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

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**Abstract.** This paper 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, improve public health and prevent future epidemics. 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 (i.e., 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.

**Keywords.** COVID-19, Coronavirus, Wind Energy, Wind power plant, Clean energy, Climate, environmental sustainability, sustainable development, Environmental pollution.

**JEL.** F21, F68, O53, K23.

## **1. 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 &

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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<sub>2</sub> concentrations associated with downwards airflows cause of NO<sub>2</sub> 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 Northern 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) reveals 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.

## 2. Methods and research techniques

### 2.1. 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](#)).

### 2.2. Measurements

- *Polluting industrialization and particulate compounds emissions.* Total days exceeding the limits set for PM<sub>10</sub> 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<sup>2</sup>) in 2019
- *Production of renewable wind energy.* Power in MW of overall wind farms in all regions at January 2020

### 2.3. 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<sub>10</sub> or for ozone)
  - Cities with *low polluting industrialization* ( $\leq$  100 days per year exceeding the limits set for PM<sub>10</sub> 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<sub>10</sub> (variable  $x$ ).

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

$$\log y_t = \alpha + \beta \log x_{t-1} + u \tag{1}$$

$\alpha$  is a constant;  $\beta$ = coefficient of regression;  $u$  = error term

An alternative model [1] applies as explanatory variable the density of population per km<sup>2</sup> 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.

### 3. 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

	Days exceeding limits set for PM <sub>10</sub> or ozone 2018	Infected Individuals 17 <sup>th</sup> March 2020	Infected Individuals 7 <sup>th</sup> April 2020	Infected Individuals 27 <sup>th</sup> April 2020	Density inhabitants/km <sup>2</sup> 2019	Wind km/h Feb-Mar 2020
<i>Cities in regions with 94% of wind energy production</i> N=5						
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
<i>Cities in regions with 6% of wind energy production</i> 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<sub>10</sub> 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<sub>10</sub> 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

<i>Cities with high polluting industrialization: &gt;100days exceeding limits set for PM<sub>10</sub> N=20</i>	Days exceeding limits set for PM <sub>10</sub> or ozone 2018	Infected Individuals 17 <sup>th</sup> March 2020	Infected Individuals 7 <sup>th</sup> April 2020	Infected Individuals 27 <sup>th</sup> April 2020	Density inhabitants/km <sup>2</sup> 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
<i>Cities with low polluting industrialization: &lt;100days exceeding limits set for PM<sub>10</sub> N=35</i>						
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

	<i>Cities in regions with 94% of wind energy production</i>	<i>Cities in regions with 6% of wind energy production</i>
	<i>Log Days exceeding limits set for PM<sub>10</sub> or ozone 2018</i>	<i>Log Days exceeding limits set for PM<sub>10</sub> or ozone 2018</i>
<i>Log Infected Individuals 17<sup>th</sup> March, 2020</i>		
Pearson Correlation	.81	.69**
<i>Log Infected individuals 7<sup>th</sup> April, 2020</i>		
Pearson Correlation	.74	.55**
<i>Log Infected individuals 27<sup>th</sup> April, 2020</i>		
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 17<sup>th</sup> March ( $r=.69$ ,  $p$ -value<.01), 7<sup>th</sup> April ( $r=.55$ ,  $p$ -value<.01) and 27<sup>th</sup> 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

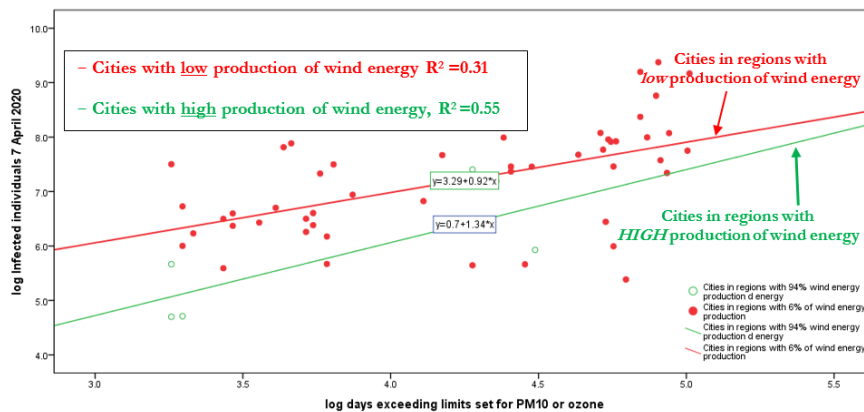
↓DEPENDENT VARIABLE	Cities in regions with 94% of wind energy production	↓DEPENDENT VARIABLE	Cities in regions with 6% of wind energy production
	Explanatory variable: Log Days exceeding limits set for PM <sub>10</sub> or ozone 2018		Explanatory variable: Log Days exceeding limits set for PM <sub>10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

Note: Explanatory variable: log Days exceeding limits set for PM<sub>10</sub> 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<sub>10</sub>, 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.

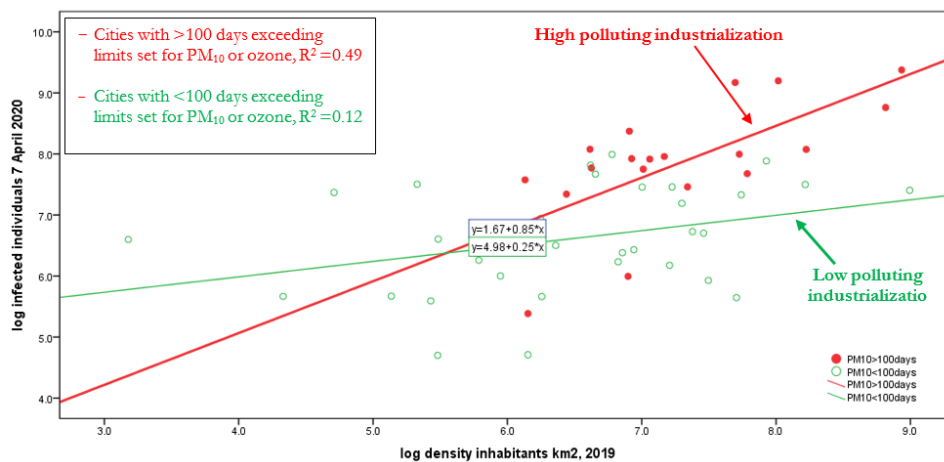
In order to confirm this findings, table 6 considers cities with a high and low polluting industrialization.

**Table 6.** Parametric estimates of the relationship of Log Infected individuals on Log Density inhabitants/km<sup>2</sup> 2019, considering the groups of cities with high and low polluting industrialization

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

**Note:** Explanatory variable: log Density inhabitants/km<sup>2</sup> 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<sub>10</sub> 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.

### 4. 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

M. Coccia, JSAS, 8(2), 2021, p.52-70.

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 policies 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<sub>2.5</sub> concentrations to 15 µg/m<sup>3</sup> would result in reductions of 70% in total PM<sub>2.5</sub>-related non-accidental mortality and 95% in total PM<sub>2.5</sub>-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)<sup>1</sup>. In fact, following the COVID-19 outbreak, The Economist Intelligence Unit (EIU) points out that the global economy

<sup>1</sup> 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).

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 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)<sup>2</sup>. 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.

## 5. 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

<sup>2</sup> 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.

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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