Turkish Economic Review

www.kspjournals.org

Volume 8 — March 2021 — Issue 1

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

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Abstract. This paper endeavors to explain how wind speed can affect the diffusion of COVID-19. 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.

Keywords. COVID-19, Air pollution, Environmental pollution, Wind speed, Coronavirus, SARS-CoV-2, Public health, Air quality, Environmental science.

JEL. D81, D91, E71, G01, G41, H11, I18, Z18.

1. 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,

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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.

2. Study design

2.1. 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).

2.2. 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

2.3. 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:

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

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.

3. 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 19th March 2020	Infected Individuals 6th April 2020	Infected Individuals 26th April 2020	Density inhabitants/ km^2 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 19th March 2020	Infected Individuals 6th April 2020	Infected Individuals 26th April 2020	Density inhabitants/ km^2 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 emissions in the atmosphere: *>100days* exceeding limits set for PM_{10} *N=20*	Days exceeding limits set for PM_{10} or ozone 2018	Infected Individuals 19th 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	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 19th 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*

	Cities in regions low wind speed in the atmosphere (≤9 km/h)		*Cities in regions high wind speed in the atmosphere (≤9 km/h)*
↓DEPENDENT VARİABLE	*Explanatory variable:* *Log* Days exceeding limits set for PM_{10} or ozone 2018	↓DEPENDENT VARİABLE	*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).

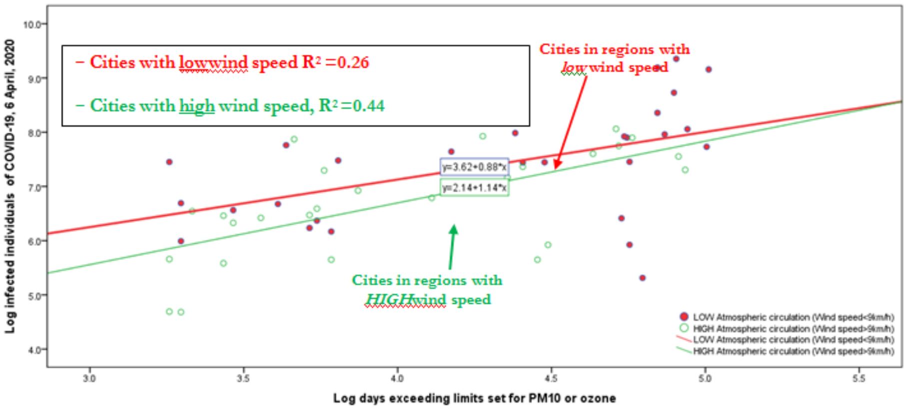

Figure 1. *Regression lines of Log Infected Individuals on Log Air pollution and particulate compounds emissions in the atmosphere according to wind speed of cities.*

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*

↓DEPENDENT VARIABLE	Cities with *low* air pollution and particulate compounds emissions *Explanatory variable:* *Log* Density inhabitants/km² 2019	↓DEPENDENT VARIABLE	Cities with *high* air pollution and particulate compounds emissions *Explanatory variable:* *Log* Density inhabitants/km² 2019
log infected 6th April, 2020		*log* infected 6th April, 2020	
Constant α (St. Err.)	4.62*** (.76)	Constant α (St. Err.)	1.61 (1.52)
Coefficient $\beta 1$ (St. Err.)	.32** (.12)	Coefficient $\beta 1$ (St. Err.)	.85*** (.21)
R^2 (St. Err. of Estimate) *F*	.18 (.78) 7.42**	R^2 (St. Err. of Estimate) *F*	.48 (.75) 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.

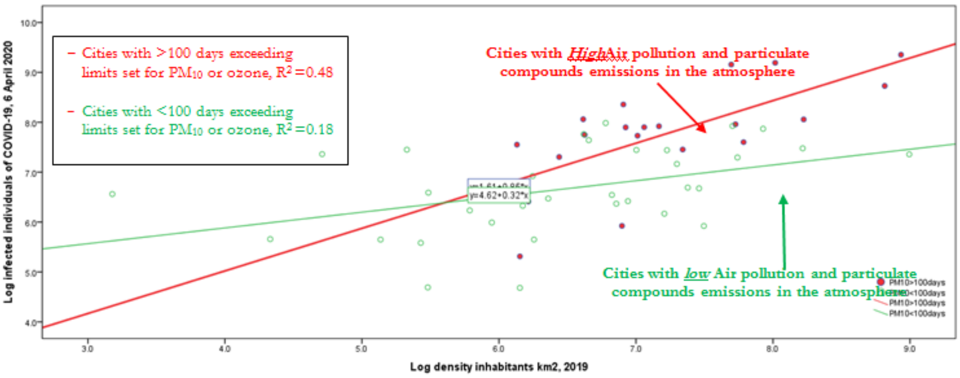

Figure 2. *Regression line of Log Infected people on Log population density inhabitants, considering the groups of cities with high or low air pollution and particulate compounds emissions in the atmosphere. Note: This result reveals that diffusion of COVID-19 is higher in cities with high Air pollution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

4. 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 environmental policy for a

[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.,

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).

5. 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.

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.

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