Diffusion Covid-19 In Polluted Regions: Main Role of Wind Energy for Sustainable and Health

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Abstract: The COVID-19 pandemic, caused by the coronavirus disease 2019, is rapidly spreading worldwide, resulting in a significant number of deaths. This ongoing environmental and sustainability discussion has raised novel and relatively unexplored questions. One of these questions pertains to the impact of heavily polluting industrial processes and less environmentally friendly production methods on the spread of COVID-19 infections. This study aims to elucidate the connection between air pollution, particulate emissions, wind conditions, energy production, and the dissemination of COVID-19 infections. The primary focus of the statistical analysis is on Italy, a country that has seen a rapid surge in confirmed cases and fatalities. The findings of this study can be summarized as follows: 1) Cities located in regions with high wind speeds and significant wind energy production in megawatts (MW) tend to have fewer COVID-19 infections. 2) Conversely, cities situated in hinterland areas, especially those adjoining large urban conglomerates, characterized by heavy industrialization, low wind speeds, and less environmentally friendly production methods, tend to have a higher number of COVID-19 cases and total fatalities. These results suggest that addressing the current COVID-19 pandemic and preparing for future epidemics similar to COVID-19 requires more than just advancements in medical and microbiological research and practices. It also necessitates a proactive approach focused on sustainable development. In conclusion, this study underscores the importance of incorporating sustainability science into strategies aimed at preventing future epidemics like COVID-19. Such an approach involves promoting renewable energy sources and cleaner production methods to reduce pollution from industrialization, ultimately influencing the factors that contribute to the transmission of coronavirus diseases and other infections within society.

Keywords: Wind Energy, Wind Resource, Renewable Energy, Coronavirus Disease, Sustainable Growth, Cleaner Production. JEL codes: K32, Q01, Q20; Q40, Q50, Q53, Q54.

1. INTRODUCTION

The contemporary discourse surrounding environmental and sustainability issues continually introduces new and relatively unexplored themes within the realm of science. This research project delves into the investigation of the causes, repercussions, and sustainable policy solutions related to the spread of Coronavirus Disease 2019 (COVID-19) within the context of environmental and sustainability science.

COVID-19, which emerged in China in 2019, is responsible for a spectrum of symptoms, ranging from mild to severe respiratory ailments and even fatalities in a substantial number of individuals globally (Ogen, 2020; Dantas et al., 2020). This viral infection has evolved into an ongoing global health crisis, leading to socio-economic turmoil and pessimistic economic forecasts on a worldwide scale (Saadat et al., 2020). Several studies have indicated a potential association between air pollution and the emission of particulate compounds with the diffusion of COVID-

19 infection (Fattorini and Regoli, 2020; Frontera et al., 2020). Scholars have also posited that elevated levels of air pollution may augment the infectivity and lethality of COVID-19 (Contini and Costabile, 2020). Conticini et al. (2020) argue that populations residing in regions with elevated levels of particulate compound emissions face an increased likelihood of developing respiratory disorders due to infectious agents. Notably, countries with high levels of air pollution, such as the USA, Spain, Italy, UK, Russia, China, Brazil, France, and others, have reported a high incidence of COVID-19 infections (Frontera et al., 2020). Research confirms correlations between exposure to air pollution, the spread of SARS-CoV-2, and the severity of respiratory conditions in populations with a high prevalence of ailments like chronic obstructive pulmonary disease (COPD) and lung cancer (Fattorini and Regoli, 2020). Ogen (2020, p.4) suggests that elevated NO2 concentrations, coupled with downward airflows, contribute to NO2 accumulation near the surface. This geographic phenomenon, combined with specific atmospheric conditions characterized by low wind speeds, hampers the dispersion of air pollutants, thereby contributing to a heightened incidence of respiratory disorders and inflammation among populations in certain European regions, such as Northern Italy. In summary, exposure to air pollution, coupled with Coronavirus infection, may contribute to elevated mortality rates in countries like Italy (14.06%), Spain (11.90%), UK (14.37%), Belgium (16.40%), France (15.32%), and others (Center for System Science and Engineering at Johns Hopkins, 2020).

The study conducted by van Doremalen et al. (2020) reveals that viral particles of SARS-CoV-2 in China can remain suspended in the air for several minutes. This finding potentially explains the high number of infections and fatalities from COVID-19 observed in countries like the USA, Spain, Russia, France, Italy, Brazil, Turkey, Iran, and elsewhere (Center for System Science and Engineering at Johns Hopkins, 2020). Overall, these studies posit the hypothesis that regions with high levels of air pollutants, combined with specific climatic factors, may support the prolonged presence of viral particles in the air, thereby facilitating the spread of COVID-19 through mechanisms of air pollution-to-human transmission, in addition to human-to-human transmission (Frontera et al., 2020). To further investigate these critical aspects in the development of COVID-19 outbreaks worldwide, especially in regions characterized by significant industrial pollution, the objective of this study is to examine the relationship between the number of infected individuals, air pollution levels, wind speeds, and the interconnected production of renewable wind energy. This analysis aims to shed light on critical interdependencies that influence the spread of COVID-19 and its adverse effects on the environment and public health. The ultimate goal of this research is to provide insights that can inform sustainable long-term policies aimed at promoting cleaner production methods to mitigate and prevent the dissemination of future epidemics akin to COVID-19.

2. METHODS

2.1. Data sources and research setting

This research is centered on fifty-five (N=55) cities in Italy, specifically provincial capitals. Italy is one of the countries that has been severely impacted by the COVID-19 pandemic, with a reported death toll exceeding 31,360 cases as of May 15, 2020 (Lab24, 2020). Epidemiological data regarding COVID-19 infections were sourced from the Italian Ministry of Health (Ministero della Salute, 2020). Information pertaining to polluting industrialization, air pollution levels, and particulate emissions were gathered from the Regional Agencies for Environmental Protection in Italy (Legambiente, 2019). Climatological data were obtained from meteorological stations located within Italian provinces (il Meteo, 2020). Population density figures were sourced from the Italian National Institute of Statistics (ISTAT, 2020), and data concerning the production of wind energy in various Italian regions were sourced from the Italian Transmission Operator, Terna (Terna, 2020)

2.2. Measurements

- Polluting Industrialization and Particulate Compounds Emissions: This aspect involves tracking the total number of days in 2018 when pollution levels for PM10 and ozone exceeded the established limits in Italian provincial capitals. These data points are crucial as they directly impact the environment and public health. Additionally, 2018 serves as the baseline year for comparing air pollution and particulate emissions, allowing for an examination of their effects independent of COVID-19 infection.

- Diffusion of COVID-19 Infection: The study considers the number of individuals infected with COVID-19 in the months of March and April 2020. This data is a critical indicator of the spread of the virus within the chosen cities.

- Climatological Information: Climatological factors, specifically the average wind speed measured in kilometers per hour during February and March 2020, are taken into account. Wind speed can influence the dispersion of airborne particles and, potentially, the spread of the virus.

- Indicators of Interpersonal Contact Rates: Population density figures for the year 2019, expressed as the number of individuals per square kilometer, are used to assess the density of cities. This indicator relates to the potential for interpersonal contact and its role in virus transmission.

- Production of Renewable Wind Energy: The study incorporates data on the total power capacity, measured in megawatts (MW), generated by wind farms across all regions as of January 2020. This information is relevant in exploring the relationship between renewable energy production and COVID-19 diffusion.

- These variables and data sources collectively contribute to the comprehensive analysis of the complex interplay between air pollution, environmental factors, public health, and the spread of COVID-19 within the context of Italian provincial capitals.

2.3. Primary data analysis and statistics

Descriptive Statistics: The study starts by performing descriptive statistics on Italian provincial capitals. It categorizes these capitals into groups based on two key factors:

- Renewable Wind Energy Production: Capitals are classified into two groups:

1. Cities with high wind energy production: These cities belong to regions responsible for 94% of the national production of wind energy.

2. Cities with low wind energy production: These cities are located in regions that contribute only 6% of the national production of wind energy.

- Polluting Industrialization and Particulate Compounds Emissions: Capitals are grouped based on their level of polluting industrialization and particulate compound emissions:

1. Cities with high polluting industrialization: This group comprises cities where pollution levels exceed the limits for PM10 or ozone on more than 100 days per year.

2. Cities with low polluting industrialization: This group includes cities where pollution levels remain within or below the specified limits (100 days or less per year).

Correlation and Regression Analyses: The study proceeds to examine relationships between these categorized variables. Specifically, regression analysis is employed to investigate the link between the number of infected individuals in Italian provincial capitals (variable y) and the explanatory variable of total days exceeding the pollution limits set for PM10 (variable x). Regression Model Specification: The study employs a log-log regression model to specify the linear relationship between the variables. This log-log model is utilized to better capture the potential nonlinear relationship between the variables.

In essence, the research employs a rigorous analytical approach to explore the interplay between renewable wind energy production, pollution levels, and the spread of COVID-19 in Italian provincial capitals, with a particular focus on assessing whether a logarithmic model better explains the relationship between these variables.

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

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

Alternative Model: In addition to the previously mentioned log-log model, an alternative model is considered in this study [1]. In this alternative model, the explanatory variable used is the population density per square kilometer (density of population/km2). Cities are grouped based on both their level of polluting industrialization and their location in regions with high or low wind energy production.

Categorization of Cities: The cities are categorized into groups based on the following factors: Polluting Industrialization and Particulate Compounds Emissions: Cities are classified as having either a high or low level of polluting industrialization and particulate compounds emissions. Intensity of Wind Energy Production: Cities are also categorized based on whether they are located in regions with high or low intensity of wind energy production. Estimation Method: The estimation of the alternative model [1] is carried out using the Ordinary Least Squares (OLS) method. OLS is a statistical technique used to estimate the unknown parameters in linear models like equation [1]. It is widely employed for linear regression analysis. Statistical Analysis Software: The statistical analyses, including the estimation of the alternative model, are performed using the Statistical Software SPSS® version 24. SPSS is a commonly used software package for statistical analysis, providing tools for data manipulation, visualization, and regression analysis. In summary, this section of the study introduces an alternative regression model [1], which incorporates population density and categorizes cities based on their level of polluting industrialization and their location in regions with varying levels of wind energy production. The Ordinary Least Squares (OLS) method is employed for parameter estimation, and the statistical analyses are conducted using SPSS® version 24.

3. RESULTS

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)

Wind Energy Production in Italy: Seven regions in Italy, including Molise, Puglia, Calabria, Basilicata, Campania, Sicilia, and Sardegna, are responsible for 94% of the total wind energy production in the country. These regions collectively have a capacity of at least 1 GW, with Puglia leading the way with 2.5 GW in the South-East of Italy. Italy as a whole had approximately 5,645 wind farms with nearly 7,000 wind turbines of varying power sizes. There are 313 wind plants with a power capacity exceeding 10 MW, totaling just over 9 GW. The majority of wind systems fall within the power class range of 20 to 200 kW, with 3,956 systems having a combined capacity of approximately 234 MW. Puglia stands out as the region with the largest share of wind power installations in Italy, accounting for 24.8% of the total capacity and featuring 92 plants with capacities exceeding 10 MW. COVID-19 Infection and Wind Energy Production: Results from Italian provincial capitals, categorized into two groups based on regions with high or low wind energy production, suggest a correlation between wind energy production and COVID-19 infection rates. Cities in regions with high wind energy production (representing 94% of the total) have reported a very low number of COVID-19 infections during March and April 2020. Conversely, cities situated in regions with low-intensity wind energy production (constituting 6% of the total) have reported a significantly higher number of COVID-19 infections. This information indicates a potential relationship between wind energy production and the spread of COVID-19 within Italian provincial capitals, with regions having higher wind energy production showing lower infection rates.

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

Cities in regions with 94% of wind energy production N=5	Days exceeding limits set for PM_{10} or ozone 2018	Infected Individuals 17th March 2020	Infected Individuals 7th April 2020	Infected Individuals 27th April 2020	Density inhabitants/km^2 2019	Wind km/h Feb-Mar 2020
Mean	48.00	59.80	505.60	708.20	2129.00	14.60
Std. Deviation	30.27	90.84	646.12	949.19	3384.10	5.45
Cities in regions with 6% of wind energy production N=50						
Mean	79.44	475.58	2119.68	3067.67	1385.76	8.10
Std. Deviation	41.70	731.11	2450.71	3406.67	1489.31	3.08

Relationship Between Wind Energy Production, Polluting Industrialization, and COVID-19 Infections: Table 2 reveals that cities located in regions with low production of wind energy (constituting 6% of the total) tend to have a higher level of polluting industrialization. Specifically, they experience more polluted days, with around 70 days per year exceeding the limits set for PM10 or ozone, compared to cities in regions with high wind energy production, which have approximately 48 polluted days per year. These preliminary findings suggest that regions characterized by both high wind energy production and low levels of polluting industrialization may have a lower rate of COVID-19 infection in their populations. Impact of Polluting Industrialization and Wind Energy Production: Table 3 further explores the relationship by considering the level of polluting industrialization in cities. Cities with high polluting industrialization and particulate compound emissions (exceeding 100 days per year for PM10 or ozone) and low wind energy production are found to have a significantly higher number of COVID-19 infections. This high infection rate is observed in an environment characterized by a high average population density and low average wind speed. Taken together, these findings provide evidence that regions with high wind energy production and low levels of polluting industrialization may indeed exhibit a lower spread of COVID-19 infections. This correlation underscores the potential role of renewable energy sources and reduced industrial pollution in public health outcomes during a pandemic like COVID-19. Further analysis may help confirm these observations and uncover additional insights.

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

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

Table 4: Correlation

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

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

Correlation Between Polluting Industrialization and COVID-19 Infections: In regions where wind energy production accounts for less than 6% of the total, there is a noticeable positive correlation between polluting industrialization and the number of COVID-19 infections on specific dates: On March 17th, 2020, there is a strong positive correlation ($r = 0.69$) between polluting industrialization and infected individuals, and this correlation is statistically significant (p-value < 0.01). On April 7th, 2020, the positive correlation remains significant ($r = 0.55$, p-value < 0.01). On April 27th, 2020, there is a weaker but still significant positive correlation ($r = 0.36$, p-value < 0.01) between polluting industrialization and COVID-19 infections. Regions with High Wind Energy Production: Interestingly, in regions with a high intensity of wind energy production, these correlations between polluting industrialization and COVID-19 infections do not appear to be statistically significant. These findings suggest that in regions where wind energy production is low (less than 6% of total production), there is a stronger association between polluting industrialization and the spread of COVID-19. This correlation is most pronounced on March 17th, 2020, and remains significant through early April. However, in regions with high wind energy production, this relationship is not as apparent. These results underscore the potential importance of renewable energy and pollution reduction measures in mitigating the impact of infectious diseases like COVID-19, particularly in areas with less reliance on fossil fuels.

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

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

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

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

- o cities in regions with 94% of wind energy production have not significant results because of low number of cases in sample
- o 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 PM10, 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.

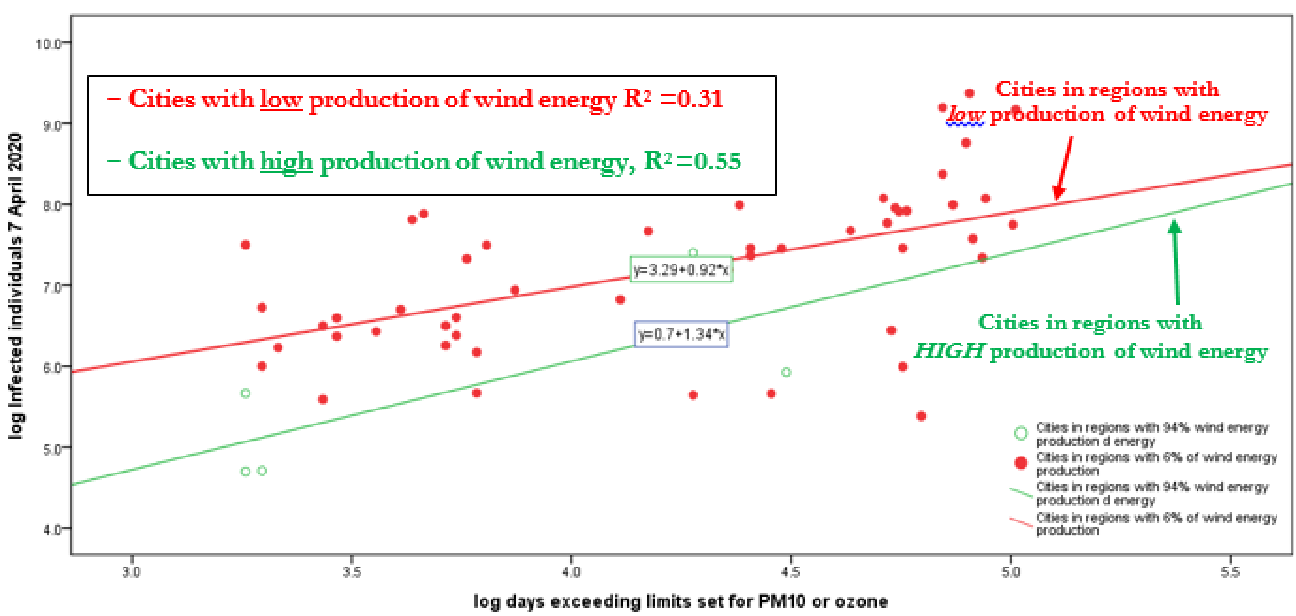

Figure 1: Regression lines of Log Infected Individuals on Log polluting industrialization according to production of wind energy of cities. Note: This result suggests that diffusion of COVID-19 infection increases with polluting industrialization in regions having low production of wind energy, i.e., 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^2 2019, considering the groups of cities with *high* and *low* polluting industrialization

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

Note: Explanatory variable: *log* Density inhabitants/km^2 in 2019; dependent variable *log* infected individuals. *** *p*-value<0.001; ** *p*-value<0.01; * *p*-value<0.05

Impact of Population Density on COVID-19 Infections: Table 6 demonstrates that the impact of population density on the expected number of COVID-19 infections varies depending on the level of polluting industrialization and particulate compound emissions in cities. In cities with low levels of polluting industrialization and low particulate compound emissions, a 1% increase in population density is associated with a modest increase of about 0.25% in the expected number of infected individuals. This relationship is statistically significant (P = 0.042). Conversely, in cities with high levels of polluting industrialization, a 1% increase in population density leads to a substantial 85% increase in the expected number of infected individuals. This correlation is highly significant (P < 0.001).

Figure 2: Regression Lines on April 7th, 2020: Figure 2 visually represents the regression lines for this analysis, focusing on April 7th, 2020, which is in the middle phase of the COVID-19 outbreak in Italy. The figure illustrates that in regions characterized by polluting industrialization, which generates a pollution-rich atmosphere combined with a climate factor of low wind speed, there is a more pronounced and significant increase in the diffusion of COVID-19 infections as population density rises. These findings emphasize the importance of considering the interaction between environmental factors, such as pollution levels, climate conditions, and population density, when assessing the spread of infectious diseases like COVID-19. They highlight the role of air quality and wind speed as contributing factors to the dynamics of the pandemic.

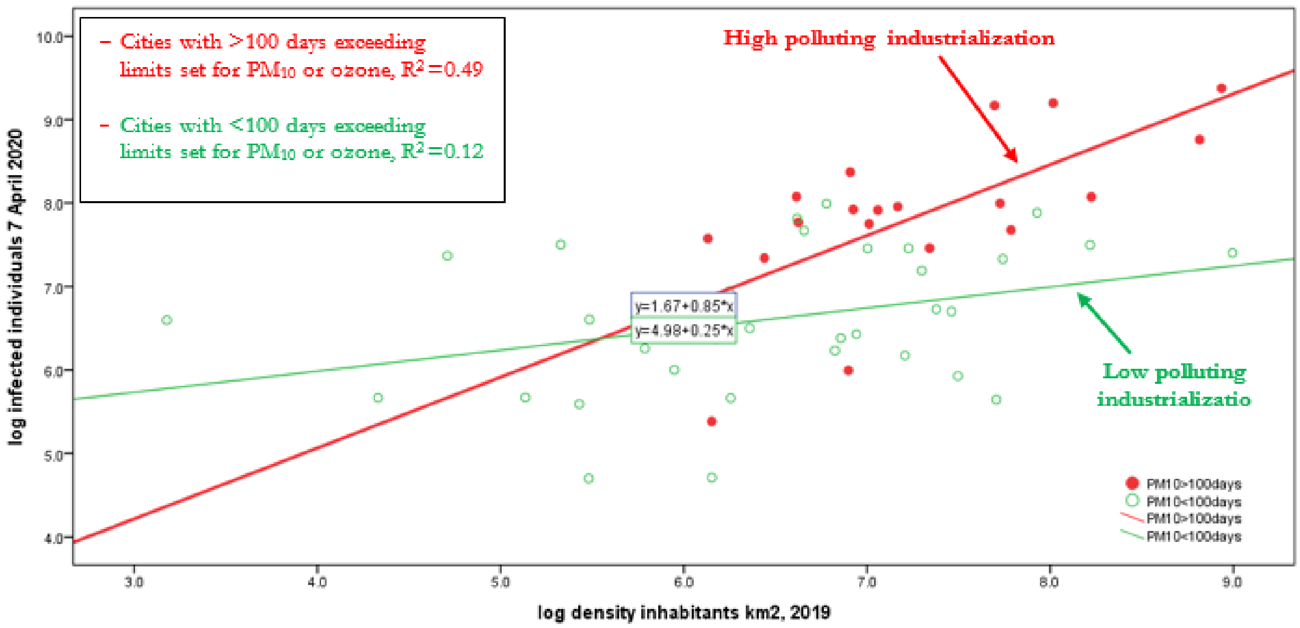

Figure 2: Regression line of Log Infected people on Log population density inhabitants, considering the groups of cities with high or low polluting industrialization

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

Impact of Air Pollution and Polluting Industrialization: When considering regions in Italy based on their levels of air pollution and particulate compounds emissions, and weighting the percentage of infected individuals and total deaths with the population of these regions, it is revealed that a substantial proportion of COVID-19 infections and fatalities are concentrated in regions characterized by: High levels of air pollution; High levels of polluting industrialization; Low production of renewable energy based on wind resources.

Percentage of Infections and Deaths: Specifically, about 74.50% of the infected individuals and approximately 81% of the total deaths in Italy due to COVID-19 infection are concentrated in these regions. These findings underscore the significant impact of environmental factors, such as air pollution and industrialization, on the spread and severity of COVID-19 in different regions of Italy. Regions with higher levels of pollution and lower reliance on renewable energy sources appear to bear a disproportionate burden of COVID-19 cases and fatalities. This highlights the potential importance of cleaner and more sustainable environmental policies in mitigating the impact of pandemics and protecting public health.

4. DISCUSSION AND LIMITATIONS

This recent study has uncovered a possible link between geo-environmental factors and the accelerated spread of COVID-19 in northern Italian cities, resulting in a higher incidence of infections and fatalities. The research involved an analysis of COVID-19 data in conjunction with environmental and wind energy-related information. The key discovery was that cities characterized by low wind speeds and frequent episodes of elevated air pollution, surpassing recommended levels for ozone and particulate matter, exhibited a higher prevalence of COVID-19 cases and associated deaths. These findings underscore the notion that addressing the ongoing COVID-19 pandemic and preparing for future epidemics similar to COVID-19 requires more than just advancements in medical, immunological, and microbiological research and practices; it also necessitates the development of industrial tools and practices geared toward sustainability and cleaner production. These insights offer valuable perspectives on the role of geo-environmental and industrial factors in potentially expediting the transmission of COVID-19 and other comparable viral agents.

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

- o The diffusion of COVID-19 in Italy has a high association with high polluting industrialization in cities
- o 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.

In light of the previously discussed findings, the crucial question arises: what is the relationship between the spread of COVID-19, polluting industrialization, and the presence of renewable wind energy in specific regions? The results suggest that among the provincial capitals in Italy, cities characterized by high levels of polluting industrial activity, situated in inland areas (often distant from the coastline), experiencing low average wind speeds, and having lower temperatures, tended to have a higher number of COVID-19 infections. Particularly in hinterland cities, such as Bergamo, Brescia, Lodi, and those in the Lombardy region of North West Italy, which border large urban centers, the combination of substantial polluting industrialization, low wind speeds, and limited wind energy production led to a significant increase in the average number of COVID-19 cases in April 2020. Conversely, cities located in regions with substantial wind energy production in Italy tended to exhibit lower levels of polluting industrialization, reduced air pollution, and fewer emissions of particulate compounds. These cities also benefited from a higher intensity of wind speed, which contributed to cleaner air and aligns with current research indicating a reduced risk of Coronavirus transmission under such conditions (Fattorini and Regoli, 2020). Conversely, areas with high levels of polluting industrialization, primarily in Northern Italy, where wind speeds are generally low and wind energy production is limited, experienced air pollution stagnation in the atmosphere, potentially facilitating the spread of COVID-19 infection (Contini and Costabile, 2020; Conticini et al., 2020). The implications for a sustainable policy are evident: the COVID-19 outbreak appears to have lower rates of diffusion in regions characterized by low levels of polluting industrialization and high production of renewable wind energy. Therefore, the Northern Italian region covered by this study should prioritize strategies aimed at reducing pollution from industrial sources and curbing emissions of particulate compounds in order to prevent the accelerated transmission dynamics of COVID-19 and similar infectious agents in the future.

To further underscore these conclusions with a perspective on sustainable policies, other studies have investigated the impact of various environmental factors on the dispersion of fine particulate matter (PM). For instance, Xu et al. (2020) explored the effect of moisture on the explosive growth of fine PM and proposed a novel approach for simulating the growth and dissipation of fine PM in ambient air. Their research indicated that winds play a significant role in the dispersion of fine PM, with high concentrations of fine PM persisting for only a brief period before dissipating. Additionally, climatological factors such as wind speed, wind direction, temperature, and humidity have critical implications for urban ventilation and the concentration of pollutants in city streets (Yuan et al., 2019).

Recognizing the advantages of wind as a resource capable of reducing air pollution and, consequently, viral infectivity with substantial public health benefits, Gu et al. (2020) have advocated for enhancing air quality in cities through improved urban ventilation. Urban ventilation refers to the capacity of an urban area to dilute pollutants and heat by enhancing the exchange of air between different zones within and above the urban canopy. The effectiveness of urban ventilation depends on several urban geometry characteristics, including frontal and plan area density, and the aspect ratio of urban morphology. Studies have shown that variations in building height can have positive effects on the levels of breathability in urban environments, while larger aspect ratios of urban canyons can lead to elevated concentrations of pollutants within city streets.

In the context of the Northern Italian region's hinterland areas, which tend to experience low wind speeds and possess urban climatological characteristics and regional topography conducive to air pollution stagnation, it becomes imperative to implement long-term sustainable policies aimed at reducing polluting industrialization and promoting the generation of renewable energy (Wang and Zhu, 2020). The health and economic benefits associated with national and local reductions in air pollution are widely acknowledged. For example, a study conducted in China by Cui et al. (2020) demonstrated that reductions in ambient air pollution and particulate compound emissions had prevented thousands of premature deaths and morbidity cases, resulting in substantial economic benefits.

In summary, this study underscores the importance of implementing comprehensive sustainable policies that address the reduction of air pollution and support the production of renewable energy. These policies are crucial not only for mitigating the effects of the current COVID-19 pandemic but also for preventing future epidemics by creating environmental conditions less conducive to the spread of airborne viral diseases. Indeed, the health and economic benefits associated with reducing air pollution are widely acknowledged. Cui et al. (2020), drawing from their study in China, have presented compelling evidence of the positive outcomes resulting from reductions in ambient air pollution and particulate compound emissions. Their research indicated that these reductions led to the avoidance of more than 2,300 premature deaths and over 15,800 morbidity cases in 2017, resulting in approximately US$ 318 million in economic benefits.

Moreover, Cui et al. (2020) argued that further reductions in fine particulate matter (PM2.5) concentrations, specifically lowering them to 15 μg/m3, could yield even more substantial benefits. This reduction was projected to result in a 70% decrease in total PM2.5-related non-accidental mortality and a 95% reduction in total PM2.5-related morbidity, with economic benefits exceeding US$ 1,289.5 million. In summary, sustainable policies aimed at reducing air pollution and particulate compound emissions offer significant advantages across environmental, public health, social, and economic dimensions.

This study emphasizes that in order to prevent epidemics akin to COVID-19 and other infectious diseases, nations must adopt sustainable policies aimed at reducing air pollution. Air pollution not only poses direct risks to public health but also amplifies the negative effects of airborne viral diseases. Additionally, a sustainable development policy should incorporate considerations of urban climatology, focusing on the climatic properties of urban areas, as advocated by Gu et al. (2020). Furthermore, it should actively support renewable energy sources like wind energy, which create environmental conditions conducive to reducing air pollution on a trans-regional scale, as highlighted by Wang and Zhu (2020).

In summary, certain areas characterized by a combination of climatic conditions with low wind speeds, a specific urban climatology observed in hinterland cities, high levels of polluting industrialization, regional topographical features, and physical geography tend to experience stagnation of air pollution and increased emissions of particulate compounds, particularly during the fall and winter seasons. These factors appear to have contributed to the accelerated spread of COVID-19 in northern Italian cities, resulting in a higher number of infected individuals and fatalities. This aligns with the findings of Contini and Costabile (2020), Conticini et al. (2020), and Fattorini and Regoli (2020).

Additionally, the study's results suggest that among Italian provincial capitals, cities that exceeded the limits for PM10 or ozone on more than 100 days per year, were situated in hinterland zones (away from the coast), had low average wind energy production, and experienced lower temperatures tended to have a higher number of COVID-19 infections. In particular, hinterland cities, often located near major urban centers, exhibited a significant increase in the average number of infected individuals in April, especially when these factors coincided with low wind speeds. These findings offer valuable insights into the role of geo-environmental and industrial factors in accelerating the diffusion of COVID-19 and similar viral agents.

Given this context, a proactive strategy to mitigate the impact of future epidemics should focus on reducing air pollution levels in hinterland and polluted cities, as this appears to be a critical factor in controlling the spread of such diseases.

Nonetheless, it's important to acknowledge that these conclusions remain tentative due to the inherent challenges associated with such studies, especially when conducted in real-time. The available data sources can only capture certain aspects of the com plex interactions between polluting industrialization, the spread of viral infectivity, and various economic factors. Therefore, it is essential to encourage further investigations into these aspects of COVID-19 diffusion in highly industrialized areas.

These ongoing studies can help inform the development of appropriate sustainable policies aimed at implementing long-term public health measures to reduce air pollution and effectively control the spread of infections similar to COVID-19, as suggested by Ou et al. (2020). In summary, the presence of high levels of polluting industrialization and low production of renewable energy in regions that can facilitate the spread of epidemics in environments characterized by high levels of air pollution and particulate compound emissions underscores the need for a comprehensive strategy. This strategy should be rooted in sustainability science and prioritize cleaner production methods within socioeconomic systems to prevent future epidemics akin to COVID-19.

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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