number of ICUs in hospitals (Gattinoni *et al*., 2020; Sterpetti, 2020). Table 3 shows tentative results for second wave of COVID-19 pandemic: correlation has a significant positive association between fatality rates and confirmed cases (r=.30, p-value <.01), whereas coefficient between ICUs and confirmed cases correlation is negative with an association higher than in the first epidemic wave (r=–.38, p-value <.01) likely because a lot of confirmed cases have not severe symptoms of COVID-19 and do not require utilization of ICUs.

Table 3. *Bivariate correlation of indicators in the Second Wave of COVID-19 pandemic*

	Fatality rates	Admission to ICUs	Confirmed cases
Fatality rates	1		
Admission to ICUs	-0.177	1	
Confirmed cases	0.303**	-0.381**	1

***Note*:** Values in *log* scale; ** Correlation is significant at the 0.01 level (2-tailed); Fatality rate = ratio of deaths at (t) /confirmed cases at (t-14); Admission to ICUs = ratio of admission to ICUs (t) / confirmed cases at (t-5); Confirmed cases = ratio of confirmed cases (t) / swab test (t-2); N=105 observations form starting of the wave in August 2020.

Table 4. *Estimated relationships, based on linear model of regression*

DEPENDENT VARİABLE (*log*)	1W Fatality rates	2W Fatality rates	1W Admission ICU	2W Admission ICU	1W Confirmed cases	2W Confirmed cases
Constant α	–1.02***	–4.31***	–.001	–1.94***	–1.02***	–5.33***
Coefficient β	–.016***	.004*	–.096	–.003**	–.037***	.032***
Stand. Coeff. Beta	–.608	.23	–.16	–.33	–.88	–.887
R^2	.37	.05	.03	.11	.77	.82
(St. Err. of Estimate)	(.63)	(.54)	(.27)	(.31)	(.61)	(.46)
F	60.31**	5.56*	2.76	12.38***	353.13***	456.15***

Notes: W=pandemic wave. ; Explanatory variable: *time units;* Dependent variables: Fatality rate = ratio of deaths at (t) /confirmed cases at (t-14); Admission to ICUs =

ratio of admission to ICUs (t) / confirmed cases at (t-5); Confirmed cases = ratio of confirmed cases (t) / swab test (t-2); *N*= 105 observations from starting of the wave; *Significance:* ***p-value<0.001¸**p-value<0.01¸*p-value<0.05

Table 4 shows the estimation of parameters in linear relationships between a number of variables and time as explanatory variable. The coefficient of regression of the model of fatality rate (dependent variable) indicates that in the first wave of COVID-19 pandemic, an increase of 1 day, it reduces the expected fatality rate by.02 (*p-value* = .001), whereas for second wave of the COVID-19, an increase of 1 day, it increases the expected fatality rate by a mere .004 (*p-value* = .05). The model's R^2 value indicates in the first wave that about 37% of the variation of fatality rate can be attributed (linearly) to time, whereas for second pandemic wave the coefficient of determination is rather low. The coefficient of regression of the model of admission to ICUs (dependent variable) indicates not significant results in the first wave, whereas in the second wave an increase of 1 day, it decreases the expected admission to ICUs by .003 (*p-value* = .001).Finally, the coefficient of regression using confirmed cases as dependent variable indicates that in the first wave of COVID-19 pandemic, an increase of 1 day, it reduces the confirmed cases by about .037 (*p-value* = .001), whereas for the second waves of COVID-19 pandemic, it increases by .032 (*p-value* = .001). In the last models for first and second wave of COVID-19 pandemic, R^2 coefficient indicates that more than 76% of the variation of confirmed cases can be attributed (linearly) to time.

General observation of regression analysis is that the first wave of the COVID-19 pandemic after national containment measures and the evolution towards summer season has a tendency to reduce fatality rates and confirmed cases, whereas during the first 105 days the second wave of COVID-19 has a low increase of fatality rate and confirmed cases but a moderate reduction of admission of patients to

ICUs likely also for the evolution towards autumn-winter season when climate conditions can affect the COVID-19.

Analysis within the first and second wave of COVID-19 pandemic

In order to analyze the impact of the COVID-19 pandemic over time in society, variables under study are represented simultaneously in the same graph for 105observations from starting day of the pandemic wave. Figure 4 shows that the first wave of COVID-19 pandemic from February 2020 has a declining trends of confirmed cases, the admission to ICUs has a high level rather stable, whereas the fatality rates after a decline in the first 30 days of the pandemic, in March or thereabout it becomes stable over time.

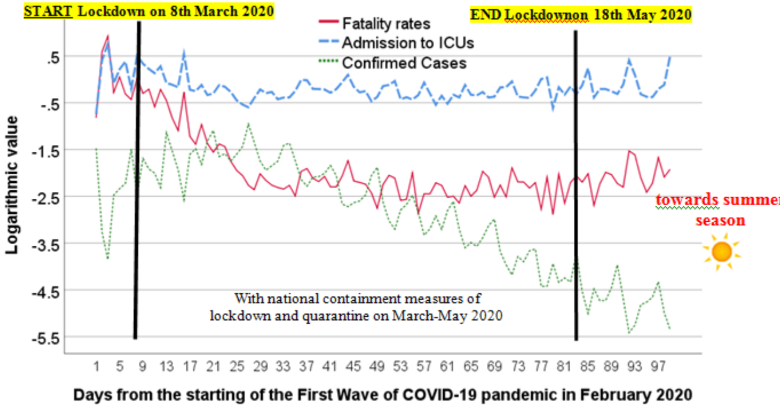

Figure 4. *Effects of the first wave of COVID-19 pandemic on public health in Italy, first 105 days from February 2020*

Figure 5 shows trends for second wave of COVID-19 from August 2020 to November 2020: admissions to ICUs are rather stable and with a level lower than first wave, whereas trend of confirmed case has a consistent grow, finally trend of fatality rates seems to have a stability in this period of autumn season.

These results suggest that in general the first wave has had a stronger impact on public health, reduced with the approaching of summer season and national containment measures. Instead, the second wave of COVID-19 pandemic has a dynamic still in evolution that seems also to be related to climate and seasonality that may increase the impact on public health in autumn-winter season 2020-2021 like all influenza diseases, though with a lower intensity compared to the first wave of COVID-19 pandemic.

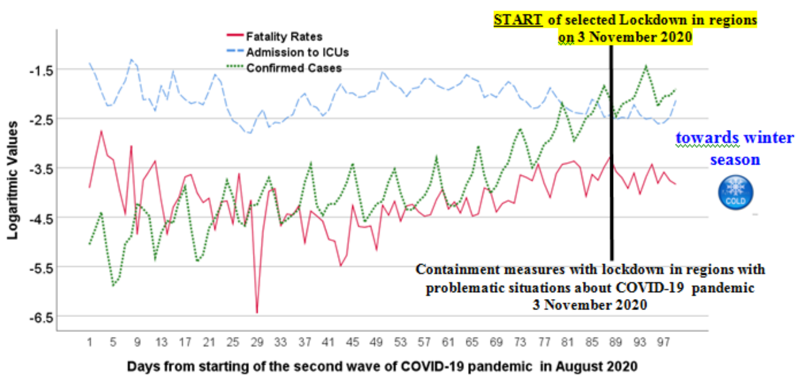

Figure 5. *Effects of the second wave of COVID-19 pandemic on public health in Italy, first 105 days from August 2020*

Discussion

What this study adds to current studies on the COVID-19 global pandemic crisis is that an accurate comparison of the first and second wave of COVID-19 pandemic suggests that the first one seems to have had a stronger impact on public health, until now. In addition, government responses in the first wave of COVID-19 pandemic, based on national lockdown and quarantine, seem to have lightly constrained the diffusion of COVID-19, also helped with the approaching of summer season 2020 (cf., Coccia, 2020d, 2020f; Tobías, 2020). In general, the COVID-19 pandemic tends to have natural dynamics and seasonality that policy responses of nations seem to mitigate but without generate a significant reduction of infected cases and fatality rates (Coccia, 2020f). In fact, countries with the on-going COVID-19 pandemic have showed an uncertain governance and an unrealistic optimism about their low vulnerability that a second wave of this pandemic cannot hit them (cf., Weinstein, 1987). Although the severe impact on public health of the first wave of COVID-19 pandemic, many countries have shown still a low capability of national planning for crisis management adopting ambiguous, delayed and uncertain policy responses in the presence of recurring waves of COVID-19 pandemic crisis. In general, it seems that countries have not used in comprehensive way the process of institutional learning of the first wave of COVID-19 pandemic for supporting effective and timely critical decisions to cope with similar problematic situations generated by second pandemic wave on public health (cf., Coccia, 2018, 2019, 2020; 2020e).

Conclusion remarks

The study here sought to understand different impact on public health of the first and second wave of the COVID-19 pandemic, analyzing a case study in Italy.

The results of analysis are:

- ☐ First wave of COVID-19 pandemic showed an average fatality rate of 24%, whereas second wave of COVID-19 indicates an average fatality rate of about 1.9%.
- ☐ Average admission to Intensive Care Units (ICUs) was an 87.7% in the first wave and is about 13% in the second one.
- ☐ Average confirmed cases was about 9% in the first pandemic wave of COVID-19 and is about 5% in the second one.

- ☐ However, confirmed cases are growing for second pandemic wave, whereas the first one had a declining trend also because of national containment measure and the progression of COVID-19 pandemic towards summer season.
- ☐ Analysis of relationships between variables shows a high impact on public health of the first wave of COVID-19 pandemic that reduces intensity over time, whereas second wave of COVID-19 pandemic has until now a lower impact on public health but evolutionary dynamics seems to increase the intensity with the progression in the direction of winter season.

The positive side of this study is that considers a large European country, Italy, that was the first country in western world to experience a rapid increase in confirmed cases and deaths; subsequently, many countries have had a similar impact on public health of COVID-19 pandemic crisis. However, these results are based on a case study and future studies, to be reinforced in terms of generalization of suggested findings, have to enlarge the sample considering other European countries to maintain a comparable framework for statistical analyses. Hence, these conclusions are of course tentative becausein the presence of the second and future waves of the COVID-19 pandemic manifold socioeconomic and environmental factors play a critical role (Coccia, 2020a, 2020b, 2020c, 2020d). There is need for much more detailed research on how COVID-19 pandemic and similar epidemics evolve in different economic, social, environmental and institutional contexts and especially in a specific period of time of a given geographical area (Coccia, 2020e). Overall, then, the investigation and explanation of the effects of pandemic waves on public health and economy are important, very important in order to design effective containment measures, apply new technologies and support R&D investments for public research directed to minimize the impact of future COVID-19 outbreaks and other epidemics similar to the COVID-19 in society, as well as interventions for not deteriorating structural indicators of the economic system of nations[2].

To conclude, although vital results of the first wave of the COVID-19 pandemic from February to August 2020, policymakers have had an unrealistic optimist behavior that a new wave of COVID-19, started in September 2020, could not hit their countries and, especially, a low organizational capacity to plan effective policy responses to cope with recurring COVID-19 pandemic crisis (cf., Coccia, 2020f, 2020g). As a result, inappropriate and delayed policy responses associated with inefficient practices of crisis management to constrain impact of new wave of COVID-19 is again generating negative effects, *déjà vu*, on public health and of course economic systems.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No funding was received for this study.

[2] Cf., Coccia, 2016, 2017a, 2017b, 2018a, 2019a, 2020h; Forman et al., 2020.

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5 Different effects of lockdown on public health and economy of countries: results from first wave of the COVID-19 pandemic

Introduction

The main goal of this study is to explain the effect of a policy response of lockdown on public health and economy to reduce the impact of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which is the strain of novel coronavirus that causes Coronavirus disease 2019 (COVID-19) in society.This study focuses on data of the first wave of COVID-19 pandemic (from March to August, 2020) in countries that have applied longer or shorter period of lockdown to assess the effective reduction of infected cases and fatality rates as well as the impact on Gross Domestic Product. Lessons learned from this study can be important to design effective public responses for constraining future waves of the COVID-19 and similar epidemics of new infectious diseases.

In the presence of COVID-19 pandemic, and in general of vast epidemics, as governments have to cope with consequential threats on public health, it is important, very important to analyze what containment measures are effective and which are not. Nicoll & Coulombier (2009, p.3ff) argue that containment measures have the goal to stop as many transmissions of infectious disease as possible. In particular, governments take actions to constrain/prevent chains of transmission and outbreaks, through vigorous contact tracing, quarantine of contacts, general lockdown of people and economic activities, etc. The crux of the study here is rooted in the concept of *lockdown* as policy response of countries to cope with diffusion of pandemic in society and some brief backgrounds are useful to understand and clarify it. The dictionary by Merriam-Webster (2020) defines lockdown as:"a temporary condition imposed by governmental authorities (as during the outbreak of an epidemic disease) in which people are required to stay in their homes and refrain from or limit activities outside the home involving public contact (such as dining out or attending large gatherings)". Atalan (2020) shows that COVID-19 pandemic can be contained with a containment measures of social restrictions, such as lockdown. Tobías (2020, p.2) states that: "Lockdown, including restricted social contact and keeping open only those businesses essential to the country's supply chains, has had a beneficial effect". This containment measure, in the presence of a pandemic or epidemic, has a variable period and includes one or more of actions, such as: school and workplace closing, cancellation of public/private events and closure of museums, restrictions on mass gatherings in public and private places, stay at home requirements, restriction on internal mobility and international travel, etc. (Nicoll & Coulombier, 2009; Petherick *et al.,* 2020). Atalan (2020) argues that countries can decide to start the lockdown when there is an acceleration of daily confirmed cases beyond a critical threshold and to end it when there is a strong reduction of Intensive Care Unit (ICU)admissions. In general, lockdown as policy responses has main effects on public health, environment and economies of countries (Chakraborty & Mait, 2020).

What is already known on these topics is based on manifold studies. Islam *et al.* (2020) argue that early application of the control measure of lockdown can generate a reduction of the incidence of COVID-19. The model by Balmford *et al.* (2020) also reveals that countries that applied immediately lockdown reduced deaths compared to countries that delayed the application of this strong containment measure. Chaudhry *et al.* (2020) explain, analyzing 50 countries having high number of confirmed cases of COVID-19, that 40 countries applied a full lockdown, 5 a partial one and 5 curfew only with different effects. In addition, this study suggests that lockdowns and pervasiveness of testing in society were not associated with COVID-19 mortality per million people, but full lockdowns and decreased country vulnerability to biological threats were significantly associated with the increase of patient recovery rates (Chaudhry *et al.,* 2020). Gatto *et al.* (2020), at March 2020, analyzing results of their transmission model, argue that restriction to mobility and human interactions can reduce transmission dynamics of the COVID-19 by about 45%. Tobías (2020) shows that after the first lockdown in Spain and Italy, the slopes of daily confirmed cases, of deaths and of Intensive Care Unit (ICU) admissions have been flattened, but the natural dynamics of COVID-19 pandemic has not changed the underlying trend that is continued to increase. However, the second lockdown, based on more containment measures for mobility, seems to have changed the trend, reducing daily diagnosed cases, total deaths and ICU admissions. Other studies show the effects of COVID-19 lockdown on environment and in particular on level of air pollution. Briz-Redón *et al.* (2021) analyze changes in air pollution during COVID-19 lockdown in Spanish cities and show that lockdown has reduced the atmospheric levels of

NO_2, CO, SO_2 and PM_{10}, except the level of O_3. Ghahremanloo et al. (2021) analyze the impact of COVID-19 containment measures on air pollution levels in East Asia and confirm that the concentrations of pollutants in February 2020 are lower than those of February 2019. In addition, NO_2also had significant reductions in Beijing-Tianjin-Hebei regions, Wuhan, Seoul, and Tokyo. In this context, Liu *et al.* (2021) analyze the effects of COVID-19 lockdown in about 600 major cities worldwide and show that NO_2 air quality index value falls more precipitously relative to the pre-lockdown period, followed by PM_{10}, SO_2, $PM_{2.5}$, and CO, but the level of O_3 increases. Moreover, Liu *et al.* (2021) argue that the impact of COVID-19 lockdown on environmental pollution generates health benefits in terms of the expected averted premature deaths due to air pollution declines. In general, the evidence that COVID-19 outbreaks have reduced levels of air pollution and detrimental effects of polluted environment on human health is now rarely contested. However, *what is hardly known in these research topics* is whether and how the application of general lockdown during the first wave of COVID-19 has been or has not been effective to reduce the negative impact on public health and economic system. This investigation is part of a large research project on factors determining the transmission dynamics of the COVID-19 pandemic and its socioeconomic impact. Results of the study here can explain the effects of lockdown in the first wave of COVID-19 in society and can be important, very important to design effective strategies and support sustainable technologies to cope with future waves of COVID-19 and future epidemics of new infectious diseases, without damaging economic system[1].

[1] For studies about the interaction between science, technology and innovation for supporting socioeconomic systems, see: Coccia, 2005,

Data and study design

Data and their sources

The study here focuses on six countries in Europe having a comparable institutional and socioeconomic framework: three countries with a shorter period of lockdown and three with a longer period of lockdown. In particular:

- *Countries with a shorter period of lockdown* are (average about 15 days of lockdown):
  - Austria from 3/16/2020 to 4/13/2020, 29 days
  - Portugal from 3/19/2020 to 4/2/2020, 15 days
  - Sweden did not apply any lockdown
- *Countries with a longer period of lockdown* are (average roughly 61 days of lockdown):
  - France from 3/17/2020 to 5/11/2020, 56 days
  - Italy from 3/09/2020 to 5/18/2020, 71 days
  - Spain from 3/14/2020 to 5/09/2020, 57 days
- Period under study: from March to August 2020, indicating the first wave of the COVID-19 pandemic.

The study here considers data of confirmed cases, fatality rate and GDP aggregates in these countries after the application of lockdown, i.e., from 15 April to 30 August 2020, a period that indicates the first wave of COVID-19 pandemic. These data provide important information to

2015, 2016, 2017, 2017a, b, c, d; 2018, 2018a; 2019, 2019a, b; Coccia and Finardi, 2012; Coccia and Wang, 2016; Coccia and Watts, 2020. Cf., also in this context studies about the interaction between science, technology and innovation, their sources, evolution, diffusion and impact on socioeconomic systems, see: Cavallo et al., 2014; Coccia, 1999, 2001, 2004, 2005, 2005a, b, c, 2006, 2007, 2008, 2009, 2009a,b,c; 2010, 2010a,b; 2012, 2012a,b; 2013; 2014, 2014a, b, c, d; 2015, 2015a, b; 2016, 2016a; 2017, 2017a, b, c, d, e, f, g, 2018, 2018a, b, c, d, e, f, g, h, i; 2019, 2019a, b, c, d, e, f, g, h, i, l, m, n; Coccia, 2020a, b, c, d, e, f, g, h, i, l, m, n, o, p, q; Coccia and Bellitto, 2018, Coccia and Cadario, 2018; Coccia et al., 2015; Coccia and Finardi, 2012, 2013; Coccia et al., 2012; Coccia and Rolfo, 2008, 2009, 2010, 2013, Coccia and Watts, 2020.

assess the effectiveness of policy responses based on lockdown to cope with COVID-19 global pandemic crisis. Data about public health are from Johns Hopkins Center for System Science and Engineering (2020) and economic data are from Eurostat (2020).

Measures

- *Numbers of COVID-19 related infected individuals* are measured with confirmed cases of COVID-19 divided by population % of countries under study
- *Numbers of COVID-19 related deaths* are measured by fatality rate of COVID-19 given by total infected individuals divided by deaths (%) of countries
- *Economic activity of countries* is measured with Gross Domestic Product (GDP) and main components (output, expenditure and income). Unit of measure is chain linked volumes, index 2010=100. The accounting period is the calendar quarter (Q), based on 2019-Q2, 2020-Q1 and 2020-Q2 (Q1= January, February, March; Q2=April, May, June). Quarterly national accounts data are a vital instrument to economic analysis and policy and in assessing the state of the business cycle (cf., Coccia, 2010).

Data analysis procedure

Firstly, data are analyzed with descriptive statistics, using a comparative approach between countries with longer and shorter period of lockdown, considering arithmetic mean of confirmed cases standardized with population, of fatality rates from April to August 2020 and of the quarterly national accounts of GDP. In addition, to assess the effects of lockdown on public health, it is calculated the average variation of confirmed cases standardized with population and fatality rate from 15 April 2020 to 30 August 2020, a period indicating the first wave of the COVID-19 pandemic.

Secondly, in order to assess whether the difference of arithmetic mean and average variation of confirmed cases standardized with population, fatality rate and GDP aggregate between countries with shorter and longer period of lockdown is significant, the Independent Samples *t*-Test is performed. In particular, the Independent Samples *t*-Test compares the means of two independent groups in order to determine whether there is statistical evidence that the associated population means are significantly different. The 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 countries with shorter and longer period of lockdown

H_1: $\mu_1 \neq \mu_2$, the two population means are not equal in countries with shorter and longer period of lockdown

Considering the small sample, the nonparametric Mann-Whitney *U* Test is also performed tocompare whether there is a difference in the dependent variable for these two independent groups. It compares whether the distribution of the dependent variable (i.e., confirmed cases standardized with population and fatality rate) is the same for the two groups and therefore from the same population.

Thirdly, the study represents the trends of average value of infected individuals and fatality rates of countries understudy from April to August 2020 aggregated in two groups, given by:

- ❑ Countries with a shorter period of lockdown are (average about 15 days)
- ❑ Countries with a longer period of lockdown are (average roughly 61 days)

The study analyzes these trends with simple regression model, using the specification of a linear relationship:

- $y_t = \alpha + \beta t + u$ (1)
- y = number of infected individuals or deaths

- t = time from April to August 2020

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

Statistical analyses are performed with the Statistics Software SPSS® version 26.

Results

Impact of COVID-19 and lockdown on public health

Descriptive statistics are in Table 1.

Table 1. *Descriptive statistics for the impact of lockdown on public health, period April-August 2020*

Period April-August 2020	groups	N	Mean	Std. Deviation	Std. Error Mean
Days of lockdown	1	3	14.670	14.503	8.373
	2	3	61.330	8.386	4.842
Average cases/population	1	3	0.004	0.002	0.001
	2	3	0.004	0.001	0.001
Average fatality rate	1	3	0.055	0.032	0.018
	2	3	0.127	0.020	0.012
Variation average cases/population	1	3	0.004	0.003	0.002
	2	3	0.003	0.002	0.001
Variation fatality rate	1	3	-0.007	0.012	0.007
	2	3	-0.019	0.020	0.011

Note: group 1= countries with a shorter period of lockdown (Austria, Portugal, Sweden); group 2= countries with a longer period of lockdown (France, Italy and Spain)

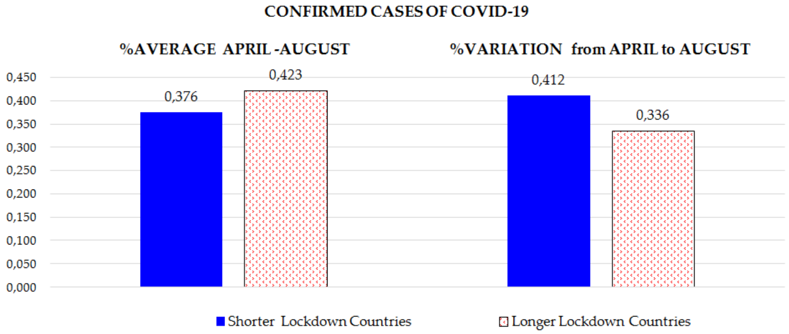


Figure 1. *Average values and average variation of confirmed cases/population (%) over April-August 2020 in countries with shorter and longer period of lockdown.*

Figure 1 reveals that countries with shorter periods of lockdown have a lower average values of confirmed cases/population (%) but a higher variation of confirmed cases/population (%) than countries with longer periods of lockdown form April to August 2020 (the first wave of the COVID-19 pandemic).

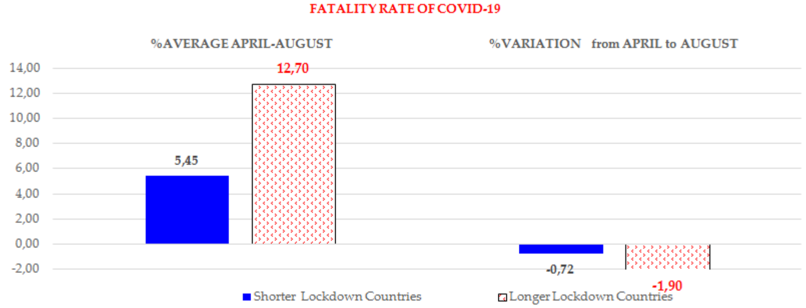


Figure 2. *Average values and average variation of fatality rate (%) over April-August 2020 in countries with shorter and longer period of lockdown.*

Figure 2 reveals that countries with shorter periods of lockdown have a lower average magnitude of fatality rates (%) and a reduction of fatality rate lower than countries with longer period of lockdown over April - August 2020 (–0.72% vs. –1.90%). In order to assess the significance of the difference of arithmetic mean and average variation of confirmed cases standardized with population and fatality rates between countries with shorter and longer period of lockdown, the Independent Samples *t* Test is performed; considering the small sample under study also the nonparametric Mann-Whitney *U* Test is performed as countercheck to reinforce results.

Table 2. *Independent Samples Test for the impact of lockdown on public health*

		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
Days of lockdown	Equal variances assumed	0.445	0.541	-4.825	4	0.008	-46.667	9.672
	Equal variances not assumed			-4.825	3.203	0.015	-46.667	9.672
Average cases/population	Equal variances assumed	0.047	0.84	-0.382	4	0.722	0.000	0.001
	Equal variances not assumed			-0.382	3.83	0.723	0.000	0.001
Average fatality rate	Equal variances assumed	1.51	0.286	-3.343	4	0.029	-0.073	0.022
	Equal variances not assumed			-3.343	3.386	0.037	-0.073	0.022
Variation average cases/population from April to August	Equal variances assumed	0.132	0.735	0.376	4	0.726	0.001	0.002
	Equal variances not assumed			0.376	3.704	0.727	0.001	0.002
Variation fatality rate from April to August	Equal variances assumed	0.393	0.565	0.878	4	0.429	0.012	0.013
	Equal variances not assumed			0.878	3.273	0.440	0.012	0.013

The *p*-value of Levene's test is not significant, and we have to consider the output of "Equal variances assumed". Based on results, there is a significant difference in mean days of lockdown (t_4 = -4.825, $p< .01$) and average fatality rates (t_4 = -3.343, $p< .05$) between countries with longer and shorter days of lockdown. In particular, the average fatality rate of countries with shorter period of lockdown was -7.3 percent points lower than countries with longer period lockdown because of higher initial incidence. Other indicators are not significant (Table 2).

Table 3. *Mann-Whitney Test. Rank for the impact of lockdown on public health*

Period from April to August, 2020	Groups	N	Mean Rank	Sum of Ranks
Days of lockdown	1	3	2	6
	2	3	5	15
	Total	6		

Average cases/population	1	3	3	9
	2	3	4	12
	Total	6		
Average fatality rates	1	3	2	6
	2	3	5	15
	Total	6		
Variation average cases/population	1	3	3.67	11
	2	3	3.33	10
	Total	6		
Variation fatality rate	1	3	3.67	11
	2	3	3.33	10
	Total	6		

Note: group 1= countries with a shorter period of lockdown (Austria, Portugal, Sweden) group 2= countries with a longer period of lockdown (France, Italy and Spain)

Table 4. *Mann-Whitney Test for the impact of lockdown on public health*

Test Statistics[a)]

	Days of lockdown	Average cases/population	Average fatality rates	Variation average cases/population from April to August	Variation fatality rate from April to August
Mann-Whitney U	0	3	0	4	4
Wilcoxon W	6	9	6	10	10
Z	-1.964	-0.655	-1.964	-0.218	-0.218
Asymp. Sig. (2-tailed)	0.05	0.513	0.05	0.827	0.827
Exact Sig. [2*(1-tailed Sig.)]	.100[b)]	.700[b)]	.100[b)]	1.000[b)]	1.000[b)]

Note: a) Grouping Variable: groups; b) Not corrected for ties.

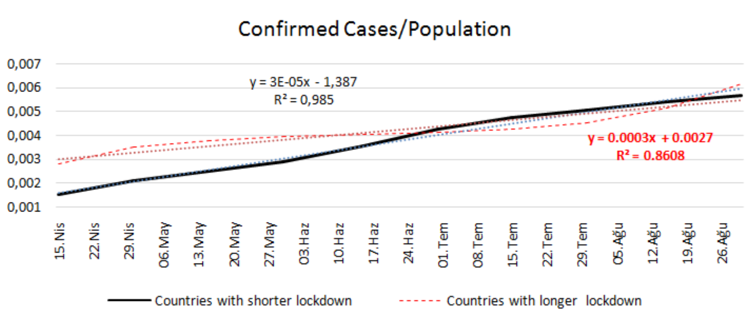
Tables 3 and 4, based on Mann-Whitney test, show that fatality rate in the group with shorter period of lockdown is significantly lower than the group of countries having a longer period of lockdown (U = 0, p-value = .005). Other indicators also here are not significant.

Finally, table 5 does not provide significant results of estimated relationships maybe due to small sample. Figure 3 provides trends of confirmed cases and fatality rates that approximatively do not suggest a difference in the temporal dynamics of evolution of the COVID-19 pandemic in countries with longer or shorter period of lockdown. In particular, the reduction of fatality rates over time in groups under study here seems to be due to the favorable climate conditions of summer season that studies show how it can reduce the diffusion of the COVID-19 rather than different strategies of longer or shorter period of lockdown (cf., studies by Coccia, 2020, 2020a, 2020b, 2020c, 2020d; Rosario Denes *et al.*, 2020).

Table 5. *Estimated relationships, based on linear model of regression*

	Confirmed cases of shorter lockdown countries	*Confirmed cases of longer lockdown countries*	*Fatality rates of shorter lockdown countries*	*Fatality rates of longer lockdown countries*
Constant α(St. Err.)	–5.34*** (.18)	–2.97***(.18)	26.00*(8.88)	21.95(14.06)
Coefficient β(St. Err.)	3.87E-10[a](.00)	2.156E-10[a](.00)	–1.88E-9[a](.00)	–1.58E-9[a](.00)
Stand. Coefficient Beta	.995	.896	–72	–.48
R^2 (St. Err. of Estimate)	.99(.00)	.77(.00)	.52 (.007)	.23 (.012)
F	869.52***	34.42***	8.54*	2.41

Note: a) not indicated; Dependent variable: *time.Significance:* *** *p*-value<0.001; ** *p*-value<0.01; * *p*-value<0.05



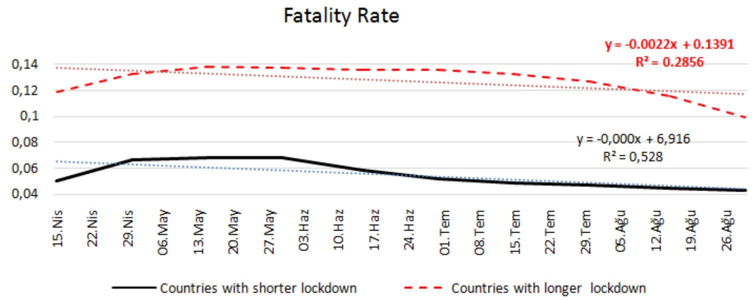


Figure 3. *Trend of confirmed cases/population and fatality rates over April-August 2020 in countries with shorter and longer period of lockdown.*

Impact of COVID-19 and lockdown on economic system

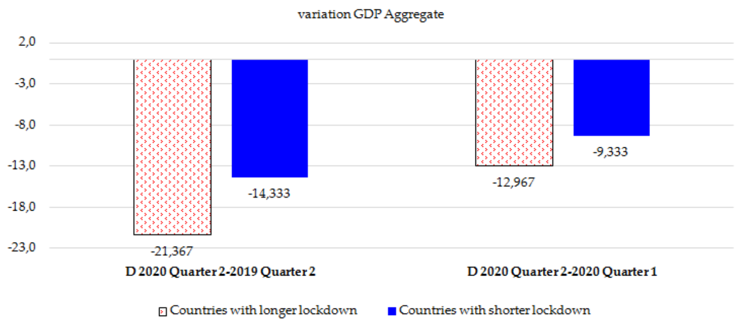


Figure 4. *Variation of GDP aggregates (index 2010=100) from 2nd quarter 2020 to 2nd quarter of 2019 and from 1st quarter 2020 to 2nd quarter of 2020 between countries with longer and shorter period of lockdown. Note: Q1= January, February, March; Q2=April, May, June*

Table 6. *Group statistics for GDP aggregates*

	Countries	N	Mean	Std. Deviation
Δ GDP(2020Q2-2019Q2)	Shorter period of Lockdown	3	-14.33	4.59
	Longer period of Lockdown	3	-21.37	2.76
Δ GDP(2020Q2-2020Q1)	Shorter period of Lockdown	3	-9.33	4.37
	Longer period of Lockdown	3	-12.97	2.83

iii. **Note:** Q=Quarter of the Gross Domestic Product, GDP; Q1= January, February, March; Q2=April, May, June.

Figure 4 and table 6 show *ictu oculi* that countries applying a longer period of lockdown they have had a higher reduction of GDP comparing the index of GDP of the second quarter 2020 to the same indicator in the same period of 2019 and comparing GDP of the second quarter 2020 to the first quarter(Q) of 2020.

Table 7. *Independent Samples Test for the impact of lockdown on economy of countries*

		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
Δ GDP (2020Q2-2019Q2)	Equal variances assumed	1.503	0.287	2.274	4	0.085	7.033	3.093
	Equal variances not assumed			2.274	3.276	0.1	7.033	3.093

Table 7 shows that the *p*-value of Levene's test is not significant, and we have to consider the output of "Equal variances assumed". Based on results, there is a significant difference in mean of GDP from Q2 in 2019 to Q2 in 2020 days between countries with longer and shorter period of lockdown (t_4 = -2-274, p< .085). In particular, considering that these countries are in the same geo-economics area, the GDP aggregate (index 2010=100) of countries applying a longer period of lockdown was about 7 points lower than countries applying a shorter period lockdown, likely due to systematic factor of deterioration of economic system given by the negative impact of COVID-19 pandemic and also different containment measures that have worsened this structural indicator of economic systems mainly in countries with longer periods of lockdown.

Discussion on what this study adds

This study analyzes how different policy responses to COVID-19 based on longer or shorter periods of lockdown have affected public health and economic system. Previous studies suggest that measures of containment can constraint the human-to-human transmission dynamics of infectious diseases in different ways (Atalan, 2020; Prem *et al.*, 2020; Tobías, 2020). However, to our knowledge, none investigations have performed a comparative analysis of the effects of longer or shorter period of lockdown on public health and economy of countries. *What this study adds to current studies* on the COVID-19 global pandemic crisis is that an accurate comparison of different government responses based on longer/shorter period of lockdown (from April to August 2020) to constraint the diffusion of COVID-19 pandemic, it suggests that a longer period of lockdown seems not to be associated with a statistically significant reduction of infected cases on population and variation of fatality rate, whereas countries applying a longer period of lockdown have a significant negative impact on economic system (given by contraction of real GDP growth % in 2020). In general, the COVID-19 pandemic tends to have natural dynamics that policy responses of lockdown at nation level seem to have a low impact in term of significant reduction of infected cases and mortality rates, but containment measures can slow down economic systems with consequent social issues. More specifically, results of the study here can be schematically summarized in the figure 5.

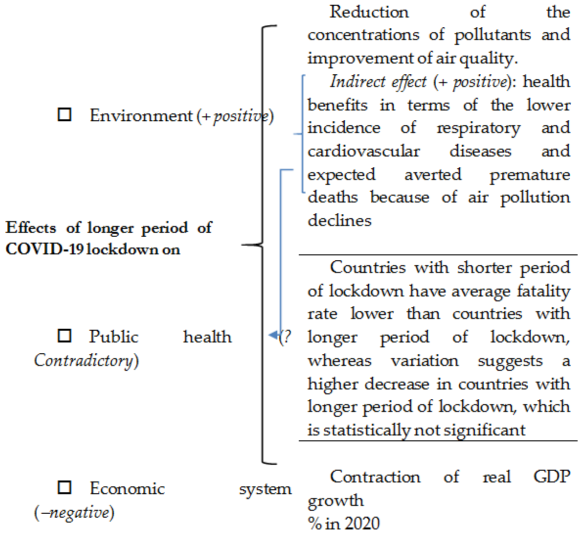


Figure 5. *Impact of national COVID-19 lockdown on environment, public health and economies*

In general, the policy response of lockdown has the main aim, as containment measure, to reduce the impact of infectious disease on public health, but results here suggest contradictory and not significant effects on reduction of confirmed cases and fatality rates of longer period of lockdown compared to shorter period. However, longer period of lockdown has a main indirect positive effect on public health because of the reduction of concentrations of pollutants that improves air quality, lowering future incidence of respiratory and cardiovascular diseases and expected averted premature deaths because of air pollution declines (cf., Coccia, 2020, 2020d; Pope, 1989, 1996). In fact, Cui *et al.* (2020), based on a case study in China, show that reductions in ambient air pollution have avoided premature deaths and related morbidity cases, with main economic benefits in terms of reduction of public health expenses and improvement of social wellbeing.

Overall, then, countries with the on-going COVID-19 pandemic have showed an uncertain governance and an unrealistic optimism about their low vulnerability that a second wave of this pandemic cannot hit them (cf., Weinstein, 1987). In fact, although the severe impact on public health of the first wave of the COVID-19 pandemic, countries have shown still a low level of national planning to manage the second wave of the COVID-19 pandemic crisis with ambiguous and uncertain policy responses based on lockdown and other containment measures. In general, it seems that they have not used in comprehensive way the process of learning of the first wave of COVID-19 pandemic to cope with similar problematic situations, supporting effective and especially timely critical decisions (cf., Coccia, 2020; 2020e).

Conclusions

The positive side of this study is that considers countries located in the same geo-economic area of the European Union having a similar social and democratic structure to perform a comparative analysis of containment measures to cope with COVID-19 pandemic. However, these results are based on a small sample of countries and future studies, to reinforce the generalization of these main findings, have to enlarge the sample, maintaining a comparable framework for statistical analyses. The statistical evidence here seems in general to show that the effects of longer *national lockdown* on public health in the first wave of COVID-19 pandemic are contradictory and not univocal, that is longer periods of lockdown seem not to significantly reduce confirmed cases and fatality rates, whereas can damage mechanisms of socioeconomic systems supporting the economic growth.

These conclusions are of course tentative because in the presence of the second and future waves of the COVID-19 pandemic and similar infectious diseases, manifold factors play a critical role. Countries are applying different policy responses of lockdown with different social restrictions in the presence of higher numbers of COVID-19 related infected individuals and deaths. However, the containment measure of lockdown, based on gradual and intermittent compulsory social restrictions, generates uncertain effects on the evolution of pandemic, public health and economic system.

Overall, then, there is need for much more detailed research on how countries in different economic, social, and institutional contexts can handle the COVID-19 pandemic crisis with different containment measures based on longer/shorter period of lockdown (Coccia, 2020e). To conclude, the investigation and explanation of the effects of shorter/longer period of lockdown on public health and economy are important, very important in order to design effective containment measures directed to minimize and/orcontain the impact of second and third waves of COVID-19 outbreaks and future epidemics similar to the COVID-19 in society, as well as to not deteriorate the economic system of nations.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No funding was received for this study.

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6 How to measure the environmental and health risk of exposure to future epidemics in cities?

Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is the strain of novel coronavirus that causes Coronavirus disease 2019 (COVID-19) with high numbers of COVID-19 related infected individuals and deaths in society (Coccia, 2020; Zhang *et al.*,, 2020). In this context, the main goal of this study is to analyze the first and second wave of the COVID-19 pandemic to compare the effects on public health in terms of confirmed cases, fatality rates and admission at Intensive Care Units. This study is important to explain the impact of COVID-19 pandemic to design effective policy responses for constraining the effects on public health and economic systems of on-going and future waves of the COVID-19 and similar epidemics.

What is already known on these topics is based on some studies from different disciplines. Glass (2020) analyses four large countries in Europe and the USA with a proposed model and results reveal that policy responses based on limited containment measures can generate an impact of the second wave of COVID-19 pandemic on public health higher than the first one: "The results indicate that relaxations took effect in terms of increasing numbers of cases with dates ranging from early June in some countries to mid-July in other countries. For the European countries, results suggest relaxations ranging from 31% to 57% are underway and if current trends continue unchecked could lead to significant second waves that last longer than the corresponding earlier waves. In the case of the US, where the number of cases has already peaked for a second time, an extended version of the model suggests that the level of transmission may now be similar to that after the first peak". Bontempi (2020) argues that from September 2020, Europe has to cope with the appearance of a COVID-19 second wave. The Italy situation compared with other large European countries (e.g., France, Germany, UK, and Spain) seems to show a lower impact on public health likely due to containment measures applied in the first wave of COVID-19 pandemic (cf., Atalan, 2020; Prem *et al.,,* 2020). Cacciapaglia *et al.* (2020) apply the *Epidemic Renormalisation Group* approach to COVID-19 pandemic, using data of the first wave, to simulate the transmission dynamics of this novel infectious disease as well as the diffusion across different European countries. Results of simulation model suggest that the peak of the second wave can be roughly between July 2020 and January 2021. In particular, the timing of the peak can be estimated considering different non-pharmaceutical measures of containment and mitigation and in addition: "The sensitivity of the second peak prognosis on the value of the infection rates gives a clear indication that social distancing measures and responsible individual behavior can have a strong effect if implemented early on" (Cacciapaglia *et al.,,* 2020). Instead, Renardy *et al.,* (2020) apply a model based on discrete and stochastic network in a case study of Washtenaw County in Michigan (USA) to forecast the second wave of the COVID-

19 pandemic. Results show that a delay of reopening does not reduce the total impact of the second peak of confirmed cases, but only delays it. However, simulations of the model reveal that a reduction of casual contacts between people can both delay and reduce the peak of the second wave of COVID-19 pandemic. Gatto *et al.,* (2020), based on their transmission model, argue that restriction to mobility and human interactions can reduce transmission dynamics of the COVID-19 pandemic by about 45%. Other studies show that specific places have a high risk to be COVID-19 outbreaks, acting as *suprspreaders* (Chang *et al.,* 2020). In particular, model by Chang *et al.* (2020), using cell phone data, predicts that a small minority of points of interest (called, POIs), such as restaurants and religious establishments, account for a large majority of infections; as a consequence, restricting maximum occupancy at each POI is more effective than uniformly reducing mobility. Moreover, higher infection rates among disadvantaged racial and socioeconomic people are due to their behavior of visiting more crowded and higher-risk places (Chang *et al.,* 2020). In this context, countries and regions can apply timely containment and mitigation measures, such as personal protective equipment, school closing, cancellation of public/private events, restrictions on mass gatherings in public and private places, restriction on internal mobility and international travel, etc. to reduce the threats of accelerated diffusion of the waves of COVID-19 pandemic and similar viral agents in society (Petherick *et al.,* 2020). Chu *et al.* (2020) also point out that mitigation measures based on social distancing and the use of facemasks seem to be effective to reduce the risk factors of transmission of the novel coronavirus. Instead, van Weert (2020) states that in the presence of a shortage of personal protective equipment, social distancing is a vital control measure to reduce the transmission dynamics of the COVID-19 pandemic in society (cf., Islam, 2020).

However, studies just mentioned are mainly based on models that generate simulations with computer experiments to predict eventual real effects of the dynamics of COVID-19 pandemic in different urban contexts. *What is hardly known in these research topics* is, using current data of COVID-19 pandemic, to explain whether the evolution of the second wave of the COVID-19 is generating an impact on public health higher or lower than first pandemic wave. The study here proposes an empirical analysis based on available data to explain the evolutionary dynamics of the second wave of COVID-19 compared to first one to design effective strategies of crisis management to cope with recurring waves of COVID-19 pandemic and future epidemics of new viral agents[1].

Study design

Data collection

The paper here is based on a case study of Italy that was the first large European country to experience a rapid increase in COVID-19 confirmed cases and deaths from March 2020. This study focuses on evolution of the first and second wave of COVID-19 pandemic in Italy. The end of the first wave of COVID-19 is detected here considering the minimum number of confirmed cases from February 2020 onwards, which is the 31 July 2020;after this date, confirmed

[1] For additional readings of these topics, see For studies about the interaction between science, technology and innovation, their sources, evolution, diffusion and impact on socioeconomic systems, see: Cavallo et al., 2014; Coccia, 1999, 2001, 2004, 2005, 2005a, b, c, 2006, 2007, 2008, 2009, 2009a,b,c; 2010, 2010a,b; 2012, 2012a,b; 2013; 2014, 2014a, b, c,d; 2015, 2015a, b; 2016, 2016a; 2017, 2017a, b, c, d, e, f, g, 2018, 2018a, b, c, d, e, f, g, h, i; 2019, 2019a, b, c, d, e, f, g, h, i, l, m; Coccia, 2020a, b, c, d, e, f, g, h, i, l, m, n, o, p, q, r; Coccia and Bellitto, 2018, Coccia and Cadario, 2018; Coccia et al., 2015; Coccia and Finardi, 2012, 2013; Coccia et al., 2012; Coccia and Rolfo, 2008, 2009, 2010, 2013, Coccia and Watts, 2020.

cases begin to increase and this study considers the starting of the second wave of COVID-19 pandemic in Italy, i.e., 1st August 2020. In particular, this study considers data for 105 days from the starting of each wave for a comparable framework of analysis:

❑ *First wave of COVID-19* from 24thFebruary, considering *N*=105 days

❑ *Second wave of COVID-19* from 1st August 2020 onwards, also considering *N*=105 days

In the context of first wave of COVID-19 pandemic, the containment measures of national lockdown and quarantine in Italy started on 8th March 2020 and ended on 18thMay 2020 (Governo Italiano, 2020). In addition, Italy is located in the North hemisphere of the globe and the summer season started on 20-21 June 2020 and ended 23 September 2020, for a period of 92 days of warmer temperatures. This period is important for current study because some papers suggest that hot weather can reduce the viral infectivity of COVID-19: "high temperatures damage the virus lipid layer decreasing its stability and infection potential and may even cause virus inactivation, therefore lowering the transmission rate" (Rosario Denes *et al.,* 2020, p. 4).

In the context of second wave of COVID-19, Italian government on 3 November 2020 applied different containment measures according to the impact of COVID-19 in regions in terms of level of admission to Intensive Care Units (ICUs) and other factors of health sector: *red* regions with full lockdown based on restrictions to individual mobility and closure of schools and public/private events; *orange* regions with a partial lockdown, and *yellow* regions in which people mainly have to wear protective mask against droplets of the coronavirus into the air and respect social distancing (cf., Chaudhry *et al.,* 2020; Coccia, 2020f; Islam, 2020).

Data of the COVID-19 pandemic under study here are:

- daily confirmed cases
- daily deaths
- daily admission to Intensive Care Units (ICUs)
- daily swabs

Period under study is from 24 February to November 2020 and source of data is the Ministero della Salute (2020) in Italy.

Variables

Dynamics of the first and second wave of the COVID-19 pandemic in Italy is measured by:

- *Daily confirmed cases standardized* = ratio of confirmed cases (t) / swab test (t-2). The lag of about 2 days from swab test to the result of positivity to the novel coronavirus (confirmed case) is based on average time of laboratories to deliver results of the COVID-19 swab test that is roughly 1-2 days from the date of specimen pickup (LabCorp, 2020).
- *Daily admission to ICUs standardized* = ratio of admission to ICUs (t) / confirmed cases at (t-5). The lag of about 5 days from initial symptoms, positivity to swab test to the hospitalization and recovery in ICUs of patients is based on average time from diagnosis to hospitalization as explained by specific studies (Faes *et al.*, 2020).
- *Daily Fatality rate* = ratio of deaths at (t) /confirmed cases at (t-14). The lag of about 14 days from initial symptoms to deaths is based on empirical evidence of some studies (Zhang *et al.*, 2020).

Methods of statistical analysis

Firstly, data are analyzed with descriptive statistics, comparing arithmetic mean of measures just mentioned between first and second wave of the COVID-19pandemic in Italy.

Secondly, each measure is represented in graphs comparing trends of the 1st wave and 2nd wave of COVID-19 pandemic, inserting the specific measure on *y*-axis (e.g., fatality rates) and temporal unit on *x*-ax is given by progressive numbers, in which the number 1 indicates the starting of the pandemic wave (i.e., 24th February for 1st wave and 1st August for 2nd wave), the number two is the second day of COVID-19 pandemic wave, and so on. Moreover, the three indicators are also compared within the 1st and 2nd wave to have a comparative analysis of the overall evolutionary dynamics of COVID-19 pandemic (cf., Coccia & Benati, 2018).

Thirdly, the study explores relationships between variables with correlation analysis and test of association. This study extends the analysis with a regression model based on a linear relationship in which variables measuring the impact of the COVID-19 on public health are linear function of time (days from starting of the pandemic wave for a period of 105 days). The specification of linear relationship is given by a semi-log model:

$$log\ y_t = \alpha + \beta t + u \qquad (1)$$

y= measures of the impact of COVID-19 pandemic in society: Daily fatality rate, Daily admission to ICUs, Daily confirmed cases

t= time given by progressive numbers representing days of the first and second wave of COVID-19 pandemic

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 SPSS® version 26.

Results

Impact of the COVID-19 pandemic on public health comparing 1st and 2nd wave

Table 1. *Descriptive statistics of variables measuring the impact on public health of waves of COVID-19 pandemic*

	1 W Fatality rates	2 W Fatality rates	1 W Admission to ICUs	2 W Admission to ICUs	1W Confirmed cases	2W Confirmed cases
Mean	0.242	0.019	0.877	0.126	0.089	0.047
Std. Error of Mean	0.034	0.001	0.027	0.004	0.009	0.005

Note: W=wave; *N*= 105 days from the starting of the wave of COVID-19 pandemic; Fatality rate = ratio of deaths at (t) /confirmed cases at (t-14); Admission to ICUs = ratio of admission to ICUs (t) / confirmed cases at (t-5); Confirmed cases = ratio of confirmed cases (t) / swab test (t-2).

First wave of COVID-19 pandemic shows from February 2020 onwards an average fatality rate of about 24%, whereas second wave of COVID-19–for the same number of 105 days from the starting in August 2020–indicates an average fatality rate of about 1.9%. Comparative analysis of the average admission to Intensive Care Units (ICUs) shows an 87.7% in the first wave and about 13% in the second one. Instead, standardized confirmed cases with swab tests show that it is about 9% in the first pandemic wave of COVID-19 and roughly 5% in the second one (Table 1). Figures 1-2-3 show the trend of variables just mentioned confirming, *ictu oculi,* that the impact of the first wave of COVID-19 pandemic in Italy on public health has been stronger than second one in the first 105 days of the evolution of this pandemic.

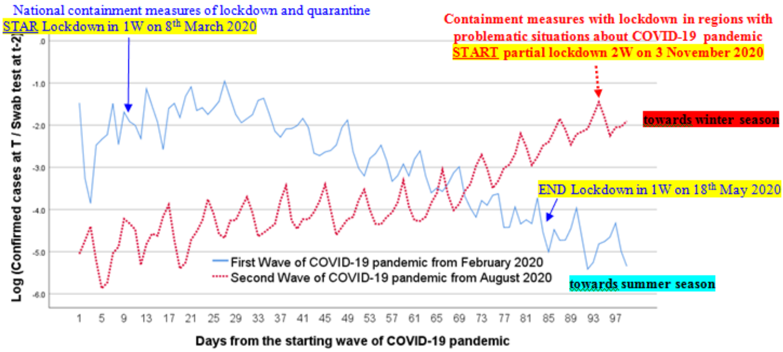

Figure 1. *Trend of confirmed cases of the first and second wave(W) of COVID-19pandemic in Italy, first 105 days*

However, Figure 1 of confirmed cases reveals a growing trend for second pandemic wave, whereas the first one has a declining trend also because of lockdown and quarantine and the progression of COVID-19 pandemic towards summer season when the novel coronavirus seems to have a seasonality with natural reduction of transmission for better weather conditions (e.g., hot temperatures) and also low levels of air pollution for containment measures applied (cf., Coccia, 2020, 2020a, 2020b; Rosario Dentes *et al.*, 2020).

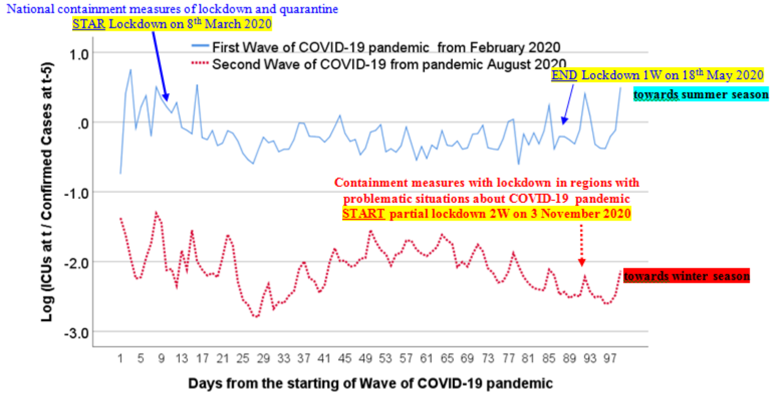

Figure 2. *Trend of ICUs of the first and second wave (W) of COVID-19 in Italy, first 105 days*

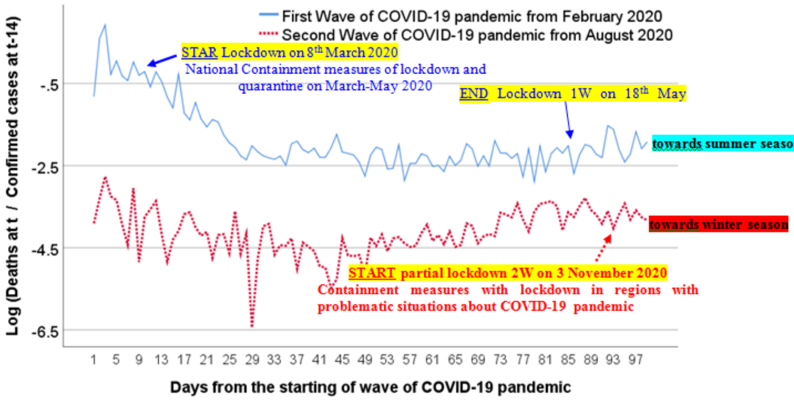

Figure 3. *Trend of fatality rate of the first and second wave(W) of COVID-19 in Italy, first 105 days*

Figure 2 shows trends of admission to ICUs: the second wave has an intensity lower than first pandemic wave and both waves seem to have stable dynamics. Instead, figure 3 shows trends of fatality rates: second pandemic wave has a low magnitude over time, suggesting a low impact on public health until November 2020.

Table 2. *Bivariate correlation of indicators in the First Wave of COVID-19 pandemic*

	Fatality rates	Admission to ICUs	Confirmed cases
Fatality rates	1		
Admission to ICUs	0.664**	1	
Confirmed cases	0.236*	-0.218*	1

Note: Values in *log* scale; ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed); Fatality rate = ratio of deaths at (t) /confirmed cases at (t-14); Admission to ICUs = ratio of admission to ICUs (t) / confirmed cases at (t-5); Confirmed cases = ratio of confirmed cases (t) / swab test (t-2); *N*=105 observations form starting of the wave in February 2020.

Table 2 shows bivariate correlation analysis of variables under study in the first wave of COVID-19 pandemic: fatality rates have a high positive association with admission to ICUs (r=.66, p-value <.01), and a lower positive association of the coefficient of correlation is between fatality rates and confirmed cases (*r*=.24, *p*-value <.05), whereas correlation between ICUs and confirmed cases is negative (*r*= –.22, *p*-value <.05). Table 2 seems to show that many infected individuals died as well as a lot of patients in ICUs likely because of low knowledge of the pathology and evolution of COVID-19 in patients, and lack of appropriate ther apies and low number of ICUs in hospitals (Gattinoni *et al.*, 2020; Sterpetti, 2020). Table 3 shows tentative results for second wave of COVID-19 pandemic: correlation has a significant positive association between fatality rates and confirmed cases (*r*=.30, *p*-value <.01), whereas coefficient between ICUs and confirmed cases correlation is negative with an association higher than in the first epidemic wave (*r*=–.38, *p*-value <.01) likely because a lot of confirmed cases have not severe symptoms of COVID-19 and do not require utilization of ICUs.

Table 3. *Bivariate correlation of indicators in the Second Wave of COVID-19 pandemic*

	Fatality rates	Admission to ICUs	Confirmed cases
Fatality rates	1		
Admission to ICUs	-0.177	1	
Confirmed cases	0.303**	-0.381**	1

***Note*:** Values in *log* scale; ** Correlation is significant at the 0.01 level (2-tailed); Fatality rate = ratio of deaths at (t) /confirmed cases at (t-14); Admission to ICUs = ratio of admission to ICUs (t) / confirmed cases at (t-5); Confirmed cases = ratio of confirmed cases (t) / swab test (t-2); *N*=105 observations form starting of the wave in August 2020.

Table 4. *Estimated relationships, based on linear model of regression*

DEPENDENT VARİABLE (*log*)	1W Fatality rates	2W Fatality rates	1W Admission ICU	2W Admission ICU	1W Confirmed cases	2W Confirmed cases
Constant α	–1.02***	–4.31***	–.001	–1.94***	–1.02***	–5.33***
Coefficient β	–.016***	.004*	–.096	–.003**	–.037***	.032***
Stand. Coeff. Beta	–.608	.23	–.16	–.33	–.88	–.887
R^2	.37	.05	.03	.11	.77	.82
(St. Err. of Estimate)	(.63)	(.54)	(.27)	(.31)	(.61)	(.46)
F	60.31**	5.56*	2.76	12.38***	353.13***	456.15***

Notes: W=pandemic wave. ; Explanatory variable: *time units;* Dependent variables: Fatality rate = ratio of deaths at (t) /confirmed cases at (t-14); Admission to ICUs = ratio of admission to ICUs (t) / confirmed cases at (t-5); Confirmed cases = ratio of confirmed cases (t) / swab test (t-2); *N*= 105 observations from starting of the wave; *Significance:* ****p*-value<0.001¸***p*-value<0.01¸**p*-value<0.05

Table 4 shows the estimation of parameters in linear relationships between a number of variables and time as explanatory variable. The coefficient of regression of the model of fatality rate (dependent variable) indicates that in the first wave of COVID-19 pandemic, an increase of 1 day, it reduces the expected fatality rate by.02 (*p-value* = .001), whereas for second wave of the COVID-19, an increase of 1 day, it increases the expected fatality rate by a mere .004 (*p-value* = .05). The model's R^2 value indicates in the first wave that about 37% of the variation of fatality rate can be attributed (linearly) to time, whereas for second pandemic wave the coefficient of determination is rather low. The coefficient of regression of the model of admission to ICUs (dependent variable) indicates not significant results in the first wave, whereas in the second wave an increase of 1 day, it decreases the expected admission to ICUs by .003 (*p-value* = .001).Finally, the coefficient of regression using confirmed cases as dependent variable indicates that in the first wave of COVID-19 pandemic, an increase of 1 day, it reduces the confirmed cases by about .037 (*p-value* = .001), whereas for the second waves of COVID-19 pandemic, it increases by .032 (*p-value* = .001). In the last models for first and second wave of COVID-19 pandemic, R^2 coefficient indicates that more than 76% of the variation of confirmed cases can be attributed (linearly) to time.

General observation of regression analysis is that the first wave of the COVID-19 pandemic after national containment measures and the evolution towards summer season has a tendency to reduce fatality rates and confirmed cases, whereas during the first 105 days the second wave of

COVID-19 has a low increase of fatality rate and confirmed cases but a moderate reduction of admission of patients to ICUs likely also for the evolution towards autumn-winter season when climate conditions can affect the COVID-19.

Analysis within the first and second wave of COVID-19 pandemic

In order to analyze the impact of the COVID-19 pandemic over time in society, variables under study are represented simultaneously in the same graph for 105observations from starting day of the pandemic wave. Figure 4 shows that the first wave of COVID-19 pandemic from February 2020 has a declining trends of confirmed cases, the admission to ICUs has a high level rather stable, whereas the fatality rates after a decline in the first 30 days of the pandemic, in March or thereabout it becomes stable over time.

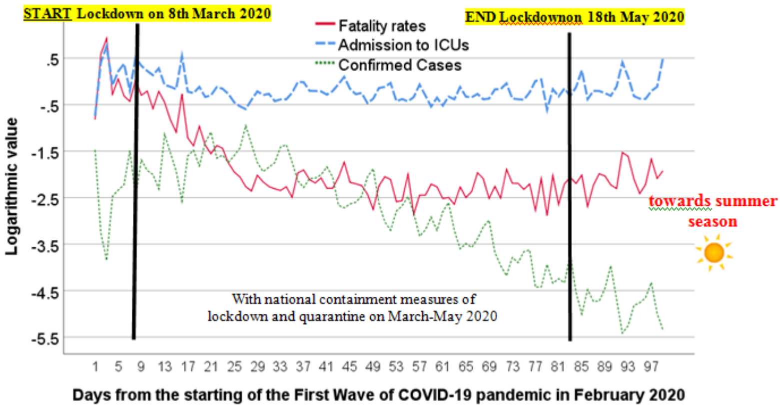

Figure 4. *Effects of the first wave of COVID-19 pandemic on public health in Italy, first 105 days from February 2020*

Figure 5 shows trends for second wave of COVID-19 from August 2020 to November 2020: admissions to ICUs are rather stable and with a level lower than first wave, whereas trend of confirmed case has a consistent grow, finally trend of fatality rates seems to have a stability in this period of autumn season.

These results suggest that in general the first wave has had a stronger impact on public health, reduced with the approaching of summer season and national containment measures. Instead, the second wave of COVID-19 pandemic has a dynamic still in evolution that seems also to be related to climate and seasonality that may increase the impact on public health in autumn-winter season 2020-2021 like all influenza diseases, though with a lower intensity compared to the first wave of COVID-19 pandemic.

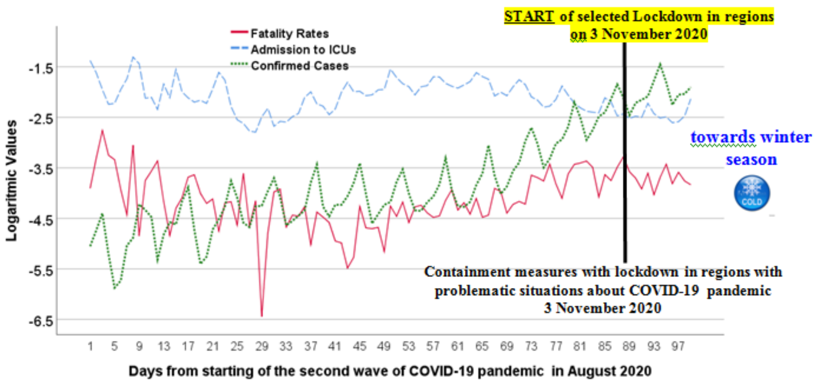

Figure 5. *Effects of the second wave of COVID-19 pandemic on public health in Italy, first 105 days from August 2020*

Discussion

What this study adds to current studies on the COVID-19 global pandemic crisis is that an accurate comparison of the first and second wave of COVID-19 pandemic suggests that the first one seems to have had a stronger impact on public health, until now. In addition, government responses in the first wave of COVID-19 pandemic, based on national lockdown and quarantine, seem to have lightly constrained the diffusion of COVID-19, also helped with the approaching of summer season 2020 (cf., Coccia, 2020d, 2020f; Tobías, 2020). In general, the COVID-19 pandemic tends to have natural dynamics and seasonality that policy responses of nations seem to mitigate but without generate a significant reduction of infected cases and fatality rates (Coccia, 2020f). In fact, countries with the on-going COVID-19 pandemic have showed an uncertain governance and an unrealistic optimism about their low vulnerability that a second wave of this pandemic cannot hit them (cf., Weinstein, 1987). Although the severe impact on public health of the first wave of COVID-19 pandemic, many countries have shown still a low capability of national planning for crisis management adopting ambiguous, delayed and uncertain policy responses in the presence of recurring waves of COVID-19 pandemic crisis. In general, it seems that countries have not used in comprehensive way the process of institutional learning of the first wave of COVID-19 pandemic for supporting effective and timely critical decisions to cope with similar problematic situations generated by second pandemic wave on public health (cf., Coccia, 2018, 2019, 2020; 2020e).

Conclusion remarks

The study here sought to understand different impact on public health of the first and second wave of the COVID-19 pandemic, analyzing a case study in Italy.

The results of analysis are:

- ☐ First wave of COVID-19 pandemic showed an average fatality rate of 24%, whereas second wave of COVID-19 indicates an average fatality rate of about 1.9%.
- ☐ Average admission to Intensive Care Units (ICUs) was an 87.7% in the first wave and is about 13% in the second one.

- ☐ Average confirmed cases was about 9% in the first pandemic wave of COVID-19 and is about 5% in the second one.
- ☐ However, confirmed cases are growing for second pandemic wave, whereas the first one had a declining trend also because of national containment measure and the progression of COVID-19 pandemic towards summer season.
- ☐ Analysis of relationships between variables shows a high impact on public health of the first wave of COVID-19 pandemic that reduces intensity over time, whereas second wave of COVID-19 pandemic has until now a lower impact on public health but evolutionary dynamics seems to increase the intensity with the progression in the direction of winter season.

The positive side of this study is that considers a large European country, Italy, that was the first country in western world to experience a rapid increase in confirmed cases and deaths; subsequently, many countries have had a similar impact on public health of COVID-19 pandemic crisis. However, these results are based on a case study and future studies, to be reinforced in terms of generalization of suggested findings, have to enlarge the sample considering other European countries to maintain a comparable framework for statistical analyses. Hence, these conclusions are of course tentative becausein the presence of the second and future waves of the COVID-19 pandemic manifold socioeconomic and environmental factors play a critical role (Coccia, 2020a, 2020b, 2020c, 2020d). There is need for much more detailed research on how COVID-19 pandemic and similar epidemics evolve in different economic, social, environmental and institutional contexts and especially in a specific period of time of a given geographical area (Coccia, 2020e). Overall, then, the investigation and explanation of the effects of pandemic waves on public health and economy are important, very important in order to design effective containment measures, apply new technologies and support R&D investments for public research directed to minimize the impact of future COVID-19 outbreaks and other epidemics similar to the COVID-19 in society, as well as interventions for not deteriorating structural indicators of the economic system of nations[2].

To conclude, although vital results of the first wave of the COVID-19 pandemic from February to August 2020, policymakers have had an unrealistic optimist behavior that a new wave of COVID-19, started in September 2020, could not hit their countries and, especially, a low organizational capacity to plan effective policy responses to cope with recurring COVID-19 pandemic crisis (cf., Coccia, 2020f, 2020g). As a result, inappropriate and delayed policy responses associated with inefficient practices of crisis management to constrain impact of new wave of COVID-19 is again generating negative effects, *déjà vu*, on public health and of course economic systems.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No funding was received for this study.

[2] Cf., Coccia, 2016, 2017a, 2017b, 2018a, 2019a, 2020h; Forman et al., 2020.

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7 Critical decisions for crisis management: an introduction

Introduction

The markets and environment have, more and more, a growing dynamism that generates uncertainty and turbulence (Johnson & Scholes, 1988; Emery & Trist, 1965). In uncertain and unstable environment, organizations/nations are open systems having activities in interaction with external factors (McDermott & Taylor, 1982; Gioia & Chittipeddi, 1991). Organizations/nations and leaders can confront crises and problematic situations that they do not face on a daily basis—for example, in the presence of hurricane, earthquake, political instability, pandemic, terroristic attacks, financial crisis, etc. (cf., Farazmand, 2001, 2007). Critical decisions are hard calls, which involve tough value trade-offs and also major changes, such as stop the production, lockdown, quarantine of population, social restrictions, staff cuts and/or move the location of firms in other geoeconomic regions, etc.In short, organization/nation and management in emergency situations have to take critical decisions to cope with consequential environmental threats in the presence of highly restricted time, endeavoringto minimize possible losses for a worst case scenario. A critical and effective decision requires interagency and inter-organizational coordination. Moreover, the effective implementation of critical decisions requires that personnel of different departments work together. In this context, public organizations are originally designed to conduct routine business in accordance with values of fairness, lawfulness, and efficiency. However, critical decisions in the presence of a crisis require flexibility, improvisation, and the breaking of rules in a very short time[1].

Type of crisis and risks for applying critical

[1] In this context, for studies about the interaction in different environments/conditions between decision systems, science, technology and innovation, their sources, evolution, diffusion and impact on socioeconomic systems, see: Cavallo et al., 2014; Coccia, 1999, 2001, 2004, 2005, 2005a, b, c, 2006, 2007, 2008, 2009, 2009a,b,c; 2010, 2010a,b; 2012, 2012a,b; 2013; 2014, 2014a, b, c,d; 2015, 2015a, b; 2016, 2016a; 2017, 2017a, b, c, d, e, f, g, 2018, 2018a, b, c, d, e, f, g, h, i; 2019, 2019a, b, c, d, e, f, g, h, i, l, m; Coccia, 2020a, b, c, d, e, f, g, h, i, l, m, n, o, p, q; Coccia and Bellitto, 2018, Coccia and Cadario, 2018; Coccia et al., 2015; Coccia and Finardi, 2012, 2013; Coccia et al., 2012; Coccia and Rolfo, 2008, 2009, 2010, 2013, Coccia and Watts, 2020.

decisions

A critical decision occurs in the presence of a crisis given by an unexpected complex problem that threats organizations, countriesor societies at risk (Farazmand, 2001). A general definition of risk for organizations/nations is a performance variance or environmental threat that negatively impacts the organization/nation/society (cf., Bouchet *et al.*, 2003, p.10). The sources of crises can either originate internally or externally to organizations/nations. If organizations/nations do not decide timely a solution, and sources of risk are left unaddressed, they can permanently damage the business, public service, organization, population and society with consequent socioeconomic problems. The identification of a crisis needs the evaluation of vital elements, such as: a) the problem must pose an imminent threat to the organization/nation; b) the situation must involve an element of surprise or shock; c) unexpected and uncertain nature of a complex problem will place pressure on organizations to make timely and effective critical decisions. Crisis can be due to manifold factors: rapid evolution of technology (Coccia, 2005a, 2006, 2014, 2017, 2017a, 2019; Coccia & Watts, 2020); natural disasters, such as earthquake, hurricane, flood, etc., as well as pandemic diseases that generate socioeconomic shock and severe health damages (cf., Coccia, 2017d); economic crisis generated by hyperinflation, high public debt, energy shortages etc. (cf., Coccia, 2005, 2007, 2010, 2016; Coccia, 2017b);political risk and revolutions (cf., Coccia, 2017c, 2019, 2019a, 2019b, 2019c; Farazmand, 2001; Miller, 1992); terrorism of some group organized that has technical skills to carry out a terrorist action directed to challenge a nation's authority and induce fear and anxiety into civilian population (cf., Crenshaw, 1981, Coccia, 2018, 2018a, 2018b, 2018c; Krueger, 2007; Newman, 2006). The effect of crises can be worsened by weak infrastructure and inefficiencies of local and national institutions; social crisis that increases violence in society.

Crisis management and types of critical decisions

Organization can design a crisis management team for managing strenuous situations and complex problems and making critical decisions to resolve, as far as possible, them. Crisis management team should deal with threats before, during, and after they have occurred (cf., Groh, 2014). Successful crisis management teams understand the different types of crisis and are thoroughly prepared for all situations. Moreover, in a crisis, leaders are expected to reduce uncertainty and provide an authoritative account of problems, solutions and difficulties. When leaders have to formulate a strategy and critical decision for complex problems, they also must get others to accept the proposed solution. In fact, the critical decisions of leaders can coincide and compete with those of other parties, who hold other positions and interests and who are likely to suggest various alternative solutions and actions (Venette, 2003). Vital factors for a critical decision in aversive environment are:

(a) a threat to the organization
(b) the element of surprise
(c) a short decision time

Different types of critical decisionsare (cf., Seeger *et al.*, 1998; Shrivastava *et al.*, 1988; Bundy *et al.*, 2017):

Responsive critical decision

When a problem hits organizations/nations, it is important to have a plan of action ready that matches the situation at hand. Crisis management executes the plan of critical decisionand handles any unexpected roadblocks that may pop up.

Proactive critical decision

Proactive critical decision anticipates a potential problem and works to prevent it, or prepare for it. For example, building an earthquake-resistant factory and sharing an evacuation plan with employees/populationare methods to prepare for natural disasters. While not all crises can be prevented or planned for, actively monitoring for threats to organizations/nationscan reduce the impact of problematic situations in society.

Recovery critical decision

Sometimes, itis not possible to see the complex problem coming (e.g., earthquake, pandemic diffusion, etc.), or it is too late to prevent the damage it caused. In these cases, organizations/nations may not be able to lessen the impact, but it can begin to salvage what is left of the situation.

Structure of decision making and strategies for critical decisions

The process of critical decisions is based on strategic operations and steps, such as (Linstone, 1999):

– the definition of a complex problem *Pr* from volatile environment, and the implicit assumption that the problem can be solved.After that, it is important to gather information for possible solutions of the problem *Pr*

– *Reductionism*, the study of complex problems in terms of a very limited number of variables and the critical interaction among them

– Identification of the purpose of critical decision about the complex problem *Pr*under study

– Suggestion and evaluation of different alternative solutions to complex problem *Pr*under study

– Ignoring or avoiding the individual interests

– Selection of the optimal solution, or the search whenever possible, for a best solution in a short time

– Implementation of the critical decision and evaluation of results

In short, the starting point of critical decision is a complex problem that we assume a possible solution exists. A complex problem has several solution concepts (*Sl*), each of which leads to several consequential problems (*Pr*) and solutions (*Sl*). A critical decision can be schematically summarizedby a tree structure of decision makingwith consequential levels of *Pr* and *Sl*(Fig. 1).

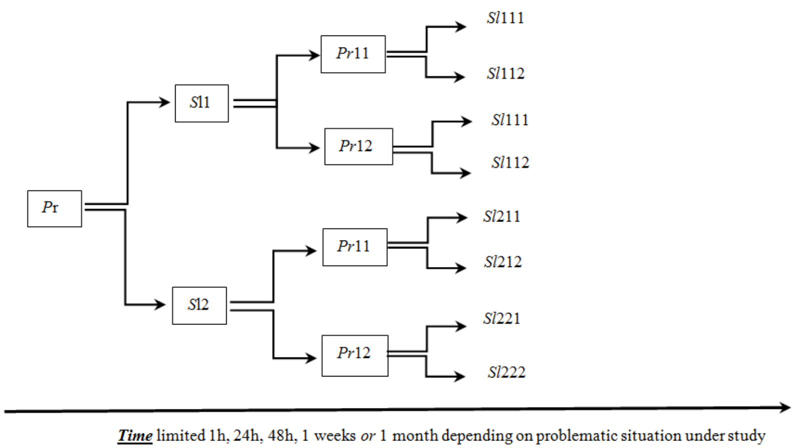

Figure 1. *The problem-solution tree for critical decisions.*

Note. *Pr*=problem; *Sl*=Solution.

Note: the increasing number from left to right indicates the sequence of decisions to cope with consequential problems

Different strategies for critical decisionsin the presence of turbulent scenario are schematically summarized in Figure 2.

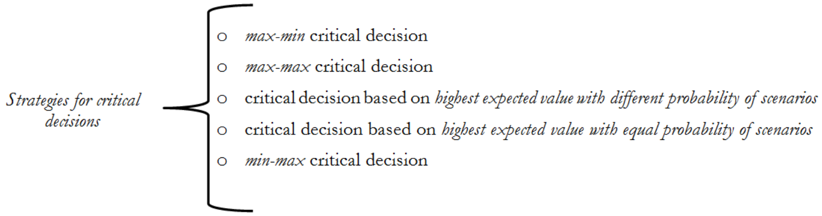

Figure 2. *Strategies for critical decisions*

A simple example can clarify these different strategies for critical decisions (cf., Lloyd & Dicken, 1977).

First of all, we create a matrix of outcome associated with strategies and environmental situations (or *payoffs*)as in Table 1.

Table 1. *Matrix of payoffs for a critical decision process*

	Environmental Situation		
	I	II	III
Strategy 1	200	155	145
Strategy 2	130	220	130
Strategy 3	118	118	225

Critical decision depends on manifold endogenous and exogenous factors, also considering the behavior of management towards risk and uncertainty. Results of critical decision listed in Figure 1 are as follows.

○ *Pessimistic critical decision* is based on a rule of *max-min*, selecting the max of the worst result in each strategy:

145 for strategy 1	Critical decision with *max-min*
130 for strategy 2	
118 for strategy 3	

○ *Optimistic critical decision* is based on a rule of *max-max*, selecting the max of the best result in each strategy:

200 for strategy 1	
220for strategy 2	
225 for strategy 3	Critical decision with *max-max*

○ *Rational critical decision*considers relative probabilities of each environmental situation.

If the probability of different environmental situations in table 1 is assumed to be:

	Probability
Environmental Situation I	0.2
Environmental Situation II	0.5
Environmental Situation III	0.3
Total (certain event in probability)	1.0

then, critical decision here is based on selecting the strategy with the *highest expected value*, given by:

Strategies		*Expected value*
strategy 1	0.2(200)+0.5(155)+0.3(145)	*=161*
strategy 2	0.2(130)+0.5(220)+0.3(130)	*=175* Critical decision
strategy 3	0.2(118)+0.5(118)+0.3(225)	*=150.1*

○ *Approximate critical decision* assumes that the probability of different environmental situations is equal. Table 1 has three environmental situations and the equal probability is 0.333 (i.e., 1/3=0.333….):

	Probability
Environmental Situation I	0.333…
Environmental Situation II	0.333…
Environmental Situation III	0.333…
Total (certain event in probability)	1.000

This critical decision is also based on selecting the strategy with *the highest expected value:*

Strategies		*Expected value*
strategy 1	0.33(200)+ 0.33 (155)+ 0.33 (145)	*=165* Critical decision
strategy 2	0.33 (130)+ 0.33 (220)+ 0.33 (130)	*=158.4*
strategy 3	0.33 (118)+ 0.33 (118)+ 0.33 (225)	*=152.5*

○ *Critical decision with Min-Max strategy*

If the critical decision, *a priori*, is strategy 3 and the environmental situation, *a posteriori*, is I in table 1, the best critical decision *ex-post*would be strategy 1, rather than strategy 3; the regret ex-post for the wrong choice done *a priori*is 83 (i.e., 200-118). The calculation of this value for each cell is the base for *Min-Max* rule of critical decision, given by minimizing the max value of strategies, i.e.,

80 for strategy 1	
95 for strategy 2	
82 for strategy 3	Critical decision with *Min-Max*

Improvisation for critical decisions

Planning can reduce uncertainty, but even the most carefully devised plans may have to be abandoned or modified in the face of unanticipated changes or challenges.

Improvisation is one of approaches that stands outside of rational models of decision making mentioned above. Improvisation is a combined behavioral and cognitive activity that requires consequential creativity under tight time constraint in order to meet performance objectives (Mendonça & Fiedrich, 2006, p. 350). Improvisation carries an immediate answer for a need in the presence of environment threats (Lee, 1995). Improvisation is also a way of take advantage of important and unexpected opportunities without formal plans or systematic procedure (Sharkansky & Zalmanovitch, 2000). While rational planning aims to control a situation by reducing the uncertainty, improvisation is a reaction to a novel situation and a way of working within uncertainty. While rational planning is directed at optimal solutions, improvisation aims at dealing with problems rather than solving them in an optimal manner. In short, improvisation may be employed to overcome the limitations of rational planning. Understanding of cognition in highly non-routine situations can lead to improvements for decision-making in these situations (Klein, 1993). A two-stage process for improvisation may be: 1) the organizationrecognizes either that no plan applies to the current situation or that plan cannot be executed; 2) the responding organizationhas to develop and deploy one or more new procedures. Mendonça & Fiedrich (2006, p. 350) argue that:

The improvisation may range from substitution (e.g., using a close substitute resource for one that is unavailable) to the construction of new procedures (e.g., developing an entirely new procedure). In the case of substitution, the responding organization 'mixes and matches' existing procedures and/or the materiel used in them. At the other end of the spectrum, the organization must develop new procedures and possibly find new material for use in those procedures. More radically, it may also entail changing the goals of the response (e.g., deciding in the field that the real problem to be solved is providing shelter in place rather than evacuating).

The question of when to improvise for a critical decision may be conceptualized as a choice problem, in which the ability or likelihood of a decision-maker to categorize correctly is influenced by a number of factors, such as penalties associated with making an incorrect choice and the likelihood that the response will succeed. The question of how to improvise may be conceptualized as a search and assembly problem, which may be influenced by factors, such as time available for planning, risk in the environment and the results of prior decisions. In short, learn how to develop and deploy new procedures and critical decisions in a consequential manner under time constraint; after that, inform multiple decision-makers and make inferences about the present and likely future states of complex systems (Weick, 1993, 1998). Indeed, training has proven capable of improving human ability to recognize salient similarities and differences between current and past situations for critical decisions– even at a very fine-grained level (Klein, 1993). Hence, improvisation involves the ability to act in real time, when the need arises, and to find an action when none of the established alternatives appear to be practical. It is useful when there is uncertainty, few precedents, or few reliable facts and suitable routines; and when there is pressure to act in a short time or with resources that appear to be insufficient. Stressful environments may foster improvisation more than less fraught ones. Thus, unpredictable and rapidly changing environments are probably more likely to promote improvisation than more stable environments. Improvisation may be more likely when there is not enough time, information, knowledge, or material resources to plan, measure, weigh, consider, and document an optimal response, or when opposing demands are so intense that calculated compromise appears unproductive. Thus, critical decision with improvisation is likely to occur in emergencies, crises, and novel situations, and when the problem it comes to address is perceived to be intractable. Improvisation has inherent drawbacks. It may generate instability and consequential improvisations to cope with the effects of previous improvisations. Improvisation tends to be judged by its results that can lead to success or fail.

Conclusions

The decision rule and mechanism for critical decisions, of course, change according to the situation that can be affected by manifoldorganizational and environmental variables. In this context, it is important to consider the *ecological rationality* that claims *how* the rationality of a decision depends on circumstances in which it takes place, so as to achieve one's goals in a specific context. What is considered rational under the theory of rational choice account, it might not always be considered rational under the ecological rationality account. In particular, rational choice theory puts a premium on internal logical consistency, whereas ecological rationality also targets external performance in the world (cf., Allais, 1953; Kahneman *et al.*, 1982; Gigerenzer & Todd, 1999; Simon, 1955). However, within process of critical decisions, it is also important to consider bounded rationalityof decision makers, i.e., rationality is limited when individuals make decisions by the tractability of the decision problem, the cognitive limitations of the mind, manifold environmental variables and the time available to make the decision. Organizations/nations, in a context of *bounded rationality*, aim to a behavior of *satisficing* rather than maximizing critical decisions to cope with consequential environmental threats in the presence of highly restricted time (Simon, 1947; 1957; Gigerenzer & Selten, 2002). In general, acritical decisions provide vital material and information for a process of learning for turbulent and problematic situations in future. In fact, critical decisions are part of collective memory within and between organizations/nations and a vital source for historical analogies useful to leaders and organizations/nations in future complex situations (cf., Seeger *et al.,* 1998; Shrivastava *et al.,* 1988; Bundy *et al.,* 2017). Overall, then, critical decisions deal with problems that are choicesituations in which what is done makes a significant difference to those who make the choice (Ackoff & Rovin, 2003, p.9). These problems can be treated in different ways as follows (Ackoff & Rovin, 2003, pp.9-10):

- *Resolution* is when management employs behavior previously used in similar situations, adapted if necessary, so to obtain an outcome that is good enough. This approach for critical decisions is based on past experience, trial and error, and a common sense.
- *Solution* means to discover or create a behavior that yields the best, or approximately the best possible outcome, one that optimizes. However, change in environment and new information can cause solutions to deteriorate. In general, solutions do not exist in isolation from other problems and environment.
- *Dissolution* means to redesign either the organization that has the problems or the environment in such way as to eliminate the problem or the conditions that caused it, thus enabling the organization to do better in the future than the best it can do today. Moreover, stakeholders might seize upon the lessons of crises to advocate measures and policy and organizational reforms to improve overall efficiency of organization/nation (cf., Bundy *et al.,* 2017).

The critical decision of consequential problems can be based on a mix of these ways in the presence of more and more, turbulent markets, uncertain and volatile environments.

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Conclusion

This book here has tried to clarify some questions of COVID-19 pandemic to explain and generalize, as far as possible, some temporal and spatial aspects of the evolution of COVID-19 in society and effects of policy responses on public health, environment and economic system.

The results described in chapters suggest that the impact of COVID-19 on public health, environmental and economic systems depends on manifold environmental, social and economic factors as well as policy responses of governments. The studies show that policymakers have had an unrealistic optimist behaviour that new waves of COVID-19 could not hit their countries and, especially, had a low organizational capacity to plan effective policy responses to cope with recurring COVID-19 pandemic crisis. As a result, inappropriate and delayed policy responses associated with inefficient practices of crisis management to constrain impact of new wave of COVID-19 can again generate negative effects, *déjà vu*, on public health and of course economic systems.

The results of the first and subsequent waves of COVID-19 pandemic suggest that extensive containment policies (i.e., national lockdowns) can create more damages than benefits in society and economic systems with uncertain effects on public health of nations. As a consequence, the complex problem of epidemic threats has to be treated and solved with interdisciplinary approaches in science, using, whenever possible the method of dissolution: it means to redesign the strategies and protocols to cope with future epidemics in such way as to eliminate the conditions that caused accelerated diffusion of COVID-19, thus enabling advanced nations to do better in the future than the best it can do today.

In this context, policy responses of containment need to be revised and focused mainly on specific places having a high risk to be COVID-19 outbreaks. In fact, new studies reveal that a minority of places (such as restaurants, gyms, etc.) can generate a large number of infections; selected containment measures in these places (e.g., restricting maximum occupancy, social distancing and compulsory wearing of facemask) are more effective policies than general lockdown and reduction of mobility. In fact, new studies confirm that a reduction of casual contacts between people can both delay and reduce the peak of the wave of COVID-19 pandemic and similar epidemics.

There are several challenges to such studies concerning COVID-19 pandemic and novel viral agents. Given the exponential growth of the literature in this research field, the next years should witness substantial progress in our understanding of infectious diseases in all its various guises. On a broader plain, social studies have made great strides in developing a body of applied results that complements biological and medical studies to cope with future epidemics. There is every reason to suspect that this trend will continue, and the chapters in this volume strongly support that claim.

Overall, then, this book presents some aspects of COVID-19 pandemic, whereas other topics need to be clarified and other ones are in a *terra incognita*. Hence, there is need for much more detailed research on how COVID-19 pandemic and similar epidemics evolve in different economic, social, environmental and institutional contexts and especially in a specific period of time of a given geographical area. These studies here and future knowledge can be more and more important to treat patients, design effective policy responses, and apply new technologies directed to minimize the impact of future epidemics similar to the COVID-19 in society, as well as to prevent them.

To conclude, this book can lay a foundation for the interdisciplinary studies to clarify some complex aspects of the sources and effects of infectious diseases in human society.

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