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An index to quantify environmental risk of exposure to future epidemics of the COVID-19 and similar viral agents: Theory and practice

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ABSTRACT

In the presence of the novel Coronavirus Disease (COVID-19) and other new viral agents, one of the fundamental problems in science is the evaluation of environmental and social weaknesses of cities/regions to the exposure of infectious diseases for preventing and/or containing new COVID-19 outbreaks and the diffusion of other viral agents that generate a negative impact on public health and economy of countries. The current monitoring of transmission dynamics of infectious diseases is mainly based on reproduction number (R0) and fatality rates. However, this approach is a real-time monitoring of transmission dynamics for mitigating the numbers of COVID-19 related infected individuals and deaths. Reproduction number does not provide information to cope with future epidemics or pandemics. The main goal of this study is to propose the Index c (as contagions) that quantifies, at-ante, the environmental risk of exposure of cities/regions to future epidemics of the COVID-19 and similar viral agents. This Index c synthetizes environmental, demographic, climatological and health risk factors of cities/regions that indicate their exposure to infectious diseases. Index c has a range from 1 (environmental and social weakness of urban areas leading to high levels of exposure to infectious diseases) to 0 (environment that reduces the risk of exposure to infectious diseases in society). The statistical evidence here, applied on case study of Italy, seems in general to support the predictive capacity of the Index c as a particularly simple but superior indicator in detecting the global correlation between potential risk of exposure of cities/regions to infectious diseases and actual risk given by infected individuals and deaths of the COVID-19. The Index c can support a proactive environmental strategy to help policymakers to prevent future pandemics similar to the COVID-19.

1. The problem

Severely epidemics of infectious diseases, such as the novel Coronavirus Disease (COVID-19), are a major problem for public health and economy of countries (Coccia, 2020a). The spatial and temporal variability of the spread of COVID-19 and other infectious diseases within and between countries is not random process but new novel coronavirus (SARS-CoV-2) generates higher numbers of COVID-19 related infected individuals and deaths in specific geo-environmental areas of the World (Center for System Science and Engineering at Johns Hopkins, 2020). Bontempi (2020) argues that in the presence of different mechanisms of viral diffusion, it is important to promote interdisciplinary research studies able to analyze the problem from different perspectives, including expertise of “medical, epidemiologist, and environmental specialists, but also engineering, political, economic, social, and demographic sectors”. In particular, Bontempi et al. (2020) point out that pandemic’s diffusion patterns are due to manifold environmental, economic and social factors (Coccia, 2016). In fact, it is extremely important that nations acknowledge the reality that this novel coronavirus spreads so rapidly and generates numerous deaths in cities with intensive social interactions, high commercial exchanges at international level, and specific geo-environmental factors given by little wind and frequently high levels of air pollution (Coccia, 2020; Coccia, 2020b).

The monitoring of transmission dynamics of COVID-19 is mainly based on basic reproduction number, called R0, that is the expected number of infected individuals directly generated by one infected person in a population with all susceptible people to infection (Chintalapudi et al., 2020, p. 327; Wallinga and Teunis, 2004; Liu et al., 2020). A specific approach calculates real-time effective reproduction numbers by averaging overall transmission networks that are compatible with the observed epidemic curve (Delamater et al., 2019). In this context, Gatto et al. (2020) estimate a generalized reproduction number, for Italian case study, that measures the potential spread in the absence of

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containment interventions. However, this indicator $R_0$ monitors real-time transmission dynamics of infectious diseases for detecting the spread of pandemics and/or epidemics in specific areas and, as far as possible, supports decision-making of policymakers with appropriate measures of containment and/or mitigation to constrain high numbers of COVID-19 related infected individuals and deaths (Yuan et al., 2020). Moreover, for basic reproduction number $R_0$, assumptions need to be re-examined, such as age structure in social mixing patterns, distribution of mobility, hospitalization, fatality, etc. Bontempi (2020, p. 2) suggests that a more exhaustive and comprehensive approach to the explanation of transmission dynamics of the COVID-19 can be achieved by considering different parameters that may be not strictly related to sanitary implications. Hence, the pandemic of COVID-19 and future epidemics/pandemics of similar viral agents challenge global societies that are susceptible to infectious diseases. In this global environment, it is more and more important to design new indicators that can help policymakers to know environmental weaknesses of urban areas to the exposure of infectious diseases in order to prevent future epidemics and if they spread in society to contain negative effects on public health and economy. As a matter of fact, contemporary environmental studies and inter-related disciplines have to cope with these new problems that emerge and have to be solved in society, rapidly. In particular, one of the new problems is how we can measure the environmental risk of exposure to infectious diseases, similar to the COVID-19, of cities and/or regions, called index $c$ (as contagions). In this paper, Index $c$ (as contagions) is proposed as a new method that quantifies, ex ante (i.e., before the event), the environmental risk of exposure of cities, regions and other geo-economic areas to new epidemics and/or pandemics. To put it differently, the proposed Index $c$ is a measure, ex ante, of the potential risk of fast diffusion of infectious diseases within and between cities generating negative effects on public health and economy. The prediction of this study is that a high risk of exposure of cities/regions to infectious diseases is given by an Index $c$ close to 1 (maximum value): a zone with environmental, health, climatological and demographic weaknesses having a high risk of exposure to severe infectious disease outbreaks that would result in high numbers of infected individuals and deaths compared to a location with a low magnitude of the Index $c$ (i.e., close to zero, the minimum). The statistical evidence here seems in general to support the predictive results of the Index $c$ as particularly simple but superior indicator in detecting the global correlation between potential risk of exposure of cities/regions to infectious diseases and actual risk given by numbers of COVID-19 related infected individuals and deaths. Overall, then, the proposed Index $c$ here is a new method that can support a preventive strategy that helps policymakers to know the vulnerability of urban areas to infectious diseases and to prevent whenever possible epidemics of COVID-19 and similar viral agents with appropriate policies based on environmental and sustainable sciences.

2. Method: Index $c$ (contagions) for the evaluation of environmental risk of exposure to infectious diseases of cities

The principal factors determining the diffusion of infectious diseases, such as the COVID-19, are assumed to be:

Air pollution—(Factor 1). Studies reveals that areas 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 (Coccia, 2020; Martelletti and Martelletti, 2020). Moreover, high concentrations of nitrogen dioxide and particulate air pollutant induce serious damages to the immune system of people, weakening it to cope with infectious diseases of novel viral agents (Glencross Drew et al., 2020).

Atmospheric stability/instability measured with wind speed—(Factor 2). A high wind speed, creating atmospheric instability, seems to reduce the number of infected individuals because it fosters the dispersion of air pollution that can act as carrier of the SARS-CoV-2 in the air, whereas a stable atmosphere with low wind speed prevents the dispersion of air pollutants that remain stagnant in the air with content of bacteria and viruses, such as SARS-CoV-2, generating a higher diffusion of COVID-19 and other infectious diseases (Coccia, 2020h; Rosario Denes et al., 2020; Eslami and Jalili, 2020). To put it differently, high concentrations of air pollutants, together with low wind speeds (level of calm/light air in the Beaufort wind scale) may promote a longer permanence of viral particles in the air, thus favoring an indirect means of diffusion of viral infectivity (e.g., SARS-CoV-2), in addition to the direct diffusion with human-to-human transmission dynamics (cf., Frontera et al., 2020).

Demographic aspect given by density of population — habitants per km$^2$ — (Factor 3). It is a main factor determining human-to-human transmission of infectious diseases (Kucharski et al., 2020). This factor can be a proxy of social interaction within cities. In this context, Bontempi et al. (2020) argue that it is difficult to measure social interaction at the microscopic level of each person-to-person contact, and in an interdisciplinary perspective these scholars consider certain economic variables to assess population mobility and social interaction that play a vital role for the human-to-human transmission dynamics of COVID-19. The economic variables are mainly at aggregate levels in databases that measure for instance, commercial exchanges (trade import and export) between regions worldwide and that can explain the initial diffusion of COVID-19 (Bontempi, 2020; Bontempi et al., 2020). In this study here, population density is considered to be an indicator of social interaction and researchers maintain that a high population density is a potential risk factor for transmission dynamics and the spread of COVID-19 at local and regional level (cf., Rosario Denes et al., 2020; Del Buono et al., 2020).

Respiratory disorders of people, given by mortality rate for trachea, bronchi and lung cancer—(Factor 4). Nicoll and Coulombour (2009) identify people that are considered more at risk of becoming infected with viral agents, such as people with chronic respiratory diseases. Amao et al. (2020) show that air pollution could increase respiratory diseases, such as chronic obstructive pulmonary diseases and lung cancer, because air pollution is genotoxic and contributes to the development of tumor via inducing sustained inflammmation. Lung cancer (LC) is a: “cancer that forms in tissues of the lung, usually in the cells lining air passages”. Lung cancer is one of the main diseases in several countries and a leading cause of cancer death – both sexes – worldwide (National Cancer Institute, 2020). US Center for disease control and prevention states that people of any age having cancer are at increased risk to be affected by COVID-19 (CDC, 2020).

Step 1. Let Factors $i$ ($i = 1, 2, 3, 4$), just mentioned, observed per $j$-th units (e.g., cities, regions, countries, etc.) with $j = 1, ..., n$.

Step 2. For each Factor $i$ ($i = 1, 2, 3, 4$) is calculated the percentile $25^{	ext{th}}$, $50^{	ext{th}}$ and $75^{	ext{th}}$ and subsequently the $j$-th units (e.g., a city/region) are grouped in four sets according to their value for each Factor $i$:

- Set 1. If Factor $i$ of $j$-th unit has a value lower than $25^{	ext{th}}$ percentile
- Set 2. If Factor $i$ of $j$-th unit has a value between $25^{	ext{th}} – 50^{	ext{th}}$ percentile
- Set 3. If Factor $i$ of $j$-th unit has a value between $50^{	ext{th}} – 75^{	ext{th}}$ percentile
- Set 4. If Factor $i$ of $j$-th unit has a value greater than $75^{	ext{th}}$ percentile

Table 1

| Grade | Index $c$ of unit $j$ | Level of risk of exposure to infectious diseases of urban area |
|-------|----------------------|-------------------------------------------------------------|
| 1     | $<0.25$              | Low                                                         |
| 2     | $0.25-0.50$          | Moderate                                                    |
| 3     | $0.51-0.75$          | High                                                        |
| 4     | $>0.75$              | Very High                                                   |

- Step 3. To each $j$-th unit (e.g., cities, regions, etc.) is assigned a score
from a minimum of 0 to a maximum of 3, according to location in the Set 1, 2, 3 and 4 (as indicated in the step 2) as follows:

| Location of j-th unit for the Factor i in the following Set | Score (pk) assigned |
|-----------------------------------------------------------|---------------------|
| 1 Set                                                     | 0 (low intensity of Factor i) |
| 2 Set                                                     | 1                   |
| 3 Set                                                     | 2                   |
| 4 Set                                                     | 3 (high intensity of Factor i) |

**Step 4.** If j-th unit has the max score of 3 (three) for the four Factors i (i = 1, 2, 3, 4), the total is 12; if j-th unit has the min score of 0 (zero) for all four Factors i, then total value is, of course, 0 (zero). In the middle, there is a range of scores for j-th units (j = 1, ..., n) from 1 to 11.

**Definition of the Index c (contagions) of environmental risk of exposure to infectious diseases.**

Let Fi (i = 1, 2, 3, 4) the four Factors that measure the environmental risk of exposure to infectious diseases of the j-th unit (j = 1, 2, ..., n), e.g., a city, a region, a nation.

Let pk the score of j-th unit assigned to each Factor Fi with values from 0 (Min), 1, 2, to 3 (Max).

Let the Max score of j-th unit for four Factors Fi equal to 12, given by (3 points × 4 Factors) = 12.

The Index c that quantifies the environmental risk of exposure to infectious diseases of j-th units is defined as follows:

\[
\text{Index } c_j = \frac{[F_1(p_k) + F_2(p_k) + F_3(p_k) + F_4(p_k)]}{12}
\]

\[
= \frac{\left(\sum_{i=1}^{4} \sum_{j=1}^{12} F_i(p_j)\right)}{12}, \quad (unit \ j = 1, \ldots, n) \quad [1]
\]

Properties of the Index c:

- **Range of variation.** Index c has a range of variability in the set of real numbers: Index c ∈ [0, 1]
- **Minimum.** The min value of the Index c is 0 (zero) and indicates a very low environmental risk of exposure of urban areas to infectious diseases
- **Maximum.** The max value of the Index c is 1 (one) and indicates a very high environmental risk of exposure of cities/urban areas to infectious diseases
- **Transitive property.** If Fi(p_k) ≤ F_j(p_k) for i ≠ j then Index c_i ≤ Index c_j for i = 1,2,3,4 and k = 0,1,2,3
- **Symmetry property.** If Fi(p_k) = F_j(p_k) then Index c_i = Index c_j for i = 1,2,3,4 and k = 0,1,2,3

The j-th units are classified in increasing order from 1st to n-th Rank according to the value of Index c that ranges from 1 to 0. In particular, a rank of urban areas close by the 1st position indicates a high environmental risk of exposure to infectious diseases, a rank close by n (last position) suggests a low environmental risk of exposure of urban areas to infectious diseases.

**Step 5.** The magnitude of Index c for j-th unit is the basis for a scale of measurement of the environmental risk of exposure to infectious diseases, based on environmental, demographic, climatological and health factors (Table 1).

The evaluation of the effectiveness and robustness of predictive capacity of the Index c is performed with the Spearman rank-order correlation coefficient r_s, a nonparametric measure of the strength and direction of association that exists between two variables measured on an ordinal scale. This study uses the ranking of j-th units based on Index c and ranking of the same j-th units based on number of confirmed cases of COVID-19 in Italy, which is the case study here. If Spearman rank-order correlation coefficient r_s provides a strong positive correlation, statistically significant, then proposed Index c can be a robust and predictive method to assess, ex ante, the environmental risk of exposure of cities, regions and other urban zones to infectious diseases. The effectiveness of Index c is also evaluated with the bivariate Pearson correlation (correlation coefficient r), which measures the strength and direction of linear relationships between pairs of continuous variables given by Index c of j-th units under study and number of infected individuals of these units in specific days of the COVID-19 outbreak in Italy. The significance test for coefficients of correlation is performed. These coefficients of correlation (r_s and r) have a value in the range [−1, +1]. The sign of these correlation coefficients indicates the direction of the relationship, while the magnitude of the correlation indicates the strength of the relationship. In particular, a positive number indicates a positive relationship. The strength of these coefficients can be assessed by following general guidelines:

0.1 < |r_s| or |r| < 0.3 indicates a weak correlation
0.3 < |r_s| or |r| < 0.5 indicates a moderate correlation
Finally, |r_s| or |r| >0.5 reveals a strong correlation.

### 3. Findings and discussion

**Application of Index c for forecasting the environmental risk of exposure of cities and/or regions to infectious diseases: Italian case study**

- **Sample.** Fifty-five polluted cities (N = 55), selected randomly, that are provincial capitals in Italy, one of the first countries to experience a rapid increase in confirmed cases and deaths of the COVID-19.
- **Factor 1: Air pollution.** Total days exceeding the limits set for PM_{10} or for ozone in 2018 per Italian provincial capitals. Frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — are a main factor that affects public health (Coccia, 2020c).
- **Factor 2: Atmospheric stability/turbulence.** Average wind speed in km/h on February-March 2020, during the COVID-19 outbreak in Italy. Sources are based on data of meteorological stations in Italian provinces (Coccia, 2020c).
- **Factor 3: Demographic aspect given by density of population (inhabitants per km²).** Data of the density of population in 2019 are from the Italian National Institute of Statistics (Coccia, 2020c).
- **Factor 4: Mortality rate of trachea, bronchi and lung cancer.** Rate of mortality per 10 000 people for trachea, bronchi and lung cancer in 2017 (Coccia, 2020c).

### Table 2

| Percentiles | Total days exceeding the limits set for PM_{10} 2018 | p (k) | Density of population inhabitants per km² 2019 | p (k) | Wind Speed* km/ h 2020 | p (k) | Rates of mortality for trachea, bronchi and lung cancer 10 000 people 2017 | p (k) | Total score | Index c |
|-------------|-----------------------------------------------|------|---------------------------------------------|------|-------------------------|------|-------------------------|------|-------------|--------|
| <25th       | 38                                             | 0    | 470                                         | 0    | >                       | 0    | 5.23                    | 0    | 0           | min    | 0      |
| 50th        | 72                                             | 1    | 950                                         | 1    | 10.5                    | 1    | 5.58                    | 1    | 4           | .33    | 1      |
| 75th        | 116                                            | 2    | 1738                                        | 2    | 9.4                     | 2    | 6.7                     | 2    | 8           | .67    | .7      |
| >75th       | >116                                           | 3    | >1738                                       | 3    | 7.85                    | 3    | >6.7                    | 3    | 12          | Max    | 1      |

Notes: * wind speed has inverted percentages from 75th to 25th in order to assign a low score to high percentile (when high wind speed fosters dispersion of air pollution) and high score to low percentile (when low wind speed prevents dispersion of air pollution, cf., Coccia, 2020c).
Control Factor is the diffusion of COVID-19 across polluted cities under study in Italy. Number of confirmed cases on March-April 2020 across polluted cities under study (Coccia, 2020c)

Table 2 shows the percentile of these Factors in the sample under study here.

The application of the formula of Index $c$, as described in methods of this study (see [1]), provides results of Table 3.

Table 3 shows the Index $c$ that assesses, ex ante (before the event), the risk of exposure of cities to the COVID-19 ($0 = \text{min}$, $1 = \text{Max}$) and the ranking of cities also from the highest risk of exposure (rank 1st) to the lowest risk of exposure (rank 55th) to infectious diseases. Moreover, Table 3 shows actual number, ex post (after the event), of infected individuals of the COVID-19 on 27 March and April 7, 2020 and the ranking from 1st to 55th position, indicating the cities from the highest number of infected individuals to the cities with the lowest number of infected individuals.

To test the predictive capacity of Index $c$, the coefficient of correlation of Spearman’s Rho ($r_s$) is calculated between the ranking of cities based on Index $c$ (from high to low value of the risk of exposure to the COVID-19) and ranking of cities (from the highest to lowest position) based on number of confirmed cases of the COVID-19 at March 27, 2020.
and April 7, 2020, during the COVID-19 outbreak in Italy. Results in Table 4 show a strong positive correlation of Spearman’s Rho (N = 55 Italian cities).

Table 4
Coefficient of correlation of Spearman’s Rho (N = 55 Italian cities).

| Ranking of infected individuals April 7, 2020 | Ranking of infected individuals March 27, 2020 | Ranking Index c |
|---------------------------------------------|---------------------------------------------|----------------|
| 1                                           | .929*                                       | 1              |
| .602*                                       | .607*                                       | 1              |

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

Table 5
Coefficient of correlation of Pearson (N = 55 Italian cities).

| Infected individuals April 7, 2020 | Infected individuals March 27, 2020 | Index c |
|---------------------------------|---------------------------------|--------|
| 1                               | .975*                           | 1      |
| .593*                           |      .567*                       |        |

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

Table 6
Scale of measurement of environmental risk of exposure to COVID-19 in Italy.

| Grade | Index c | Average Index c for Italian case study | Potential risk of exposure to infectious diseases | Actual Average number of COVID-19 infected individuals for Italian case study on April 7, 2020 | 1 | <0.25 | 0.15 | Low | 598.67 |
|-------|--------|--------------------------------------|-----------------------------------------------|-------------------------------------------------------------------------------------------------|---|------|-----|-----|--------|
| 2     | 0.25-0.50 | 0.42                                | Moderate                                       | 1336.09                                                                                           |---|------|-----|-----|--------|
| 3     | 0.51-0.75 | 0.64                                | High                                           | 2481.35                                                                                           |---|------|-----|-----|--------|
| 4     | >0.75   | 0.85                                | Very High                                      | 6025.65                                                                                           |---|------|-----|-----|--------|

| Grade | Index c | Average Index c for Italian case study | Potential risk of exposure to infectious diseases | Actual Average number of COVID-19 infected individuals for Italian case study on April 7, 2020 |
|-------|--------|--------------------------------------|-----------------------------------------------|------------------------------------------------------------------------------------------------|
| 1     | <0.25  | 0.15                                 | Low                                          | 598.67                                                                                           |
| 2     | 0.25-0.50 | 0.42                             | Moderate                                     | 1336.09                                                                                           |
| 3     | 0.51-0.75 | 0.64                             | High                                         | 2481.35                                                                                           |
| 4     | >0.75   | 0.85                                 | Very High                                    | 6025.65                                                                                           |

In addition, to confirm this result, the coefficient of correlation by Pearson (r) is calculated between Index c of cities and number of infected individuals on 27 March and April 7, 2020. Results confirm that r has a high magnitude, suggesting that Index c effectively predicts the risk of exposure of cities to infectious diseases over time and space (Table 5).

Table 6 shows the average Index c into the scale of measurement of the environmental risk of exposure of cities or other urban areas to infectious diseases. In the last column, average number of infected individuals on April 7, 2020 for Italian case study shows the robustness of proposed Index c: a value higher than 0.75 (or close by 1, max of the Index c) suggests a very high risk of exposure to infectious diseases of urban areas (this high risk is confirmed in practice with higher numbers of COVID-19 related infected individuals); whereas a value less than 0.25 indicates a theoretical risk of exposure to infectious diseases rather low; this prediction is empirically confirmed by low average number of infected individuals of COVID-19 on April 7, 2020 in Italy.

The arithmetic mean of the Index c of cities per region can provide the map of theoretical risk of exposure of regions to new infectious diseases as represented in Fig. 1 (at left) to design appropriate control measures and environmental policies to cope with future epidemics or pandemics of viral agents. Of course, as the map is based on average values, within regions with high/moderate risk of exposure to infectious diseases there can be cities with very high/high risk of exposure to infectious diseases. Table 5 also shows the map (at right) of total infected individuals of the COVID-19 per 10 000 people on July 18, 2020 to assess empirically the prediction of the Index c as displayed in the map at left. Fig. 1 shows that regions with warmer colors (purple/red) are mainly in the North and Central part of Italy in the theoretical and empirical map, though the Index c tends to underestimate the risk of exposure of regions with higher numbers of COVID-19 related infected individuals, providing cautious results. For instance, Index c categorizes Northern regions of Italy with “high risk” of exposure to infectious diseases, whereas actual number of infected individuals of COVID-19 is “very high”. The small differences can be also due to the method used to aggregate data from cities to regions for constructing these maps. Moreover, these maps of Fig. 1 show a similarity with maps by Bontempi (2020) that considers data of trade importation and exportation of Italian regions with Eastern nations of the World. The explanation of the similarity of these maps can be due to manifold factors determining the transmission dynamics of the COVID-19 in Northern Italian cities and regions that are the engine of the Italian economic system with the headquarters of several national and international firms having international exchanges and commercial/financial relationships with China and other countries worldwide (Bontempi, 2020; Bontempi et al., 2020; cf., Del Buono et al., 2020). This intensive economic activity is also associated with a high density of population and frequently high levels of air pollution that may support transmission dynamics of the SARS-CoV-2, increasing the risk of exposure to current and future vital agents (cf., Coccia, 2020a).

In addition, North Italy and Po valley have a high risk of exposure to viral agents also because of climate conditions of little wind (atmospheric stability) that associated with high concentrations of air pollutants may promote a longer permanence of viral agents in the air, thus favoring an indirect means of diffusion of viral infectivity of the SARS-CoV-2, in addition to the direct diffusion with human-to-human transmission dynamics based on social interactions (Bontempi, 2020; Coccia, 2020a,b; Frontera et al., 2020). In a perspective of comprehensive analysis of the viral diffusion, these results suggest that transmission dynamics of COVID-19 is complex and affected by different factors given by socioeconomic aspects, commercial exchanges, efficiency of healthcare structures, environmental pollution, demography of cities and regions, previous respiratory disorders of people, social interactions, climatological factors (e.g., wind speed, wind direction, temperature, humidity, ...), etc. (cf., Bontempi, 2020, 2020a, Bontempi et al., 2020; Coccia, 2020a,b; Del Buono et al., 2020; Rosario Denes et al., 2020).

4. Conclusions

The Index c provides a synthetic value (based on socioeconomic, demographic, climatological and environmental factors) that can help policymakers to know the preventive risk of exposure of cities and/or regions to infectious diseases similar to the COVID-19 in order to apply appropriate policies to prevent future epidemics and/or pandemics. Policymakers, to reduce the risk of vulnerability of cities or urban areas to future epidemics and pandemics, can act on some factors determining the structure of proposed Index c given by:

1) sources of air pollution
2) urban ventilation
3) density of population and social interaction
4) causes of lung and bronchi cancer

In short, acting on these and other factors, it is possible to reduce the magnitude of Index c over time and space, and as a consequence the risk of exposure of urban areas to future infectious diseases. First of all, it is important to reduce levels of air pollution in polluted cities to improve public respiratory health. About factors related to the atmosphere, it can
be important the improvement of urban ventilation and the exchange of air between areas within and above the urban canopy to allow the atmospheric dispersion of pollutant concentration in cities, enhancing air quality. Gu et al. (2020) argue that urban ventilation is a function of manifold urban characteristics. In fact, polluted cities having atmospheric stability and lack of a wind driven natural ventilation have to apply sustainable policies and new technology to reduce main sources of air pollution and, at the same time, improve urban ventilation to foster the dispersion of particulate compounds considering the openness of surrounding areas, the coverage and heights of buildings, etc. that are factors affecting the surface roughness of cities and dispersion of air pollution (Coccia, 2020c, Coccia, 2017, Coccia, 2018). Luo et al. (2020) argue that in China the daily mean PM$_{2.5}$ concentration reduction from 2016 to 2018 by about 14.50%, applying an appropriate environmental policy, has generated benefits on public health and economic system, avoiding premature mortalities for cardiovascular diseases, respiratory diseases, and lung cancer. Amoatey et al. (2020) suggest that adoption of stringent air pollution regulations and sustainable city planning, such as the increase of urban green infrastructures, it can reduce PM$_{2.5}$ levels in urban environment, safeguarding public health from air pollution. Hence, sustainable policies that reduce air pollution generate significant environmental, public health, social and economic benefits, as well as they can reduce the risk of exposure of cities to future epidemics similar to the COVID-19. This Index $c$, based on different factors that are not strictly related to medicine, suggests that the prevention of future infectious diseases is not only a problem limited to life sciences and nonpharmaceutical interventions to reduce human-to-human transmission of viral agents but it is a larger and complex problem including socioeconomic, commercial, demographic and environmental factors. In particular, this Index $c$ suggests that in order to constraint future infectious diseases and epidemics of new viral agents that affect public health and structural indicators of economies, regions and nations have to apply a sustainable policy directed to reduce sources of air pollution and improve urban ventilation.

Overall, then, the statistical evidence here seems in general to support the predictive results of the Index $c$ as a particularly simple but superior approach in detecting the correlation between potential risk of high exposure of cities/regions to infectious diseases and actual high numbers of COVID-19 related infected individuals. The proposed Index $c$ can support a ex-ante strategy that helps policymakers to know vulnerability of urban areas to infectious diseases and to prevent future outbreaks of the COVID-19 and other new viral agents in society. Of course, Index $c$ needs to be updated periodically as more data become available in order to provide the real level of risk of exposure of cities and/or regions to infectious diseases with the greatest reliability to support efficient decision making.

Moreover, the proposed Index $c$ has the limit to consider some indicators but other factors associated with social interactions and economic system of regions should be included in future development of this new method considering that some areas (e.g., Northern Italian Regions, large urban conurbations of New York City and Barcelona, etc.) are the core of national economies. However, the explicit structure of the suggested Index $c$ (contagions) here, based on environmental, demographic, social and geographical factors that influence the spread of vital agents, closely reproduces the empirical evidence of confirmed cases of the COVID-19 in Italy and has a potential to be generalized over time and space. To conclude, this study encourages further investigations for developing comprehensive and general indexes also

Fig. 1. Theoretical map of the risk of exposure of Italian regions to infectious diseases, based on Index $c$ (at left), and empirical map based on total infected individuals of the COVID-19 on July 18, 2020 in Italy (at right). Notes: Maps are based on four colors given by values lower than 25th percentile (white/low), from 25th to 50th percentile (yellow/moderate), from 50th to 75th percentiles (red/high) and finally values higher than 75th percentile (purple/very high). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
based on environmental and socioeconomic factors, and not only with parameters related to medicine (such as, reproduction number) that can help ex-ante policymakers to evaluate vulnerability of cities and urban areas to future epidemics in order to support appropriate long-run strategies that prevent negative effects of infectious diseases on public health, economy and society.

Author contribution

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.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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