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How do low wind speeds and high levels of air pollution support the spread of COVID-19?

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ABSTRACT

The pandemic of coronavirus disease 2019 (COVID-19) is generating a high number of infected individuals and deaths. One of the current questions is how climatological factors and environmental pollution can affect the diffusion of COVID-19 in human society. This study endeavours to explain the relation between wind speed, air pollution and the diffusion of COVID-19 to provide insights to constrain and/or prevent future pandemics and epidemics. The statistical analysis here focuses on case study of Italy and reveals two main findings: 1) cities with high wind speed have lower numbers of COVID-19 related infected individuals; 2) cities located in hinterland zones (mostly those bordering large urban conurbations) with little wind speed and frequently high levels of air pollution had higher numbers of COVID-19 related infected individuals. Results here suggest that high concentrations of air pollutants, associated with low wind speeds, may promote a longer permanence of viral particles in polluted air of cities, thus favouring an indirect means of diffusion of the novel coronavirus (SARS-CoV-2), in addition to the direct diffusion with human-to-human transmission dynamics.

1. Introduction and goal of the scientific investigation

This study has the main goal to investigate, in environments with frequently high levels of atmospheric pollution, how wind speeds are linked to the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which is the strain of novel coronavirus that causes Coronavirus disease 2019 (COVID-19).

Manifold studies analyse possible relations between air pollution and diffusion of COVID-19 (Bashir et al., 2020; Fattorini and Regoli, 2020; Sciomer et al., 2020; Tung et al., 2021). Coccia (2020) reveals that cities with 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. Scholars maintain that air pollution can operate as one of the factors determining the spread of COVID-19 in society (cf., Coccia, 2020a). In addition, climatological, environmental, demographic, and geographical factors can influence the spread of COVID-19 in cities (Rosario Denes et al., 2020; Sarmadi et al., 2020; Bashir et al., 2020a; Sahin, 2020). Zhong et al. (2018) argue that static meteorological conditions may explain the increase of bacterial communities in the presence of air pollution. van Doremalen et al. (2020) reveal the stability of SARS-CoV-2 in the air; i.e., this novel coronavirus can remain viable and infectious in aerosols for hours. Overall, then, researchers support that air pollution can create a fruitful habitat for the spread of SARS-CoV-2 (Coccia, 2020; Tung et al., 2021).

The purpose of the present study is to see whether statistical evidence supports the hypothesis that higher numbers of COVID-19 related infected individuals in cities can be explained with an atmosphere having little wind and frequently high levels of air pollution.

This study extends the findings by Coccia, 2020b, Coccia (2020a, 2020b) and presents new experimental results of geo-environmental factors that are supporting the spread of COVID-19 in polluted cities, leading to a higher number of infected individuals and deaths. This study is in line with the Goal 3 (Ensure healthy lives and promote well-being for all at all ages) of the 2030 agenda for sustainable development by the United Nations (2020) – i.e., to substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination (point 3.9) –. Results here can suggest a long-run environmental policy directed to alleviate air pollution in cities with little wind for reducing the diffusion of future epidemics similar to the COVID-19 and, as a consequence, negative effects on public health.
2. Methodology

2.1. Working hypothesis (WHP)

WHP here is that high concentrations of air pollutants in the atmosphere, associated with low wind speeds, may promote a longer permanence of the novel coronavirus (SARS-CoV-2) in the air, thus favouring the diffusion of viral infectivity in society.

2.2. Sample and data sources

This study focuses on fifty-five ($N = 55$) polluted cities (randomly selected) that are provincial capitals in Italy (Coccia, 2020). Data of confirmed cases of COVID-19 are from Ministero della Salute (Department of Health) of Italy; data of air pollution are from Regional Agencies for Environmental Protection located in Italian provincial capitals; instead, climatological data are from meteorological stations of Italian provinces (Coccia, 2020); data of the mortality of respiratory and cardiovascular diseases in polluted cities under study are from ISTAT (2020); finally, data of the density of population, index of seniority of people and population aged more than 65 years old in polluted cities are also from the Italian National Institute of Statistics (ISTAT, 2020a, 2020b).

2.3. Measures

- **Diffusion of the COVID-19** in cities under study is measured with the number of infected individuals on April 7, 2020, during the first wave of COVID-19 outbreak in Italy.
- **Atmospheric turbulence/stability** (irregular/regular air motions characterized by winds that vary in speed and direction) is measured with average wind speed (km/h) of cities under study on February-March-April 2020, before and during the diffusion of COVID-19 in Italy.
- **Air pollution** of cities is measured with total days exceeding the limits set for PM$_{10}$ or for ozone in 2018. Experimental results reveal that PM$_{2.5}$ and PM$_{10}$ have a strong correlation (Zhou et al., 2016; Kong et al., 2016). Fig. 1A in Appendix shows the map with the air quality monitoring stations of Italian polluted cities under study (Figure 1A).
- **Demographic data of cities** are given by:
  - Population density of cities (inhabitants/km$^2$), 2019
  - Elderly people index, 2019
  - People aged >65 years old, 2019
- **Data of public health of cities** are based on mortality of specific diseases:
  - Rate of mortality per malignant tumours of the trachea, bronchi and lungs per 10,000 people in 2017. Lung and bronchi cancer is a: “cancer that forms in tissues of the lung, usually in the cells lining air passages” (National Cancer Institute, 2020).
  - Rate of mortality for diseases of respiratory system per 10,000 people, 2017. Zhu et al., 2019 demonstrate that air pollution can increase respiratory diseases and lung cancer because particulate matter and other air pollutants are genotoxic and contribute to the development of tumour and other diseases (e.g., COPD) via inducing sustained inflammation.
  - Rate of mortality for diseases of cardiovascular system per 10,000 people, 2017 (cf., Hadei and Naddafi, 2020; Çapraz et al., 2016; Pangaribuan et al., 2019).

2.4. Data analysis procedure

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

- **wind speed**, based on arithmetic mean of the sample given by 9.28 km/h
  - cities with high wind speed ($>9.28$ km/h) that in the Beaufort wind scale indicates a wind force from light to moderate breeze (average wind force of light breeze means that wind felt on face, leaves rustle, vanes begin to move, whereas a wind force of moderate breeze generates the wind effect of dust, leaves and loose paper lifted, small tree branches move)
  - cities with low wind speed ($\leq 9.28$ km/h) that in the Beaufort wind scale indicates a wind force from calm air to light breeze.
- **Location of cities**
  - Hinterland
  - Coastal/Near coast ($<50$ km from coast)
- **Air pollution**
  - Cities with high air pollution ($>100$ days per year exceeding the limits set for PM$_{10}$ or for ozone)
  - Cities with low air pollution ($\leq 100$ days per year exceeding the limits set for PM$_{10}$ or for ozone)

Correlation (bivariate and partial) and regression analyses verify relationships between variables understudy. Regression analysis considers that the number of infected individuals on April 7, 2020 across Italian cities (dependent variable $y$) is a linear function of the explanatory variable of wind speed (explanatory variable $x$) or Population Density in a model of simple regression.

In order to respect the four assumptions associated with linear regression model (i.e., Linearity, Homoscedasticity, Independence and Normality), the specification is based on a log-log model:

$$\log y_i = \alpha + \beta \log x_{i,1} + u$$

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

The estimation of equation [1], using the explanatory variable of population density, is also performed with a categorization of cities according to wind speed (higher or lower than arithmetic mean of the sample). A multiple regression analysis is also performed with dependent variable given by number of infections (confirmed cases of COVID-19) on April 7, 2020 and explanatory variables given by: Log population density, Log days exceeding limits set for PM$_{10}$ or ozone, Log elderly index of seniority, and wind speed. Visual representation of the effect of wind speed on the spread of COVID-19 is displayed in graphs with regression lines. Of course, factors determining the spread of COVID-19 are complex and variables under study here cannot detect all determinants, and many of them relapse in the residuals of regression models. Ordinary Least Squares (OLS) method is applied for estimating the unknown parameters of linear models [1] just mentioned. Statistical analyses are performed with the Statistics Software SPSS® version 26.

3. Results

Table 1 shows that cities in regions with low wind speed have a higher number of days of air pollution than cities with a high wind speed (about 88 polluted days vs. 65 polluted days exceeding PM$_{10}$ or ozone per year). This preliminary result suggests that high intensity of wind speed improves the dispersion of gaseous and particulate matters, and as a consequence, it can mitigate the diffusion of COVID-19 associated with
the interaction between novel coronavirus and air pollution (Coccia, 2020). Table 1 also shows that polluted cities with high wind speed have a lower population density but an older population and a higher incidence of the mortality rate of lung and bronchi cancer, of respiratory and cardiovascular diseases than polluted cities with low wind speed. These demographic and health indicators suggest that cities with a high wind speed have people at increased risk for getting COVID-19 (because of prior higher mortality of respiratory and cardiovascular diseases, and lung cancer, see Table 1; cf., CDC, 2020); however, the number of infected individuals of the SARS-CoV-2 is lower than cities having an atmospheric stability (i.e., low wind speed). In order to confirm this result, Table 2 shows descriptive statistics considering the categorization of polluted cities in hinterland and coastal. Coastal cities in Italy, for their geographical position, are windy and results reveal a lower number of infected people, though having an increased risk factor for COVID-19 because of prior higher incidence of older adults in society and higher mortality of people for diseases of respiratory and cardiovascular system (cf., Coccia, 2020; Nicoll and Coulombier, 2009).

Table 3 focuses on categorization of cities having levels of high or low air pollution: especially, cities with frequently high levels of air

### Table 1
Descriptive statistics of Italian province capitals according to wind speed (higher or lower than arithmetic mean of 9.28 km/h).

| Wind speed of polluted cities | Air Pollution | COVID-19 | Atmosphere | Demographic indicators, 2019 | Mortality (per 10000 people in 2017) |
|------------------------------|---------------|----------|------------|-----------------------------|-----------------------------------|
|                              | Days exceeding limits set for PM$_{10}$ or ozone 2018 | Infected Individuals 7th April 2020 | Wind km/h 2020 | People aged >65 years old | Elderly Index of seniority | Population Density inhabitants/km$^2$ | Lung, trachea, bronchi cancer | Respiratory system diseases | Cardiovascular system diseases |
| Low ($<9.28$ km/h), $N=27$  | Arithmetic Mean | 89.11 | 2853.41 | 7.06 | 23.81 | 185.85 | 1695.11 | 5.72 | 9.21 | 38.78 |
|                             | Std. Error of Mean | 8.58 | 591.55 | 0.48 | 0.45 | 6.92 | 358.15 | 0.21 | 0.41 | 1.55 |
| High ($\geq9.28$ km/h), $N=28$ | Arithmetic Mean | 64.50 | 1123.93 | 11.43 | 24.40 | 195.73 | 1220.18 | 6.09 | 9.67 | 41.81 |
|                             | Std. Error of Mean | 6.65 | 166.81 | 0.49 | 0.48 | 6.72 | 290.63 | 0.15 | 0.30 | 1.27 |

### Table 2
Descriptive statistics of Italian province capitals according to their location in hinterland/coastal.

| Location of cities | Air Pollution | COVID-19 | Atmosphere | Demographic indicators, 2019 | Mortality (per 10000 people in 2017) |
|--------------------|---------------|----------|------------|-----------------------------|-----------------------------------|
|                    | Days exceeding limits set for PM$_{10}$ or ozone 2018 | Infected Individuals 7th April 2020 | Wind km/h 2020 | People aged >65 years old | Elderly Index of seniority | Population Density inhabitants/km$^2$ | Lung, trachea, bronchi cancer | Respiratory system diseases | Cardiovascular system diseases |
| Hinterland, $N=45$ | Arithmetic Mean | 80.40 | 2201.44 | 8.81 | 24.02 | 189.04 | 1480.11 | 5.88 | 9.34 | 2.72 |
|                    | Std. Error of Mean | 6.21 | 545.05 | 0.50 | 0.33 | 5.01 | 227.22 | 0.14 | 0.27 | 0.15 |
| Coastal, $N=10$   | Arithmetic Mean | 59.40 | 944.70 | 11.42 | 24.52 | 199.14 | 1332.80 | 6.04 | 9.91 | 2.75 |
|                    | Std. Error of Mean | 12.21 | 227.11 | 0.74 | 1.07 | 14.37 | 778.88 | 0.35 | 0.71 | 0.39 |

### Table 3
Descriptive statistics of Italian provincial capitals according to air pollution.

| Level of Air Pollution: Days exceeding limits set for PM$_{10}$ | Air Pollution | COVID-19 | Atmosphere | Demographic indicators, 2019 | Mortality (per 10000 people in 2017) |
|---------------------------------------------------------------|---------------|----------|------------|-----------------------------|-----------------------------------|
| Days exceeding limits set for PM$_{10}$ or ozone 2018 | Infected Individuals 7th April 2020 | Wind km/h 2020 | People aged >65 years old | Elderly Index of seniority | Population Density inhabitants/km$^2$ | Lung, trachea, bronchi cancer | Respiratory system diseases | Cardiovascular system diseases |
| > 100 days, $N=20$                                       | Arithmetic Mean | 125.25 | 3650.00 | 8.24 | 23.65 | 183.74 | 1981.40 | 5.87 | 8.65 | 2.69 |
|                                                   | Std. Error of Mean | 3.00 | 724.22 | 0.69 | 0.49 | 7.47 | 444.68 | 0.15 | 0.34 | 0.16 |
| ≤ 100 days, $N=35$                                    | Arithmetic Mean | 48.77 | 1014.63 | 9.88 | 24.37 | 194.96 | 1151.57 | 5.93 | 9.90 | 2.75 |
|                                                 | Std. Error of Mean | 3.61 | 129.97 | 0.57 | 0.43 | 6.24 | 247.85 | 0.19 | 0.33 | 0.21 |
pollution (>100 days exceeding limits set for PM$_{10}$ or ozone per year) and low wind speed, they have a very high number of infected individuals in April 2020, though an environment with a lower risk of getting infectious diseases because of a low mortality of respiratory and cardiovascular diseases in previous years (cf., CDC, 2020; Coccia, 2020; Nicoll and Coulombier, 2009).

Table 4 shows that cities with high and low wind speed, they have a high positive correlation (p-value<.01) between air pollution and infected individuals of COVID-19 in April 2020. Table 5 shows that cities with low air pollution, they have a high negative correlation (r = -.43, p-value<.01) between wind speed and infected individuals of COVID-19, suggesting that wind speed can reduce the numbers of COVID-19 related infected individuals in society because cleaning the air, it decreases the permanence of viral particles (e.g., SARS-CoV-2) commingled with air pollution.

Table 6 shows correlation analysis using all cities of the sample and confirms a negative correlation (r = -.27, p-value<.05) between wind speed and infected individuals of COVID-19 in April 2020, but a high positive correlation between infected individuals and air pollution (r = 0.60, p-value<.001), and population density (r = 0.53, p-value<.001). The vital role of wind speed in reducing the spread of COVID-19 is confirmed in Table 7 with partial correlation (r = -.29, p-value<.01), whereas air pollution has a positive association with infected individuals of COVID-19 (r = 0.50, p-value<.001), controlling population density; finally, controlling both population density and air pollution, wind speed has also a negative correlation with infected individuals (r = -.20, p-value<.07).

Table 7 confirms results with partial correlation, controlling manifold variables. In short, Table 8 reveals that wind speed has a negative correlation with infected individuals (r = -.23, p-value<.05), whereas air pollution has a positive association with infected individuals (r = 0.28, p-value<.05), ceteris paribus.

Simple regression analysis in Table 9 shows that the increase of wind speed generates, in average, a reduction of infected people given by $\beta = -0.088$ (p-value = .05). Fig. 1 shows, ictu oculi, the negative relationship between wind speed and numbers of COVID-19 related infected individuals. Table 9 also shows results of multiple regression, which includes three explanatory variables (i.e., Population Density, Air pollution and Wind speed). The partial coefficient of regression of the model indicates that a 1% higher level of the density of population, it increases the expected confirmed cases of infections by 0.32% (p-value = .01, controlling other explanatory variables), whereas a 1% higher
level of days of air pollution, it increases expected infected individuals by 0.74% (p-value = .001, controlling other independent variables). The explanatory variable of wind speed is not significant here. The multiple regression model’s R² value indicates that about 47% of the variation in confirmed cases of the COVID-19 can be attributed (linearly) to these explanatory variables. F-test is significant with p-value <.001. Table 10 shows that:

| Explanatory variable: | Wind speed km/h | Explanatory variables: |
|-----------------------|-----------------|------------------------|
| Constant α (St. Err.)| 7.86*** (.42)   | Constant α (St. Err.)  |
| Coefficient β (St. Err.)| -.088* (.29) | Coefficient δ 1 (St. Err.) |
| R² (St. Err. of Estimate) | .06 (1.04) | R² (St. Err. of Estimate) |
| F                     | 4.30*           | F                       |

Note: Dependent variable is Log infected 7th April, 2020.  
*** p-value <.001.  
** p-value <.01.  
* p-value <.05.

Table 10
Estimated relationship of Log Infected individuals on Log population density (inhabitants/km² in 2019), considering wind speed of cities.

| Cities with low wind speed <9.28 km/h | Cities with high wind speed >9.28 km/h |
|---------------------------------------|----------------------------------------|
| Explanatory variable:                | Explanatory variable:                 |
| Log Population Density               | Log Population Density                |
| Constant α (St. Err.)                | 3.49*** (.90)                          |
| Coefficient β I (St. Err.)           | .58*** (.13)                           |
| Stand. Coefficient Beta              | .67                                    |
| R² (St. Err. of Estimate)            | .44(.83)                               |
| F                                    | 19.79***                               |
|                                      |                                        |
| Constant α (St. Err.)                | 4.45*** (1.20)                         |
| Coefficient β I (St. Err.)           | .33 (.18)                              |
| Stand. Coefficient Beta              | .35                                    |
| R² (St. Err. of Estimate)            | .12 (.89)                              |
| F                                    | 3.51                                   |

Note: dependent variable: Log infected individuals 7th April, 2020.  
*** p-value<0.001.  
** p-value<0.01.  
* p-value<0.05.  
§ p-value<0.072.

Fig. 1. Regression line of infected individuals on wind speed.

Fig. 2. Regression lines of Log Infected Individuals on Log Density of population according to high/low wind speed of polluted cities. Note: This result suggests that the diffusion of COVID-19 is higher in polluted cities with low wind speed and moderate density of population.

- in polluted cities with low wind speed, an increase of 1% of the density of population, it increases the expected number of infected individuals by about 0.58% (p-value = .001)
- in polluted cities with high wind speed, an increase of 1% of the density of population, it increases the expected number of infected individuals by about 0.33% (p-value = .07), a lower magnitude!
speed, the increase of infected individuals is lower, suggesting that a high intensity of wind speed improves the dispersion of air pollution including viral agents, and as a consequence, this environment can mitigate the diffusion of COVID-19 in society (cf., Coccia, 2020; Coccia, 2020); whereas cities with lower wind speeds and frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — may promote a longer permanence of the SARS-CoV-2 in polluted air, thus favouring an indirect means of viral diffusion, in addition to direct mechanism of human-to-human transmission of the COVID-19. These results are displayed in Fig. 2.

4. Discussion

This study extends the results by Coccia (2020); Coccia, 2020; Coccia, 2020 and endeavours to explain how COVID-19 transmitted so rapidly in polluted cities of Northern Italy, analysing the relationships between infected people and environmental, demographic, and atmospheric (wind speed) factors that influenced its spread. Results here suggest that, among Italian cities, number of infected people are higher in polluted cities with >100 days per year exceeding limits set for PM_{10} or ozone, cities located in hinterland zones (i.e. away from the coast), and cities having a low average intensity of wind speed. Coşkun et al. (2021) argue that COVID-19 spreads more in windy weather because wind speed increases air circulation. However, this study here analyses the interaction between wind speed and air pollution and reveals that in Italy, cities with little wind and frequently high levels of air pollution in the atmosphere had higher numbers of COVID-19 related infected individuals and deaths. The explanation is that little wind can increase the stagnation of polluted air embodying viral agents (SARS-CoV-2) and support diffusion of viral infectivity, creating problems for public health.

Map 1 of the wind load on buildings | Map 2 of air pollution | Map 3 of total infected individuals of SARS-CoV-2 per 10,000 people

| Blue = high wind speed | Blue = high total air pollution | Blue = high confirmed cases |
| Yellow = moderate wind speed | Yellow = moderate air pollution | Yellow = moderate confirmed cases |
| White = low wind speed | White = low total air pollution | White = low confirmed cases |

Fig. 4. Maps of the wind load on buildings (1), of air pollution (2) and of total infected individuals of SARS-CoV-2 per 10,000 people (3). Notes: Colour of regions in Map 1 is created combining wind speed with altitude, wind pressure, wind tangent action, soil roughness and other parameters. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)
fresh and strong breeze (i.e., small trees in leaf begin to sway and larger tree branches moving, whistling in wires; cf., Furcolo, 2016). The Map 2 (in the centre of Fig. 4) shows Italian regions according to air pollution (the number of days exceeding ozone and particulate matter 10 μm or less in diameter —PM_{10}—limits). Finally, the Map 3 (at right) shows Italian regions according to the average number of infected individuals of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) that causes COVID-19 per 10,000 people from February to July 2020.

Map 1, Map 2 and Map 3 are based on three colours given by values lower than 25th percentile (white/low intensity), from 25th to 75th percentiles (yellow/moderate intensity), and finally values higher than 75th percentile (Blue/high intensity).

The observation of these maps reveals, ictu oculi, that regions of North Italy with little wind (Map 1) and frequently high levels of air pollution (Map 2) have higher numbers of COVID-19 related infected individuals (Map 3). To put it differently, regions with high speed winds and low air pollution (mainly in the South of Italy) are associated with lower numbers of COVID-19 related infected individuals (see, Fig. 4). Hence, Northern regions of Italy with little wind (white colour in the Map 1) and frequently high levels of air pollution (blue/yellow colour in the Map 2) had higher numbers of COVID-19 related infected individuals (Blue colour in Map 3 of Fig. 4). Statistical evidence, with correlation and regression analyses, substantiates these results. This study is consistent with results by Ahmadi et al. (2020) that wind speed has a significant and inverse relationship with the rate of COVID-19 related infected individuals, such that: “in the lower speed of the wind, the infection rate is higher”. Other studies maintain that “the prevalence of the COVID-19 .... in most cases, with increasing humidity and wind speed, ... has decreased” (Eslami and Jalili, 2020, p. 3). Rosario Denes et al. (2020) also reveal that wind speed presented a negative correlation with confirmed cases of the COVID-19. These results are in the context described by Cohen (2020) that transmission dynamics of the novel coronavirus is affected by different environmental factors, such as climate conditions.

In addition, the effect of wind speed on diffusion of COVID-19 can be distinguished in the presence of indoor and outdoor environments.

- **Indoor environment** can transmit COVID-19 by droplets created when infected humans cough, sneeze, talking, shouting, yawning, etc. (Coccia, 2017). However, Fattorini and Regoli (2020, p. 4) argue that: “Although the capability of this coronavirus to bind particulate matters remains to be established, chronic exposure to atmospheric contamination and related diseases may represent a risk factor in determining the severity of Covid-19 syndrome and the high incidence of fatal events”.

In order to generalize these results here, cities with low wind speed and frequently high levels of air pollution can sustain, mainly in fall and winter season, the stagnation of air pollution with viral agents that may support the spread of COVID-19 and other infectious diseases (cf., Coccia, 2020; Caliskan et al., 2020). Overall, then, Northern regions of Italy and in particular hinterland cities, covered by the study here, and other similar cities worldwide having an atmosphere with low wind speed and frequently high levels of air pollution should apply an environmental policy and sustainable technologies to reduce air pollution (Coccia, 2009, 2017; Coccia and Watts, 2020, Coccia, 2017). In fact, health and economic benefits associated with national and local reduction of air pollution have more and more a strong evidence (Coccia, 2020).

5. Conclusions and limitations

This study finds that atmospheric factors (wind speeds) and air pollution may have supported the spread of COVID-19 in Northern Italian cities, leading to a higher number of infected individuals and deaths. The statistical evidence here seems in general to support the hypothesis stated in previous section, that transmission dynamics of the SARS-CoV-2, in addition to human-to-human diffusion, can be also explained by a stagnation of atmospheric pollutants and viral agents because low wind speeds may promote a longer permanence of viral particles (e.g., the SARS-CoV-2) in polluted air, thus favouring the spread of COVID-19 in society.

However, these conclusions are of course tentative because the diffusion of infectious diseases is due to manifold factors. These findings suggest that current pandemic of the novel Coronavirus and future epidemics similar to the COVID-19 cannot be solved only with research and practitioner medicine, but with interdisciplinary scientific research also based on environmental and sustainable science. To conclude, there are several challenges to such studies of factors determining the diffusion of viral infectivity and there is need for much more detailed investigations into the complex relations between the spread of COVID-19, environmental and atmospheric factors to design appropriate sustainable policies for reducing air pollution and consequential interactions with viral agents that negatively affect public health of countries.

Declaration of competing interest

The author declares that he is the sole author of this manuscript and he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This study has none funders.
Fig. 1A. Maps of the air quality monitoring stations in Italian cities under study

References

Ahmadi, M., Sharifi, Abbas, Shadi, Dorost, Gheisareh Saeid Jafarzadeh, Negar, Ghanbari, 2020. Investigation of effective climatology parameters on COVID-19 outbreak in Iran. Sci. Total Environ. 729, 138705.
Bashir, M.F., Ma, B.J., Bilal, Komal, B., Bashir, M.A., Farooq, T.H., Iqbal, N., et al., 2020a. Correlation between environmental pollution indicators and COVID-19 pandemic: a brief study in Californian context. Environ. Res. 187, 109652.
Bashir, M.F., Ma, B., Bilal, Komal, B., Bashir, M.A., Tan, D., Bashir, M., 2020. Correlation between Climate Indicators and COVID-19 Pandemic in New York, USA, vol. 728. Science of the Total Environment art. no. 138835.
Cai, Q.C., Lu, J., Xu, Q.F., Guo, Q., Xu, D.Z., Sun, Q.W., Yang, H., Zhao, G.M., Jiang, Q.W., 2007. Influence of meteorological factors and air pollution on the outbreak of severe acute respiratory syndrome. Publ. Health 121, 258–265.
Caliskan, B., Ozengin, Nihan, Cindoruk, S. Siddik, 2020. Air quality level, emission sources and control strategies in Bursa/Turkey. Atmos. Pollut. Res. https://doi.org/10.1016/j.apr.2020.05.016 (in press).
Çapraz, O., Ede, Bahütalay, Ali, Deniz, 2016. Study on the association between air pollution and mortality in Istanbul, 2007–2012. Atmos. Pollut. Res. 7 (1), 147–154.
CDC, 2020. Centers for disease control and prevention. Coronavirus Disease 2019 (COVID-19), People Who Are at Increased Risk for Severe Illness. https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/people-at-increased-risk.html. (Accessed July 2020).
Coccia, Mario, 2009. Measuring the impact of sustainable technological innovation. International Journal of Technology Intelligence and Planning 5 (3), 276–288. https://doi.org/10.1504/IJTIM.2009.026749.
Coccia, Mario, 2017. Sources of disruptive technologies for industrial change. L’industria - rivista di economia e politica industriale 38 (1), 97–120. https://doi.org/10.1430/87140.
Coccia, Mario, 2017. The Fishbone diagram to identify, systematize and analyze the sources of general purpose technologies. Journal of Social and Administrative Sciences 4 (4), 291–303. https://doi.org/10.1453/jasav4.1518.
Coccia, M., 2020c. Scientific Data of the Principal Factors Determining the Diffusion of COVID-19 in Italy, Database Is Available to Download and View at Mendeley - Reference Management Software & Researcher Network: Mendeley Data. Elsevier. https://doi.org/10.17632/bbhhybqzgh.1 v1.
Coccia, M., 2020a. Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID. Sci. Total Environ. 729, 138473. https://doi.org/10.1016/j.scitotenv.2020.138474.
Coccia, M., 2020b. An index to quantify environmental risk of exposure to future epidemics of the COVID-19 and similar viral agents: theory and Practice. Environ. Res. 191, 110155 https://doi.org/10.1016/j.envres.2020.110155. December.
Coccia, Mario, 2020b. The effects of atmospheric stability with low wind speed and of air pollution on the accelerated transmission dynamics of COVID-19. Journal: International Journal of Environmental Studies, 1802937. https://doi.org/10.1080/00207233.2020.1802937.
Coccia, M., Watts, J., 2020. A theory of the evolution of technology: technological parasitism and the implications for innovation management. Journal of Engineering
and Technology Management 55, 101552. https://doi.org/10.1016/j.jengtecman.2019.11.003.

Cohen, J., 2020. Sick time. Science 367, 1294–1297. https://doi.org/10.1126/science.367.6484.1294.

Çoğun, H., Yıldırım, N., Gündüz, S., 2021. The spread of COVID-19 virus through population density and wind in Turkey cities. Environment 751. Article number 141663.

Eslami, H., Jalili, Mahrokh. 2020. The role of environmental factors to transmission of SARS-CoV-2 (COVID-19). Amb. Express 10 (92), 1–8.

Fattorini, D., Regoli, F., 2020. Role of the chronic air pollution levels in the Covid-19 outbreak risk in Italy. Environ. Pollut. 264, 114732.

Feng, Yu, Marchal, Thierry, Sperry, Ted, Yi, Hang, 2020. Influence of wind and relative humidity on the social distancing effectiveness to prevent COVID-19 airborne transmission: a numerical study. J. Aerosol Sci. 147, 105585.

Forcillo, N., 2016. Azioni del vento sulle costruzioni, guida al calcolo. BibLus-net. http://biblus.acca.it/calcolo-del-vento-sulle-costruzioni-parte-1/. (Accessed 15 July 2020).

Hadei, M., Naddafi, K., 2020. Cardiovascular effects of airborne particulate matter: a review of rodent model studies. Chemosphere 242, 125204.

ISTAT, 2020. Mortalità per territorio di residenza. Causa iniziale di morte. Quoziente di mortalità (per 10 000 abitanti. ISTAT, Rome (Accessed, June 2nd, 2020). http://dati.istat.it/index.aspx?DataSetCode=DCIS_POMORT1_RES.

ISTAT, 2020a. The Italian National Institute of Statistics-Popolazione residente al 1 gennaio (Accessed, June 2nd, 2020). http://dati.istat.it/index.aspx?DataSetCode=DCIS_POPRES1.

ISTAT, 2020b. Indicatore demografici (Accessed June 2020). http://dati.istat.it/index.aspx?DataSetCode=DCIS_INDEMOG1.

Jiang, S., Huang, L., Chen, X., Wang, J., Wu, W., Yin, S., Chen, W., Zhan, J., Yan, L., Ma, L., Li, J., Huang, Z., 2003. Ventilation of wards and nosocomial outbreak of severe acute respiratory syndrome among healthcare workers. Chin. Med. J. 116, 1293-1297.

Kong, L., Xin, Jinyuan, Wenyu, Zhang, Wang, Yuesi, 2016. The empirical correlations between PM2.5, PM10 and AOD in the Beijing metropolitan region and the PM2.5, PM10 distributions retrieved by MODIS. Environ. Pollut. 216, 350–360.

Marzolf, L., Marzolf, P., 2020. Air pollution and the novel covid-19 disease: a putative disease risk factor. Snp compr. Clin. Apr. 1–5. https://doi.org/10.1007/s42399-020-00274-4.

National Cancer Institute, 2020. Lung cancer—health professional version (Accessed in June 2020). https://www.cancer.gov/types/lung/hp.