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How do environmental, demographic, and geographical factors influence the spread of Covid-19

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Abstract. Italy was the first European country to experience a rapid increase in confirmed cases and deaths of the novel Coronavirus disease (COVID-19). This study explains how COVID-19 transmitted so rapidly in northern Italy, analysing the underlying relationships between infected people and environmental, demographic, and geographical factors that influenced its spread. This study analyses data on COVID-19 cases alongside environmental data. This study finds out that cities with little wind, high humidity and frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — had higher numbers of COVID-19 related infected individuals and deaths. Overall, then, results here suggest that that geo-environmental factors may have accelerated the spread of COVID-19 in northern Italian cities, leading to a higher number of infected individuals and deaths..
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1. Introduction

This study has two goals. The first is to explain the main factors determining the diffusion of COVID-19 that is generating a high level of deaths. The second is to suggest a strategy to cope with futureepidemic threats with ofaccelerated viral infectivity in society.

Coronavirus disease 2019 (COVID-19) is viral infection that generates a severe acute respiratory syndrome with serious clinical symptoms given by fever, dry cough, dyspnea, and pneumonia and may result in progressive respiratory failure and death. Kucharski *et al.*, (2020) argue that COVID-19 transmission declined in Wuhan (China) during late January, 2020 (WHO, 2019, 2020, 2020a; nCoV-2019 Data Working Group, 2020). However, as more infected individuals arrive in international locations before control measures are applied, numerous epidemic chains haveled to new outbreaks in different nations worldwide (Xu & Kraemer Moritz, 2020; Wang *et al.*, 2020; Wu *et al.*, 2020). An outbreak of COVID-19 has led to more than 13,900 confirmed deaths in Italy and more than 51,000 deaths worldwide as of April1st, 2020 (Johns Hopkins Center for System Science

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and Engineering, 2020; cf., Dong *et al.,* 2020). Understanding the primefactors of transmissiondynamics of COVID-19 in Italy, having the highest number of deaths worldwide, is crucial for explaining possible relationships underlying the temporal and spatial aspects of the diffusion of this viral infectivity. Results here are basic to design a strategy to prevent future epidemics similar to COVID-19 that generates health and socioeconomic issues for nations and globally.

Currently, as people with the COVID-19 infection arrive incountries or regionswith low ongoing transmission, efforts should be done to stop transmission, preventpotential outbreaksand to avoid second and subsequent waves of a COVID-19 epidemic (European Centre for Disease Prevention and Control, 2020; Quilty & Clifford, 2020; Wells *et al.,* 2020). Wells *et al.,* (2020) argue that at the very early stage of the epidemic, reduction in the rate of exportation could delay the importation of cases into cities or nations unaffected by the COVID-19, to gain time to coordinate an appropriate public health response. After that, rapid contact tracing is basic within the epicentre and within and between importation cities to limit human-to-human transmission outside of outbreak countries, also applying appropriate isolation of cases (Wells *et al.,* 2020). The case of severe acute respiratory syndrome outbreak in 2003 started in southern China was able to be controlled through tracing contacts of cases because the majority of transmission occurred after symptom onset (Glasser *et al.,* 2011). These interventions also play a critical role in response to outbreaks where onset of symptoms and infectiousness are concurrent, such as Ebola virus disease (WHO, 2020b; Swanson *et al.,* 2018), MERS (Public Health England, 2019; Kang *et al.,* 2016) and other viral diseases (Hoang *et al.,* 2019; European Centre for Disease Prevention and Control. 2020a). Kucharski, *et al.,* (2020) claim that the isolation of cases and contact tracing can be less effective for COVID-19 because infectiousness starts before the onset of symptoms (cf., Fraser *et al.,* 2004; Peak *et al.,* 2017). Hellewell *et al.,* (2020) show that effective contact tracing and case isolation is enough to control a new outbreak of COVID-19 within 3 months, but the probability of control decreases with long delays from symptom onset to isolation that increase transmission before symptoms. However, it is unclear if these efforts will achieve the control of transmission of COVID-19. In the presence of COVID19 outbreaks, it is crucial to understand the determinants of the transmission dynamics of this viral infectious disease for designing strategies to stop or reduce diffusion, empowering health policy with economic, social and environmental policies.This study focuses on statistical analyses of association between infected people and environmental, demographic and geographical factors that can explain transmission dynamics over time, and provide insights into the environmental situation to prevent and apply, *a priori*, appropriate control measures (Camacho *et al.,* 2015; Funk *et al.,* 2017; Riley *et al.,* 2003). In particular, this study here can explain, whenever possible, factors determining the accelerated viral infectivity in specific regionstoguide policymakers to prevent future epidemics similar to COVID-19 (Cooper *et al.,* 2006; Kucharski *et al.,* 2015). However, there are several challenges to such studies, particularly in real time. Sources may be biased, incomplete, or only capture certain aspects of the on-going outbreak dynamics.

2. Data and study design

The complex problem of viral infectivity of COVID-19 is analysed here in a perspective of reductionist approach, considering the geo-environmental and demographic factors that we study to explain the relationships supporting the transmission dynamics (cf., Linstone, 1999). In addition, the investigation of the causes of the accelerated diffusion of viral infectivity is done with a philosophical approach *sensu* the philosopher Vico (Flint, 1884). In particular, the method of inquiry is also based on Kantian approach in which theoretical framework and empirical data complement each other and are inseparable. In this case the truth on this phenomenon, transmission dynamics of COVID-19, is a result of synthesis (Churchman, 1971).

2.1. Data and their sources

This study focuses on *N*=55 Italian cities that are provincial capitals. Sources of data are The Ministry of Health in Italy for epidemiological data (Ministerodella Salute, 2020), Legambiente (2019) for data of air pollution deriving from the Regional Agencies for Environmental Protection in Italy, ilMeteo (2020) for data of weather trendbased on meteorological stations of Italian province capitals, The Italian National Institute of Statistics for density of population concerning cities under study (ISTAT, 2020).

2.2. Measures

The unit of analysis is main Italian provincial cities. In a perspective of reductionism approach for statistical analysis and decision making, this study focuses on the following measures.

- Pollution: total days exceeding the limits set for PM_{10} (particulate matter 10 micrometres or less in diameter) or for ozone in the 55 Italian provincial capitals over 2018. This measure is stable over time and the strategy of using the year 2018, before the COVID-19 outbreak in Italy, is to include the health effects of exposures to pollutants, such as airborne particulate matter and ozone (Brunekreef *et al.,* 2002). In fact, days of air pollution within Italian cities are a main factor that has affected health of population and environment (Legambiente, 2019).
- Diffusion of COVID19. Number of infected from 17 March, 2020 toApril 2020 (Ministerodella Salute, 2020). Infected are detected with COVID-19 tests according to following criteria:

– Have fever or lower respiratory symptoms (cough, shortness of breath) and close contact with a confirmed COVID-19 case within the past 14 days; OR

– Have fever and lower respiratory symptoms (cough, shortness of breath) and a negative rapid flu test

- Meteorological indicators are: average temperature in °C, Moisture %, wind km/h, days of rain and fog from 1st February to 1April, 2020 (ilMeteo, 2020).
- Interpersonal contact rates: a proxy here considers the density of cities (individual /km^2) in 2019 (ISTAT, 2020).

2.3. Data analysis and procedure

This study analyses a database of *N*=55 Italian provincial capitals, considering variables in 2018-2019-2020 to explain the relationships between diffusion of COVID19, demographic, geographical and environmental variables.

Firstly, preliminary analyses of variables are descriptive statistics based on mean, std. deviation, skewness and kurtosis to assess the normality of distributions and, if necessary to fix distributions of variables with a *log*-transformation.

Statistical analyses are also done categorizing Italian provincial capitals (*N*=55) in groups as follows:

- Hinterland cities
- Coastal cities

Categorization in:

- Windy cities
- Not windy cities

Categorization in:

- Cities of North Italy
- Cities of Central-South Italy

Categorization in:

- Cities with >100 days per year exceeding the limits set for PM_{10} or for ozone
- Cities with <100 days per year exceeding the limits set for PM_{10} or for ozone

Categorization in:

- Cities with ≤1000 inhabitant/km^2
- Cities with > 1000 inhabitant/km^2

Categorization in:

- Cities with ≤500 inhabitant/km^2
- Cities with 500-1500 inhabitant/km^2
- Cities with >1500 inhabitants/km^2

Secondly, the bivariate and partial correlation verifies relationships (or associations) between variables understudy, and measures the degree of association. After that the null hypothesis (H_0) and alternative hypothesis (H_1) of the significance test for correlation is computed, considering two-tailed significance test.

Thirdly, the analysis considers the relation between independent and dependent variables. In particular, the dependent variable (number of infected people across Italian provincial capitals) is a linear function of a single explanatory variable given by total days of exceeding the limits set for PM_{10} across Italian province capitals. Dependent variables have in general *a lag of 1 years* in comparison with explanatory variables to consider temporal effects of air pollution predictor on environment and population in the presence of viral infectivity by COVID19 in specific cities of Italy.

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

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

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

y = dependent variable is number of infected individualsin cities

x =explanatory variable is a measure of air pollution, given by total days of exceeding the limits set for PM_{10} or ozone in cities

This study extends the analysis with a multiple regression model to assess how different indicators can affect diffusion of COVID-19. The specification of the linear relationship is also a *log-log* model as follows:

$$log\ y_t = \alpha + \beta_1 log x_{1,\ t-1} + \beta_2\ log x_{2,\ t-1} + u \qquad (2)$$

y = dependent variable is number of infected individuals in cities

x_1 =explanatory variable is a measure of air pollution, given by total days of exceeding the limits set for PM_{10} or ozone in cities

x_2 = density of cities, inhabitants /km^2

In addition, equation [2] is performed using data of infected at t=17th March, 2020 in the starting phase of growth of the outbreak in Italy, and the at *t+16days*= 1st April, 2020 in the phase of maturity of viral infectivity during lockdown and quarantine to assess the magnitude of two explanatory variables in the transmission dynamics of COVID-19. The estimation of equation [2] is also performedusing hierarchical multiple regression, a variant of the basic multiple regression procedure that allows to specify a fixed order of entry for variables in order to control for the effects of covariates or to test the effects of certain predictors independent of the influence of others.The R^2 changes are important to assess the predictive role of additional variables. The adjusted R-square and standard error of the estimate are useful as comparative measures to assess results between models. The *F*-test evaluates if the regression model is better than using only the mean of the dependent variable. If the *F* value is very small (e.g., 0.001), then the independent variables reliably predict the dependent variable.

Moreover, the linear relationship is also specified with a quadratic model as follows:

$$y_t = \alpha + \beta x_{t-1} + \beta (x_{t-1})^2 + u \qquad (3)$$

the goal is to apply an optimization approach, to calculate the minimum of equation [3] thatsuggests the maximum number of days in which cities can exceed the limits set for PM_{10}. or ozone. Beyond this critical estimated limit, there are environmental inconsistencies of air pollution associated with meteorological conditions that can trigger a take-off of viral infectivity with damages for health of population and economic system (cf., Coccia, 2017c, 2017d). The max number of days in which cities can exceed the limit set for air pollution that minimizes the number of people infected, before the take-off of epidemic curve, can also suggest implications of proactive strategies and critical decision to cope with future epidemics similar to COVID-19 in society. Ordinary Least Squares (OLS) method is applied for estimating the unknown parameters of relations in linear regression models [1-3]. Statistical analyses are performed with the Statistics Software SPSS® version 26.

4. Results

Descriptive statistics of variables in *log* scale, based on Italian province capitals (*N*=55), have normal distribution to apply appropriate parametric analyses.

Table 1. *Descriptive statistics of Hinterland and Coastal Italian province capitals*

	Days exceeding limits set for PM_{10} or ozone 2018	Infected 17th March 2020	Infected 1st April 2020	Density inhabitants/km² 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020	Rain Days Feb-Mar 2020	Fog Days Feb-Mar 2020
Hinterland cities N=45									
Mean	80.40	497.00	1929.69	1480.11	9.11	68.31	8.02	4.81	4.14
Std. Deviation	41.66	767.19	2265.86	1524.25	2.20	7.68	3.69	2.38	3.13
Coastal cities N=10									
Mean	59.40	171.30	715.80	1332.80	10.61	74.40	11.73	5.10	3.25
Std. Deviation	38.61	164.96	522.67	2463.04	2.20	7.38	2.60	2.71	3.68

Table 1 shows that hinterland cities have and average higher level of infected individuals than coastal cities. Hinterland cities have also a higher air pollution (average days per years) than coastal cities, in a context of meteorological factors of lower average temperature, lower average wind speed, lower rain days and lower level of moisture % than coastal cities.

Table 2. *Descriptive statistics of windy and not windy of Italian province capitals*

	Days	Infected	Infected	Density	Temp °C	Moisture	Wind	Rain	Fog

	exceeding limits set for PM_{10} or ozone 2018	17th March 2020	1st April 2020	inhabitants/km² 2019	Feb-Mar 2020	% Feb-Mar 2020	km/h Feb-Mar 2020	Days Feb-Mar 2020	Days Feb-Mar 2020
Low windy cities N=41									
Mean	84.32	536.20	2036.15	1517.41	9.05	68.23	7.30	4.56	4.18
Std. Deviation	43.31	792.84	2333.72	1569.70	2.12	7.50	2.77	2.33	2.94
High windy cities N=14									
Mean	53.93	149.57	750.86	1265.64	10.36	72.89	12.77	5.75	3.39
Std. Deviation	25.87	153.55	640.02	2108.31	2.43	8.37	3.46	2.56	4.00

Table 2 shows that cities with low intensity of wind speed (7.3km/h) have and average higher level of infected individuals than windy cities (average of 12.77km/h). Cities with lower intensity of wind speed have also a higher level of air pollution (average days per years), in a meteorological context of lower average temperature, lower rain days, lower level of moisture % and a higher average days of fog.

Table 3. *Descriptive statistics of Northern and Central-Southern Italian province capitals*

	Days exceeding limits set for PM_{10} or ozone 2018	Infected 17th March 2020	Infected 1st April 2020	Density inhabitants/km² 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020	Rain Days Feb-Mar 2020	Fog Days Feb-Mar 2020
Norther cities N=45									
Mean	80.51	515.60	1968.42	1448.00	9.05	69.40	7.89	4.80	4.31
Std. Deviation	42.67	759.18	2230.43	1538.10	1.97	7.61	3.15	2.42	3.06
Central-Southern cities N=10									
Mean	58.90	87.60	541.50	1477.30	10.88	69.50	12.31	5.15	2.50
Std. Deviation	32.36	129.98	735.21	2424.50	2.92	9.64	4.44	2.52	3.65

Table 3 shows that cities in the central and southern part of Italy have, during the COVID-19 outbreak, a lower number of infected than cities in North Italy. This result is in anenvironment with lower air pollution (average days per years), higher average temperature, higher average wind speed, higher rain days and lower level of moisture %.

Table 4. *Descriptive statistics of Italian provincial capitals according to days exceeding the limits set for PM_{10}*

	Days	Infected	Infected	Density	Temp °C	Moistur	Wind	Rain	Fog

	exceeding limits set for PM_{10} or ozone 2018	17th March 2020	1st April 2020	inhabitants/ km² 2019	Feb-Mar 2020	e % Feb-Mar 2020	km/h Feb-Mar 2020	Days Feb-Mar 2020	Days Feb-Mar 2020
Cities with >100days exceeding limits set for PM_{10} *N=20*									
Mean	125.25	881.70	3124.75	1981.40	9.19	71.30	7.67	4.80	4.88
Std. Deviation	13.40	1010.97	2905.18	1988.67	1.46	7.63	2.86	2.57	2.65
Cities with <100days exceeding limits set for PM_{10} *N=35*									
Mean	48.77	184.11	899.97	1151.57	9.49	68.34	9.28	4.90	3.47
Std. Deviation	21.37	202.76	708.32	1466.28	2.62	7.99	4.15	2.37	3.44

Table 4 confirms previous results considering cities with >100days exceeding limits set for PM_{10} or ozone: they have, *versus* cities with less than 100days, a very high level of infected individuals, in anenvironment of higher average density of population, lower average intensity of wind speed, lower average temperature with higher average moisture % and days of fog.

Table 5. *Descriptive statistics of Italian provincial capitals according to density per km² (2 categories)*

	Days exceeding limits set for PM_{10} or ozone 2018	Infected 17th March 2020	Infected 1st April 2020	Density inhabitant s/km² 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020	Rain Days Feb-Mar 2020	Fog Days Feb-Mar 2020
Cities with ≤1000 inhabitant/km² *N=30*									
Mean	64.37	248.37	960.97	510.77	10.01	69.61	9.28	4.08	3.75
Std. Deviation	39.25	386.95	951.26	282.11	1.95	10.30	4.41	2.37	3.40
Cities with >1000 inhabitant/km² *N=25*									
Mean	91.24	665.08	2606.60	2584.40	8.63	69.19	7.99	5.80	4.26
Std. Deviation	40.24	919.70	2717.57	2000.63	2.40	3.59	2.79	2.17	3.03

Table 6. *Descriptive statistics of Italian provincial capitals according to density per km² (3 categories)*

	Days exceeding	Infected 17th	Infected 1st April	Density inhabitants	Temp °C Feb-Mar	Moisture %	Wind km/h	Rain Days	Fog Days

	limits set for PM_{10} or ozone 2018	March 2020	2020	/km² 2019	2020	Feb-Mar 2020	Feb-Mar 2020	Feb-Mar 2020	Feb-Mar 2020
Cities with <1000 inhabitant/km² N=17									
Mean	52.82	116.12	567.12	312.76	9.88	71.12	9.52	4.44	4.41
Std. Deviation	36.87	128.13	466.49	161.34	2.12	8.91	5.73	2.79	3.79
Cities with 500-1000 inhabitant/km² N=22									
Mean	84.32	430.91	1519.50	951.32	9.04	68.50	8.37	4.34	3.75
Std. Deviation	37.28	476.29	1018.07	277.77	2.65	9.17	2.33	2.06	2.99
Cities with >1000 inhabitant/km² N=16									
Mean	91.19	789.00	3182.75	3355.44	9.33	68.86	8.26	6.03	3.84
Std. Deviation	43.29	1103.03	3239.96	2151.27	1.81	4.32	2.79	2.19	3.03

Tables 5-6 show results considering categorization of cities per density of population/km². Results reveal that average number of infected individuals increases with average density of people/km², but with an arithmetic growth, in comparison to geometric growth of number of infected individuals with other categorizationsof cities. These findings suggest that density of population per km² is important for transmission dynamics but other factors may support acceleration of viral infectivity by COVID-19 rather than high probability of interpersonal contacts in cities.

In short, results suggest that among Italian province capitals:

- Number of infected people is HIGHER in: Cities with >100days exceeding limits set for PM_{10}or ozone, located in hinterland zones having a low average intensity of windspeed and lower temperature in °C.

Table 7. *Correlation*

N=55	*Log* Days exceeding limits set for PM_{10} or ozone 2018	*Log* Density inhabitants/km² 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020
Log Infected 17 March, 2020					
Pearson Correlation	.643**	.484**	-.117	.005	–.377**
Sig. (2-tailed)	.001	.001	.397	.970	.005
N=55	Days exceeding limits set for PM_{10} or ozone 2018	Density inhabitants/km² 2019	Temp °C Feb-Mar 2020	Moisture % Feb-Mar 2020	Wind km/h Feb-Mar 2020
Log Infected 1 April, 2020					
Pearson Correlation	.620**	.552**	–0.247	0.049	–0.281*
Sig. (2-tailed)	0.001	0.001	0.069	0.720	0.038

Note: **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 7 shows association between variables on 17th March and 1st April, 2020: a correlation higher than 62% (p-value<.001) is between air pollution and infected individuals, a lower coefficient of correlation is between density of population and infected individuals (*r*=48-55%, *p*-value<.001). Results also show a negative correlation between number of infected individuals and intensity of wind speed among cities (*r*= –28 to –38%, *p*-value <0.05): this effect is due to the role of wind speed that cleans air from pollutants that are associated with transmission dynamics of viral infectivity.

Table 8. *Partial Correlation*

Control Variables Temp °C Moisture % Wind km/h Feb-Mar 2020	*Pearson Correlation*	*Log* Infected 17 March, 2020	*Log* Infected 1 April, 2020
	Log Days exceeding limits set for PM_{10} or ozone 2018	0.607	.602
	Sig. (2-tailed)	.001	.001
	N	50	50

Table 8 confirms the high correlation between air pollution and infected individuals on 17th March and 1 April, 2020, controlling meteorological factors of cities under study (*r*>60%, *p*-value<.001).

Table 9. *Partial Correlation*

Control Variables *Log* Density inhabitants/km² 2019	*Pearson Correlation*	*Log* Infected 17 March, 2020	*Log* Infected 1 April, 2020
	Log Days exceeding limits set for PM_{10} or ozone 2018	0.542	.496
	Sig. (2-tailed)	.001	.001
	N	52	52
Control Variables *Log* Days exceeding limits set for PM_{10} or ozone 2018	*Pearson Correlation*	Log Infected 17 March, 2020	Log Infected 1 April, 2020
	Log Density inhabitants/km² 2019	0.279	.385
	Sig. (2-tailed)	.041	.004
	N	50	50

Partial correlation in table 9 suggests that controlling density of population on 17th march and 1st April 2020, number of infected people is associated with air pollution (*r*≥50%, *p*-value<.001), whereas, controlling air pollution the correlation between density of population in cities and infected individuals is lower (*r*=27-38%, *p*-value<.001). The reduction of *r* between infected individuals and air pollution from 17thMarch to 1st April, and the increase of the association between infected people and density of people in cities over the same time period, controlling mutual variables, suggests that that air pollution in cities seems to be a more important factor in the initial phase of transmission dynamics of COVID-19 (i.e., 17th March, 2020). In the phase of the maturity of transmission dynamics (1st April, 2020), with lockdown that reduces air pollution, the role of air pollution reduces intensity whereas human-to-human transmission increases.

Table 10. *Parametric estimates of the relationship of Log Infected 17 March and 1 April on Log Days exceeding limits set for PM_{10} and Log Density inhabitants/km² 2019 (hierarchical regression)*

	Model 1A *Step 1: Air pollution*	Model 2A, *Step 2: Interpersonal contacts*			Model 1B *Step 1: Air pollution*	Model 2B, *Step 2: Interpersonal contacts*	
	log Days exceeding limits set for $PM_{10,}$ 2018	*log* Days exceeding limits set for $PM_{10,}$ 2018	*Log* Density inhabitants/ km² 2019		*log* Days exceeding limits set for $PM_{10,}$ 2018	*log* Days exceeding limits set for $PM_{10,}$ 2018	*Log* Density inhabitants /km² 2019
*log*infected 17th March, 2020				*log*infected 1st April, 2020			
Constant α	-1.168		–2.168	Constant α	2.171**		1.089
(St. Err.)	(1.053)		(1.127)	(St. Err.)	(.827)		(.851)
Coefficient $\beta 1$	1.526***		1.266***	Coefficient $\beta 1$	1.129***		.847***
(St. Err.)	(0.250)		(.272)	(St. Err.)	(.196)		(.206)
Coefficient $\beta 2$			.309*	Coefficient $\beta 2$			.335**
(St. Err.)			(.148)	(St. Err.)			(.111)
F	37.342***b		22.059***c	*F*	33.158***b		23.604***c
R^2	0.413		0.459	R^2	.385		.476
ΔR^2.	0.413		0.046	ΔR^2.	.385		.091
ΔF	37.342***		4.388*	ΔF	33.158***		9.028**

Notes: *** *p*-value<0.001; ** *p*-value<0.01; * *p*-value<0.05; b= predictors: *log* Days exceeding limits set for PM_{10}; c= predictors: *log* Days exceeding limits set for $PM_{10,}$ 2018 year; *Log* Density inhabitants/km² 2019

These findings are confirmed with hierarchical regression that also reveals how air pollution in cities seems to be a driving factor of transmission dynamics in the growing phase of CIVID-19 (17th March, 2020). In the phase of the maturity of transmission dynamics (1st April, 2020), the determinant of air pollution is important to support infected population but reduces intensity, whereas the factor of human-to-human transmission increases, *ceteris paribus* (Table 10). This result reveals that transmissions dynamics of COVID-19 is due to human-to-human transmission but the factor of air pollution-to-human transmission of viral infectivity supports a substantial growth.

Table 11. *Parametric estimates of the relationship of Log Infected 1st April, 2020 on Log Density inhabitants/km² 2019, considering the groups of cities with days exceeding limits set for PM_{10}or ozone*

↓DEPENDENT VARIABLE	Model cities with <100 days exceeding limits set for PM_{10} or ozone, 2018 *Log* Density inhabitants/km² 2019	↓DEPENDENT VARIABLE	Model cities with >100 days exceeding limits set for PM_{10} or ozone, 2018 *Log* Density inhabitants/km² 2019
*log*infected		*log*infected	
1 April, 2020		1 April, 2020	
Constant α	4.501	Constant α	1.425
(St. Err.)	(.801)	(St. Err.)	(1.624)
Coefficient$\beta 1$	0.303*	Coefficient$\beta 1$	0.856***
(St. Err.)	(0.122)	(St. Err.)	(0.223)
R^2 (St. Err. of Estimate)	0.158 (.828)	R^2 (St. Err. of Estimate)	0.450(.803)
F	6.207*	*F*	14.714***

Note: Explanatory variable: *Log* Density inhabitants/km² in 2019; *** p-value<0.001; * p-value<0.05

Table 11 shows results of the transmission dynamics of COVID-19 considering the interpersonal contacts, measured with density of population in cities understudy. In short, results suggest that density of population explains the number of infected individuals, increasing the probability of human-to-humantransmission. However, if we decompose the sample to consider the cities with ≤100 days exceeding limits set for PM_{10} or ozone and with >100 days exceeding limits set for PM_{10} or ozone, then the expected increase of number of infected individuals is higher in cities having more than 100 days exceeding limits set for PM_{10} or ozone. In particular,

- Cities with ≤100 days exceeding limits set for PM_{10}, an increase of 1% in density of population, it increases the expected number of infected by about 0.30%
- Cities with >100 days exceeding limits set for PM_{10}, an increase of 1% in density of population, it increases the expected number of infected by about 1.43%!

The statistical output of table 11 is schematically summarized as follows:

	Cities with ≤100 days exceeding limits set for PM_{10}	Cities with >100 days exceeding limits set for PM_{10}
Density of population	0.30 (p<0.05)	1.43 (p<0.001)
F	6.207 (p<0.05)	14.714 (p<0.001)
R^2	15.8%	45%

In short, the coefficient of regression in cities with >100 days exceeding limits set for PM_{10} is much bigger than the coefficient in cities with ≤100 days exceeding limits set for PM_{10}, suggesting that air pollution-to-human transmission is definitely important to explain the transmission dynamics of COVID-19. The policy implications here are clear: COVID-19 has reduced transmission dynamics on population in the presence of lower level of air pollution and specific environments with lower intensity of wind speed. Hence, the effect of accelerated transmission dynamics of

COVID-19 cannot be explained without accounting for the level of air pollution and geo-environmental conditions of the cities.

Table 12. *Parametric estimates of the relationship of Infected 1st April, 2020 on days exceeding limits set for PM_{10} (simple regression analysis, quadratic model)*

Response variable: Infected 1 April, 2020				
Explanatory variable	B	St. Err.	R^2 (St. Err. of the Estimate)	*F* (sign.)
Days exceeding limits set for PM_{10}	–35.32	32.26	0.38 (1693.91)	15.89(0.001)
(Days exceeding limits set for PM_{10}) ^{2}	0.39*	0.194		
Constant	1438.81	1080.89		

Note: * *p*-value=0.057

A main question for environmental policy is: What is the maximum number of days in which cities can exceed the limits set for PM_{10}or ozone per year, before that the combination between air pollution and meteorological condition triggers a take-off of viral infectivity (epidemic diffusion) with damages for health of population and economy in society?

The function based on table 12 is:

$$y = 1438.808–35.322x+0.393x^2$$

y= number of infected individuals 1st April, 2020

x= days exceeding limits of PM_{10}or ozone in Italian provincial capitals

The minimization is performed imposing first derivative equal to zero.

$$Dy / x = y' = –35.322+0.786x=0$$

x=35.32/0.786= 44.94~45*days* exceeding limits of PM_{10}or ozone in Italian provincial capitals.

This finding suggests that the max number of days in which Italian provincial capitals can exceed per year the limits set for PM_{10} (particulate matter 10 micrometres or less in diameter) or for ozone, considering the meteorological condition is about 45 days. Beyond this critical point, the analytical and geometrical output suggests that environmental inconsistencies because of the combination between air pollution and meteorological conditions trigger a take-off of viral infectivity (epidemic diffusion) with damages for health of population and economy in society.

5. Discussion

Statistical analyses for *N*=55 Italian provincial capitals confirm the significant association between high diffusion of viral infectivity and air pollution. Studies show that the diffusion of viral infectivity depends on the interplay between host factors and the environment (Neu & Mainou, 2020). In this context, it is critical to understand how air quality can affect viral dissemination at national and global level (Das & Horton, 2017). Many ecological studies have examined the association between the incidence of invasive pneumococcal disease and respiratory virus circulation and various climatic factors (McCullers, 2006; Jansen *et al.*, 2008). These studies show that in temperate climates, the epidemiology of invasive pneumococcal disease has a peak incidence in winter months (Dowell *et al.*, 2003; Kim *et al.*, 1996; Talbot *et al.*, 2005). Brunekreef & Holgate (2002) argue that, in addition to climate factors, the health effects of air pollution have been subject to intense investigations in recent years. Air pollution is ubiquitous in manifold urban areas worldwide of developed and developing nations. Air pollution has gaseous components and particulate matter (PM). The former includes ozone (O_3), volatile organic compounds (VOCs), carbon monoxide (CO) and nitrogen oxides (NO_x) that generate inflammatory stimuli on the respiratory tract (Glencross *et al.*, 2020). Of these pollutants, PM has a complex composition that includes metals, elemental carbon and organic carbon (both in hydrocarbons and peptides), sulphates and nitrates, etc. (Ghio *et al.*, 2012; Wooding *et al.*, 2019).

Advanced countries, such as in Europe, have more and more smog because of an unexpected temperature inversion, which trap emissions from the city's coal-burning heating stoves and diesel powered buses near ground-level in winter. The ambient pollution mixes with moisture in the air to form a thick, foul-smelling fog that affect the health of people in the city (Wang *et al.*, 2016; Bell *et al.*, 2004). The exposure to pollutants, such as airborne particulate matter and ozone, generates respiratory and cardiovascular diseases with increases in mortality and hospital admissions (cf., Langrish & Mills, 2014). Wei *et al.*, (2020) analyse the effect of heavy aerosol pollution in northern China–characterized by long-duration, high $PM_{2.5}$ concentrations and wide geographical coverage–that impacts on environmental ecology, climate change and public health (cf., Liu *et al.*, 2017, 2018; Jin *et al.*, 2017). The biological components of air pollutants and bio aerosolsalso include bacteria, viruses, pollens, fungi, and animal/plant fragments (Després *et al.*, 2012; Fröhlich-Nowoisky *et al.*, 2016; Smets *et al.*, 2016). Studies show that during heavy aerosol pollution in Beijing (China), 50%-70% of bacterial aerosols are in sub micrometre particles, 0.56-1 mm (Zhang *et al.*, 2019; cf., Zhang *et al.*, 2016). As bacteria size typically ranges from 0.5 to 2.0 mm (Després *et al.*, 2012), they can form clumps or attach to particles and transport regionally between terrestrial, aquatic, atmospheric and artificial ecosystems (Smets *et al.*, 2016). Moreover, because of regional bio aerosol transportation, harmful microbial components, bacterial aerosols have dangerous implications on human health and also plantation (cf., Van Leuken *et al.*, 2016). Harmful bio aerosol components–including pathogens, antibiotic-resistant bacteria, and endotoxins–can cause severe respiratory and cardiovasculardiseases in society (Charmi *et al.,* 2018). In fact, the concentration of microbes, pathogens and toxic componentssignificantly increases during polluted days, compared to no polluteddays (Liu *et al.,* 2018). In addition, airborne bacterial community structureand concentration varies with pollutant concentration, which maybe related to bacterial sources and multiplication in the air (Zhang *et al.,* 2019). Studies also indicate that microbial community composition, concentration, and bioactivity are significantlyaffected by particle concentration (Liu *et al.,* 2018). To put it differently, the atmospheric particulate matter harboursmore microbes during polluted days than sunny or clean days (Wei *et al.,* 2016). These studies can explain one of the driving factors of higher viral infectivity of COVID-19 in the industrialized regions of Nord Italy, rather than other part of Italy (Tables 1-6). In fact, viable bio aerosolparticles and high microbial concentration in particulate matterplay their non-negligible role during air pollution and transmission of viral infectivity (Zhang *et al.,* 2019). For instance, airborne bacteria in $PM_{2.5}$ from the Beijing-Tianjin-Hebeiregionsin China revealed that air pollutants are main factors inshaping bacterial community structure (Gao *et al.,* 2017). Xie *et al.,* (2018) indicate that total bacteria concentration is higher inmoderately polluted air than in clean or heavily polluted air. Liu*et al.,* (2018) show that bacterial concentration is low inmoderately or heavily pollution in $PM_{2.5}$ and PM_{10}, whereas thepathogenic bacteria concentration is very high in heavy and moderatepollution. Sun *et al.,* (2018) study bacterial community duringlow and high particulate matter (PM) pollution and find outthatpredominant species varied with PM concentration.In general, bio aerosol concentrations are influenced by complex factors, such as emission sources, terrain, meteorological conditions and other climate factors (Zhai *et al.,* 2018). Wei *et al.,* (2020) also investigate the differences between inland and coastal cities in China (Jinan & Weihai, respectively) to explain the influence of topography, meteorological conditions and geophysical factors on bio aerosol.Results suggest that from clean days to severely polluted days, bacterial community structure is influenced by bacterial adaptation to pollutants, chemicalcomposition of pollutants and meteorological conditions (cf., Sun *et al.,* 2018). Moreover, certain bacteria from Proteobacteria and Deinococcus-Thermus have high tolerance towards environmental stresses and can adapt to extreme environments. As a matter of fact, bacilli can survive to harsh environments by forming spores. Moreover, certain bacteria with protective mechanisms can survive in highly polluted environments, while other bacteria cannot withstand such extreme conditions. In particular, bacteria in the atmosphere to survive must withstand and adapt to ultraviolet exposure, reduced nutrient availability, desiccation, extreme temperatures and other factors. In addition, in the presence of accumulated airborne pollutants, more microorganisms might be attached to particulate matter.Thus, in heavy or severe air pollution, highly toxic pollutants in $PM_{2.5}$and PM_{10}may inhibit microbial growth. Numerous studies also indicate the role of meteorological conditions in pollution developmentthat creates appropriate conditions for microbial community structure and abundance, and viral infectivity (Jones & Harrison, 2004). Zhong *et al.*, (2018) argue that static meteorological conditions may explain the increase of $PM_{2.5}$. In general, bacterial communities during aerosol pollution are influenced by bacterial adaptive mechanisms, particle composition, and meteorological conditions. The particles could also act as carriers, which have complexadsorption and toxicity effects on bacteria (Wei *et al.*, 2020). Certain particle components are also available as nutrition for bacteria and the toxic effect dominates in heavy pollution. The differences in bacterial adaptability towards airborne pollutants cause bacterial survival or death for different species. Groulx *et al.*, (2018) argue that microorganisms, such as bacteria and fungi in addition to other biological matter like endotoxins and spores comingle with particulate matter (PM) air pollutants. Hence, microorganisms may be influenced by interactions with ambient particles leading to the inhibition or enhancement of viability and environmental stability (e.g., tolerance to variation in seasonality, temperature, humidity, etc.). Moreover, Groulx *et al.*, (2018) claim that in the case of microbial agents of communicable disease, such as viruses, the potential for interactions with pollution may have public health implications.Thus, the variation in bacterial community structure is related to different pollution intensities. Wei *et al.*, (2020) showthat Staphylococcus increased with $PM_{2.5}$ and became the most abundant bacteria in moderate pollution. In heavy or severe pollution, bacteria, which are adaptable to harsh environments, increase.In moderate pollution, the $PM_{2.5}$ might harbour abundant bacteria, especially genera containing opportunistic pathogens. Therefore, effective measures should control health risks caused by bio aerosols during air pollution, especially for immunocompromised, elderly and other fragile individuals.This may explain the high mortality of certain individuals having previous pathologies because of COVID-19 in Italy that has the mortality rate (the percentage of deaths compared to the total of those who tested positive for COVID-19) of about 80% in individuals aged> 70 years with comorbidities as of April 1st, 2020 (IstitutoSuperioreSanità, 2020; cf., WHO, 2020c). Papi *et al.*, (2006) also indicate that chronic obstructive pulmonary disease (COPD) was significantly exacerbated by respiratory viral infections that cause reduction of forced expiratory volume in *1s* (FEV1) and airway inflammation (cf., Gorse *et al.*, 2006). Ko *et al.*, (2007) report that the most prevalent viruses detected during acute exacerbations of COPD in Hong Kong were the influenza A virus and coronavirus. They indicate that among patients with a mean age of more than 75 years, mean FEV1 was 40% of predicted normal and the FEV1/FVC (forced vital capacity) ratio was reduced to 58% of normal. De Serres *et al.*, (2009) also suggested that the influenza virus frequently causes acute exacerbations of asthma and COPD. Moreover, the study by Wei *et al.*, (2020) argues that air pollution in coastal city Weihaiin China was slightly lower than the inland city of Jinan.This study supports our results that the viral infectivity by COVID-19 is higher in hinterland cities rather than coastal cities in Italy. Wei *et al.*, (2020, p. 9) also suggest that different air quality strategies should be applied in inland and coastal cities: coastal cities need start bio aerosol risk alarm during moderate pollution when severe pollution occurs in inland cities.

Other studies have reported associations between air pollution and reduced lung function, increased hospital admissions, increased respiratory symptoms and high asthma medication use (Simoni *et al.*, 2015; Jalaludin *et al.*, 2004). In this context, the interaction between climate factors, air pollution and increased morbidity and mortality of people and children from respiratory diseases is a main health issuein society (Darrow *et al.*, 2014). Asthma is a disease that has been associated with exposure to traffic-related air pollution and tobacco smoke (Liao, 2011). Many studies show that exposure to traffic-related outdoor air pollutants (e.g., particulate matter PM_{10} with an aerodynamic diameter ≤10 μm, nitrogen dioxide NO_2, carbon monoxide CO, sulfur dioxide SO_2, and ozone O_3) increases the risk of asthma or asthma-like symptoms (Shankardass *et al.*, 2009; Weinmayr *et al.*, 2010). Especially, current evidence indicates that PM_{10} increases cough, lower respiratory symptoms and lower peak expiratory flow (Ward & Ayres, 2004; Nel, 2005). Weinmayr *et al.*, (2010) provide strong evidence that PM_{10} may be an aggravating factor of asthma in children. Furthermore, asthma symptoms are exacerbated by air pollutants, such as diesel exhaust, PM_{10}, NO_2, SO_2, andO_3 and respiratory virus, such as adenovirus, influenza, parainfluenza and respiratory syncytial virus (Jaspers *et al.*, 2005; Murdoch & Jennings, 2009; Murphy *et al.*, 2000; Wong *et al.*, 2009). The study by Liao *et al.*, (2011) confirms that exacerbations of asthma have been associated with bacterial and viral respiratory tract infections and air pollution. Some studies have focused on the effect of meteorology and air pollution on acute viral respiratory infections and viral bronchiolitis (a disease linked to seasonal changes in respiratory viruses) in the first years of life (Nenna *et al.*, 2017; Ségala *et al.*, 2008; Vandini *et al.*, 2013, 2015). Carugno *et al.*, (2018) analyse respiratory syncytial virus (RSV), the primary cause of acute lower respiratory infections in children: bronchiolitis. Results suggest that seasonal weather conditions and concentration of air pollutants seem to influence RSV-related bronchiolitis epidemics in Italian urban areas.In fact, airborne particulate matter (PM) may influence the children's immune system and foster the spread of RSV infection. This studyalso shows a correlation between short- and medium-term PM_{10} exposures and increased risk of hospitalization due to RSV bronchiolitis among infants. In short, manifold environmental factors–such as air pollution levels, circulation of respiratory viruses and colder temperatures–induce in longer periods of time spent indoors with higher opportunities for diffusion of infections between people. In fact, in Italy the high diffusion of viral infectivity by COVID-19 in North of Italy is in winter period (February-March, 2020). Studies also show that air pollution is higher during winter months and it has been associated with increased hospitalizations for respiratory diseases (Ko *et al.,* 2007a; Medina-Ramón *et al.,* 2006). Moreover, oscillations in temperature and humidity may lead to changes in the respiratory epithelium which increased susceptibility to infection (Deal *et al.,* 1980). Murdoch & Jennings (2009) correlate the incidence rate of invasive pneumococcal disease (IPD) with fluctuations in respiratory virus activity and environmental factors in New Zealand, showing how incidence rates of IPD are associated with the increased activity of some respiratory viruses and air pollution. Another side effect of air pollution exposure is the association with the incidence of mumps. Hao *et al.*, (2019) explore the effects of short-term exposure to air pollution on the incidence of mumps and show that exposure to NO_2 and $SO_2$is significantly associated with higher risk of developing mumps. Instead, Yang *et al.*, (2020) analyse the relationship between exposure to ambient air pollution and hand, foot, and mouth diseases (in short, HFMDs). Results show that the exposure of people to SO_2, NO_2, O_3, PM_{10} and $PM_{2.5}$ is associated with HFMDs. Moreover, the effect of air pollution in the cold season is higher than in the warm season. Shepherd & Mullins (2019) have also analysed the relationship between arthritis diagnosis in those over 50 and exposure to extreme air pollution in utero or infancy. Results link early-life air pollution exposure to later-life arthritis diagnoses, and suggest a particularly strong link for Rheumatoid arthritis (RA)[1]. Sheperd & Mullins (2019) also argue that exposure to smog and air pollution in the first year of life is associated with a higher incidence of arthritis later in life. These findings are important to explain complex relationships between people, meteorological conditions, air pollution and viral infectivity because millions of people continue to be exposed to episodes of extreme air pollution each year in cities around the world.

Air pollution, immune systemand genetic damages

The composition of ambient particulate matter (PM) varies both geographically and seasonallybecause of the mix of sources at any location across time and space. A vast literature shows short-term effects of air pollution on health, but air pollution affectsmorbidity also in the long run (Brunekreef & Holgate, 2002). The mechanism of damages of air pollution on health can be explained as follows. Air pollutants exert their own specific individual toxic effects on the respiratory and cardiovascular systems of people; in addition, ozone, oxides of nitrogen, and suspended particulates have a common property of being potent oxidants, either through direct effects on lipids and proteins or indirectly through the activation intracellular oxidant pathways (Rahman & MacNee, 2000). Animal and human in-vitro and in-vivo exposure studies have

[1]Rheumatoid arthritis is a chronic inflammatory disorder in which the body's immune system attacks its joints, and is one of the most common autoimmune diseases (Cooper & Stroehla, 2003). Moreover, rheumatoid arthritis is a major cause of disability that reduces patient's lifespan by 15-20% from the onset of the illness (Myllykangas-Luosujäarvi *et al.,* 1995; cf., Chang *et al.,* 2016; De Roos *et al.,* 2014; Farhat *et al.,* 2011; Jung *et al.,* 2017).

demonstrated the powerful oxidant capacity of inhaled ozone with activation of stress signalling pathways in epithelial cells (Bayram *et al.,* 2001) and resident alveolar inflammatory cells (Mochitate *et al.,* 2001). Lewtas (2007) shows in human studies that exposures to combustion emissions and ambient fine particulate air pollution are associated with genetic damages. Long-term epidemiologic studies report an increased risk of all causes of mortality, cardiopulmonary mortality, and lung cancer mortality associated with increasing exposures to air pollution (cf., Coccia, 2012, 2014; Coccia & Wang, 2015). Although there is substantial evidence that polycyclic aromatic hydrocarbons or substituted polycyclic aromatic hydrocarbons may be causative agents in cancer and reproductive effects, an increasing number of studies–investigating cardiopulmonary and cardiovascular effects–shows potential causative agents from air pollution combustion sources.

About the respiratory activity, the adult lung inhales approximately 10-11,000 L of air per day, positioning the respiratory epithelium for exposure to high volumes of pathogenic and environmental insults. In fact, respiratory mucosa is adapted to facilitate gaseous exchange and respond to environmental insults efficiently, with minimal damage to host tissue. The respiratory mucosa consists of respiratory tract lining fluids; bronchial and alveolar epithelial cells; tissue resident immune cells such as alveolar macrophages (AM), dendritic cells, innate lymphoid cells and granulocytes; as well as adaptive memory T and B lymphocytes.In health, the immune system responds effectively to infections and neoplastic cells, with a response tailored to the insult, but must tolerate (i.e., not respond harmfully to) the healthy body and benign environmental influences. A well-functioning immune system is vital for a healthy body. Inadequate and excessive immune responses generate diverse pathologies, such as serious infections, metastatic malignancies and auto-immune conditions (Glencross *et al.,* 2020). In particular, immune system consists of multiple types of immune cell that act together to generate (or fail to generate) immune responses. In this context, the explanation of relationships between ambient pollutants and immune system is vital to explain how pollution causes disease, and how pathology can be removed. Glencross *et al.,* (2020) show that air pollutants can affect different immune cell types, such as particle-clearing macrophages, inflammatory neutrophils, dendritic cells that orchestrate adaptive immune responses and lymphocytes that enact those responses. In general, air pollutants stimulate pro-inflammatory immune responses across multiple classes of immune cell. Air pollution can enhance T helper lymphocyte type 2 and T helper lymphocyte type 17 adaptive immune responses, as seen in allergy and asthma, and dysregulate anti-viral immune responses. In particular, the association between high ambient pollution and exacerbations of asthma and chronic obstructive pulmonary disease (COPD) is consistent with immunological mechanisms. In fact, diseases can result from inadequate responses to infectious microbes allowing fulminant infections, inappropriate/excessive immune responses to microbes leading to more (collateral) damages than the microbe itself, and inappropriate immune responses to self/environment, such as seems to be in the case of COVID-19. Glencross *et al.,* (2020) also discuss evidence that air pollution can cause disease by perturbing multicellular immune responses.Studies confirm associations between elevated ambient particulate matter and worsening of lung function in patients with COPD (Bloemsma *et al.,* 2020), between COPD exacerbations and both ambient particulate matter and ambient pollutant gasses (Li *et al.,* 2020) and similarly for asthma exacerbations with high concentration of ambient pollutants (Orellano *et al.,* 2017, Zheng *et al.,* 2015). In short, the associations between ambient pollution and airways exacerbations are stronger than associations with development of chronic airways diseases. Glencross *et al.,* (2020) also argue that ambient pollutants can directly trigger cellular signalling pathways, and both cell culture studies and animal models have shown profound effects of air pollutants on every type of immune cell studied. In addition to the general pro-inflammatory nature of these effects, many of studies suggest an action of air pollution to augment Th2 immune responses and perturb antimicrobial immune responses. This mechanism also explains the association between high air pollution and increased exacerbations of asthma – a disease characterized by an underlying Th2 immuno-pathology in the airways with severe viral-induced exacerbations. Moreover, as inhaled air pollution deposits primarily on the respiratory mucosa, potential strategies to reduce such effects may be based on vitamin D supplementation. Studies show that plasma levels of vitamin D, activated by ultraviolet B, are significantly higher in summer and fall than winter and spring, in a latitude-dependent manner (Barger-Lux & Heaney, 2002). Since the temperature and hour of sun are dependent upon the latitude of population residence and influenced by urban/rural residence, Oh *et al.,* (2010) argue that adequate activated vitamin D levels are also associated with diminished cancer risk and mortality (Lim *et al.,* 2006; Grant, 2002). For instance, breast cancer incidence correlates inversely with the levels of serum vitamin D and ultraviolet B exposure, which are the highest intensity in summer season. These relationships of vitamin D and cancer risk are not limited to breast cancer, but are also relevant to colon, prostate, endometrial, ovarian, and lung cancers (Zhou *et al.,* 2005).

In the context of this study and considering the negative effects of air pollution on human health and transmission dynamics of viruses, summer season may have twofold effects to reduce diffusion of viral infectivity:

1) hot and sunny weather increases temperature and improves environment that can reduce air pollution, typically of winter period, and as result alleviate transmission of viral infectivity by COVID-19 (Ko *et al.,* 2007a; Medina-Ramón *et al.,* 2006; Wei *et al.,,* 2020; Dowell *et al.,* 2003; Kim *et al.,* 1996; Talbot *et al.,* 2005);

2) sunny days and summer season induce in population a higher production of vitamin D that reinforces and improves the function of immune system to cope with viral infectivity of COVID-19.

Overall, then, statistical analysis, supported by relevant studies in these research topics, reveals that accelerated transmissions dynamics of COVID-19 is also to air pollution-to-human transmission in addition to human-to-human transmission.

6. Strategies to prevent epidemic similar to Covid-19

At the end of 2019, medical professionals in Wuhan (China) were treating cases of pneumonia cases that had an unknown source (Li *et al.,* 2020; Zhu and Xie, 2020; Chan *et al.,* 2020; Backer *et al.,* 2020). Days later, researchers confirmed the illnesses were caused by a new coronavirus (COVID-19). By January 23, 2020, Chinese authorities had shut down transportation going into and out of Wuhan, as well as local businesses, in order to reduce the spread of viral infectivity (Centers for Disease Control and Prevention, 2020; Public Health England. 2020; Manuell & Cukor, 2011). It was the first in the modern history of several quarantines set up in China and other countries around the world to cope with transmission dynamics of COVID-19.Quarantine is the separation and restriction of movement of people who have potentially been exposed to a contagious disease to ascertain if they become unwell, in order to reduce the risk of them infecting others (Brooks *et al.,* 2019). In short, quarantine can generate a strong reduction of the transmission of viral infectivity. Inthe presence of COVID-19 outbreak in North Italy, Italian government has applied the quarantine and lockdown from 11 March, 2020 to 13 April, 2020 for all Italy, adding also some holidays thereafter. In fact, Italy was not able to prevent this complex problem of epidemics and has applied quarantine as a recovery strategy to lessen the health and socioeconomic damages caused by COVID-19. Millions of people have been quarantined for the first time in Italy and is one of the largest actions in the history of Italy. In addition, Italy applied non-pharmaceutical interventions based on physical distancing, school and store closures, workplace distancing, to avoid crowded places, similarly to the COVID-19 outbreak in Wuhan (cf., Prem *et al.,* 2020). The benefits to support these measures until April, 2020 are aimed at delaying and reducing the height of epidemic peak, affording health-care systems more time to expand and respond to this emergency and, as a result reducing the final size of COVID-19 epidemic. In general, non-pharmaceutical interventions are important factors to reduce the epidemic peak and the acute pressure on the health-care system (Prem *et al.,* 2020; Fong *et al.,* 2020). However, Brooks *et al.,* (2019) report: "negative psychological effects of quarantine including post-traumatic stress symptoms, confusion, and anger. Stressors included longer quarantine duration, infection fears, frustration, boredom, inadequate supplies, inadequate information, financial loss, and stigma. Some researchers have suggested long-lasting effects. In situations where quarantine is deemed necessary, officials should quarantine individuals for no longer than required, provide clear rationale for quarantine and information about protocols, and ensure sufficient supplies are provided. Appeals to altruism by reminding the public about the benefits of quarantine to wider society can be favourable".

This strategy, of course, does not prevent future epidemics similar to the COVID-19 and it does not protect regions from future viral threats.Nations, a like Italy, have to apply *proactive strategies* that anticipate these potential problems and works to prevent them, reducing the health and economic impact in society.

Suggested proactive strategies to prevent future epidemics similar to COVID-19

Daszak *et al.*, (2020) argue thatto prevent the next epidemic and pandemic similar to COVID-19, research and investment of nations should focus on:

1) surveillance among wildlife to identify the high-risk pathogens they carry

2) surveillance among people who have contact with wildlife to identify early spillover events

3) improvement of market biosecurity regarding the wildlife trade.

In addition, high surveillance and proper biosafety procedures in public and private institutes of virology that study viruses and new viruses to avoid that may be accidentally spread in surrounding environments with damages for population and vegetation. In this context, international collaboration among scientists is basic to address these risks, support decisions of policymakers to prevent future pandemic creating potential huge socioeconomic issuesworldwide (cf., Coccia & Wang, 2016)[2]. In fact, following the COVID-19 outbreak, The Economist Intelligence Unit (EIU) points out that the global economy may contract of about by 2.2% and Italy by -7% of real GDP growth % in 2020 (EIU, 2020). Italy and other advanced countries should introduce organizational, product and process innovations to cope with future viral threats, such as the expansion of hospital capacity and testing capabilities, to reduce diagnostic and health system delays also using artificial intelligence, and as a consequencenew ICT technologies for alleviating and/or eliminating effective interactions between infectious and susceptible individuals,and finally of course to develop effective vaccines and antivirals that can counteract future global public health threat in the presence of new epidemics similar to COVID-19 (Chen *et al.*, 2020; Wilder-Smith *et al.*, 2020; Riou & Althaus, 2020; Yao *et al.*, 2020; cf., Coccia, 2015, 2017, 2019, 2020)[3].

[2] Socioeconomic shocks can lead to a general increase of prices, high public debts, high unemployment, income inequality and as a consequence violent behaviour (Coccia, 2016, 2017, 2017a).

[3] For additional studies about science and technology, cf., Coccia, 1999, 2003, 2005, 2005a, 2005b, 2005c, 2006, 2008, 2009, 2010, 2010a, 2010b, 2010c, 2011, 2012, 2012a, 2012b, 2012c, 2012d, 2013, 2014, 2014a, 2014b, 2014c, 2014d, 2014e, 2014f; 2015, 2015a, 2015b, 2015c; 2016,

This study here shows that geo-environmental factors of accelerated diffusion of COVID-19 are alsolikely associated with high air pollution and specific meteorologicalconditions (low wind speed, etc.) of North Italy and other Norther Italian regions that favour the transmission dynamics of viral infectivity. North Italy is one of the European regions with the highest motorization rate and polluting industrialization (cf., Legambiente, 2019). In 2018 in 55 provincial capitals the daily limits for PM_{10} or ozone were exceeded (i.e., 35 days for PM_{10} and 25 for ozone). In 24 of the 55 Italian province capitals, the limit was exceeded for both parameters, with negative effects on population that had to breathe polluted air for about four months in the year with subsequent health problems. In fact, the cities that last year passed the higher number of polluted daysare Brescia with 150 days (47 for the PM_{10} and 103 for the ozone), followed by Lodi with 149 (78 for the PM_{10} and 71 for the ozone),–these are two cities with severe COVID-19 outbreak–, Monza (140), Venice (139), Alessandria (136), Milan (135), Turin (134), Padua (130), Bergamo and Cremona (127) and Rovigo (121). These provincial capitals of the River Po area in Italy have exceeded at least one of the two limits just mentioned. The first city not located in the Po valley is Frosinone (Lazio region of the central part of Italy) with 116 days of exceedance (83 for the PM_{10} and 33 for the ozone), followed by Genoa with 103 days, Avellino a city close to Naples in South Italy (Campania region with 89 days: 46 for PM_{10} and 43 for ozone) and Terni with 86 (respectively 49 and 37 days for the two pollutants). Many cities in Italy are affected by air pollution and smog because of traffic, domestic heating, industries and agricultural practices and with private cars that continue to be by far the most used means of transportation (more than 39 million cars in 2019). In fact, a major source of emissions of nitrogen oxides into the atmosphere is the combustion of fossil fuels from stationary sources (heating, power generation) and motor vehicles. In ambient conditions, nitric oxide is rapidly transformed into nitrogen dioxide by atmospheric oxidants such as ozone (cf., Brunekreef & Holgate, 2002). In Italy, the first COVID-19 outbreak has been found in Codogno, a small city of the Lodi area, close to Milan. Althoughlocal lockdown as red zone on February 25, 2020, the Regional Agency for Environmental Protection showed that concentrations of PM_{10} beyond the limits in almost all of Lombardy region including the red zone (i.e., 82 mm/m^3 of air measured in Codogno). The day after, February 26, 2020, the mistral wind and then the north wind swept the entire Po valley, bringing to Lombardy region a

2016a, 2016b, 2017, 2017a, 2017b, 2017c, 2017d, 2017e, 2017f, 2017g; 2018, 2018a, 2018b, 2018c, 2018d, 2018e, 2018f, 2018g, 2018h, 2018i, 2018l, 2018m, 2018n; 2019, 2019a, 2019b, 2019c, 2019d, 2019e, 2019f, 2019g, 2019h, 2019i, 2019l, 2019m, 2019n, 2019o, 2019p; Coccia, 2020, 2020a, 2020b, 2020c, 2020d, 2020e, 2020f, 2020g, 2020h, 2020i; Coccia & Bellitto, 2020; Coccia & Benati, 2018, Coccia & Bozeman, 2016; Coccia *et al.*, 2015; Coccia & Finardi, 2012, 2013; Coccia *et al.*, 2012; Coccia & Rolfo, 2002, 2008, 2009; Coccia & Wang, 2015, 2016; Coccia & Watts, 2020.

substantial reduction in the average daily concentrations of PM_{10}, which almost everywhere were lower than 50 micrograms of particulate matter/m^3 of air.

Hence, high concentration of nitrogen dioxide, a noxious gas, particulate air pollutants emitted by motor vehicles, power plants, and industrial facilities in North Italy seems to be a platform to support diffusion of viral infectivity (Groulx *et al.,* 2018), increase hospitalizations for respiratory virus bronchiolitis (cf., Carugno *et al.,* 2018; Nenna *et al.,* 2017), increase asthma incidence (Liao *et al.,* 2011) and damage to the immune system of people (Glencross *et al.,* 2020). Transmission dynamics of COVID-19 has found in air pollution and meteorological conditions of North Italy an appropriate environment and population to carry out an accelerated diffusion that is generation more than 13,000 deaths and a huge number of hospitalizations in a short period of time.

An *indirect effect* of quarantine and lockdown in Italy is the strong reduction of airborne Nitrogen Dioxide Plummets and PM_{10}over Norther of Italy.The maps by ESA (2020) show concentrations of nitrogen dioxide NO_2 values across Italy before the quarantine and lockdown in February, 2020 and during the quarantine and lockdown in March, 2020. The reduction in NO_2 pollution is apparent in all North Italy (Po Valley). Hence, the measures taken to cope with the COVID-19outbreak (closure of schools and the reduction of traffic), particularly restrictive in the first phase on the regions of Northern Italy, have allowed a drastic reduction of concentrations of fine particulate matter, nitrogen dioxide and other polluting substances on the Po Valley. For instance, in Piedmont, one of the regions of North Italy also having a high COVID-19 diffusion, the concentration of air pollution since the beginning of March, 2020 has ever exceeded the limit values of PM_{10} and has always remained below 50μg / m^3 everywhere. Overall, then, the indirect effect of quarantine and lockdown of Italy and other European countries has reduced in a short time NO_2 and air pollution,improving the quality of environment that may reduce, associated with quarantine, physical distancing and other inter-related factors, the transmission dynamics of COVID-19. A study by Zhang *et al.,* (2019a) shows that with the implementation of air policy in China, from 2013 to 2017, fine particle ($PM_{2.5}$) concentrations have significant declined nationwide with health benefits. Now, the danger is that after the quarantine and lockdown, the industrial activity of industrialized regions in Italy has to resume at an intense pace of production and in next winter-fall season 2020-2021 there may be again the environmental and meteorologicalconditions that can lead to diffusion of viral infectivity of COVID-19 and/or other dangerous viruses. Of course, non-physical distancing and other long-run factors play a critical part in mitigating transmission dynamics of future epidemic similar to COVID-19, in particular when measures of physical distancing, school and store closures, workplace distancing, prohibition for crowded places are relaxed. The suggested strategy that regions of NorthItaly has to apply, considering their geographical locations and meteorological conditions with a high density of polluting industrialization, is to avoid to overcome the limits set of PM_{10} and other pollutants, following more and more a sustainable pathways of growth.*One of the findings here suggests that the max number of days per year that Italian provincial capitals can exceed the limits set for PM_{10} (particulate matter 10 micrometres or less in diameter) or for ozone, considering the meteorological condition has to beless than 50 days. After this critical point, the study suggests that environmental inconsistencies because of the combination between air pollution and meteorological conditions trigger a take-off of viral infectivity (epidemic diffusion) with damages for health of population and economy in society*.Italy must design and set up necessary measures to drastically reduce the concentrations of pollution present and improve air quality in cities.Italy not has to respect Legislative Decree 155/2010 that establishes a maximum number of 35 days / year with concentrations higher than 50 μg / m^3. As a matter of fact, the quarantine and other non-pharmaceutical interventions can reduce the impact of viral infectivity in the short term, but to prevent future epidemics similar to COVID-19, Italy and advanced nations have more and more to sustain a sustainable growth. Theenvironmental policy has to be associated with sustainable technologies that reduce air pollution improving the quality of air and environment for population to cope with future viral threats (cf., Coccia, 2005, 2006, 2018; Coccia & Watts, 2020)[4]. Italy must support, more and more, sustainable mobility as engine of socioeconomic change and redesign cities for people using an urban planning that improves public respiratory health.Moreover, in the presence of the association between air pollution, climate[5] and viral infectivity.Italy and other advanced nations have to immediately reduce the motorization rate of polluting machines with a transition to new electric vehicles, generating a revolution in society. It is basic to encourage sustainable mobility, by enhancing local, urban and commuter public transport with electric vehicles and creating vast Low Emission Zones within cities. Italy has to launch a real sustainable growth roadmap with the aim of complete zero emissions in all socioeconomic system. Some studies done in the past show the causality of the reduction of air pollution on health benefits. For instance, Pope (1989) describes the case of a labour dispute that shut down a large steel mill in the Utah Valley for 14 months in 1987. Toxicological studies of particulate matter collected before, during, and after the strike, in the Utah Valley case, provide strong evidence of a causal relation between exposure to ambient particulate matter and mortality and morbidity. Ambient particulate matter concentrations as well

4 cf. for dynamics of technological and economic change in society the studies by Coccia (2005a, 2005b, 2008, 2008, 2009, 2015a, 2017e, 2017f, 2017g, 2018a, 2019a, 2019b, 2019c, 2019d; Coccia and Finardi, 2012; Coccia & Rolfo, 2008).

5 Some studies show that in addition to human-to-human contact, ambient temperature is an important factor in the transmission and survival of coronaviruses (Zhu *et al.*, 2020) as well as temperature variation and humidity may also be important factors affecting the COVID-19 mortality (Ma *et al.*, 2020)

as respiratory hospital admissions were clearly decreased during the strike, increasing to prestrike levels after the dispute ended (Pope, 1989; cf., the reduction of mortality described by Pope, 1996). Another example includesthe reductions in acute-care visits and hospital admissions for asthma in Atlanta (GA, USA), in conjunction with reduced air pollution due to traffic restrictions taken during the 2000 Olympic games (Friedman, 2001).

7. Concluding remarks

The intensity of human interactions with Earth systems has accelerated in recent decades, because of urban development, population growth, industrialization, deforestation, construction of dams, etc., with changes in physical, biological, and chemical processes in soilsand waters. In particular, human activity, driven by a high level of world population that is about eight billion (U. S. Census Bureau 2020), has induced changes to Earth's surface, cryosphere, ecosystems, and climate that are now so great and rapid, advancing the geological epoch of Anthropocene (Crutzen & Stoermer, 2000; Foley *et al.,* 2013). The beginning of the Anthropocene at around 1780 AD marks the beginning of immense rises in human population and carbon emissions as well as atmospheric CO^2 levels (Ellis *et al.,* 2013). The scale of carbon emissions associated with industrial activity is leading to a rise in atmospheric greenhouse gases at a rate unprecedented and gradual rise in carbon dioxide (Glikson, 2013; Coccia, 2014a). In this era of Anthropocene, the health effects of air pollution have been subject to intense study in recent years. Exposure to airborne particulate matter and ozone has main health effects associated with increases in mortality and hospital admissions for respiratory and cardiovascular diseases (Kampa & Castanas, 2008; Hoek *et al.,* 2013). The idea that air pollution episodes have a detrimental effect on health is now rarely contested, and acute exposures to high concentrations of air pollutants exacerbate cardiopulmonary disorders in human population worldwide (Langrish & Mills, 2014).

This study shows that factors determining the diffusion of epidemics similar to COVID-19 are due to manifold elements, in addition to human-to-human transmission, given by:

1. *General factors*that are the same for all locations and associated with innate biological characteristics of the viruses, incubation time, effects on infected and susceptible people, etc.
2. *Specific factors* that are different for each location and even for each individual, such us level of air pollution over time and space, meteorologicalconditions of specific location, season, density of areas, economic wealth, cultural characteristics (religious habits, food culture, etc.), organization and efficiency of healthcare sector, facilities and equipment in health sector, immune system of people, average age of population, sex of people, etc.

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

- The acceleration of transmission dynamics of COVID-19 in North Italy has a high association with air pollution of cities measured with days of exceeding the limits set for PM10 or ozone
- Cities having more than 100 days of air pollution (exceeding the limits set for PM_{10}), they have a very high average number of infected individual (about 3,100 infected), whereas cities having less than 100 days of air pollution, they have a lower average number of infected (about 900 infected individuals)
- Hinterland cities with higher number of average days exceeding the limits set for PM_{10} have a very high number of infected people on 1st April, 2020 (arithmetic mean is about 2,000 infected, with average polluted days more than 80), than coastal cities also having days of exceeding the limits set for PM10 or ozone (arithmetic mean about 700 infected, with average polluted days about 60). In fact, coastal cities have an average higher intensity of wind speed (about 12 km/h) than hinterland cities (8 km/h) and statistical analysis reveals a negative coefficient correlation between number of infected and intensity of wind speed (r= –28 to –38%, p-value <0.05): in fact, wind speed and other elements clean air from pollutants that are associated with transmission dynamics of viral infectivity.
- Air pollution in cities under study seems to be a more important predictor in the initial phase of transmission dynamics (on 17th March 2020, $b_1 = 1.27$, $p<0.001$) than human-to-human transmission ($b_2 = 0.31$, $p<0.05$). In the second phase of the transmission dynamics of viral infectivity, air pollution reduces intensity (on 1st April,2020 $b'_1 = .85$, $p<0.001$) also because of indirect effect of lockdown and human-to-human transmission slightly increases ($b'_2 = 0.34$, $p<0.01$): *This result reveals that accelerated transmissions dynamics of COVID-19 is due to mainly air pollution-to-human transmission in addition to human-to-human transmission.*
- To minimize future epidemics similar to COVID-19, the max number of days per year in which Italian provincial capitals can exceed the limits set for PM_{10} (particulate matter 10 micrometres or less in diameter) or for ozone, considering their meteorological conditions, is about 45 days.

Hence, high concentration of nitrogen dioxide, a noxious gas, particulate air pollutants emitted by motor vehicles, power plants, and industrial facilities in North Italy seems to be a platform to support diffusion of viral infectivity (Groulx *et al.,* 2018), increase hospitalizations for respiratory virus bronchiolitis (cf., Carugno *et al.,* 2018; Nenna *et al.,* 2017), increase asthma incidence (Liao *et al.,* 2011) and damage to the immune system of people (Glencross *et al.,* 2020). Beelen *et al.,* (2013) report the need to draw attention to the continuing effects of air pollution on health. A socioeconomic strategy to prevent future epidemics similar to the COVID-19 is also the reduction of pollution with fruitful environmental and health effect by the rationalization of manufacturingindustry in a perspective of sustainable development, de-industrializing polluting activities in the geographical development of current capitalism. De-industrialization of polluting industries and sustainable development impose often huge social costs in the short term on people, households, and families but they have long-run benefits for human societies. Studies show that public and environmental health policy interventions are necessary and have the potential to reduce morbidity and mortality across Europe (cf., Raaschou-Nielsen *et al.,* 2013). In fact, the improvements in air quality have been accompanied by demonstrable benefits to human health. Pope *et al.,* (2009) reported that $PM_{2.5}$ concentrations fell by a third from the early 1980s to the late 1990s across major US metropolitan areas, with each 10 μg/m^3 reduction associated with an increase in life expectancy of 0.61 years. Because of health problems of polluting industrialization, Wei *et al.,* (2020) suggest different air pollution regulations in regions having varied geographical and climatic conditions, and different bio aerosol pollution. In particular, Wei *et al.,* (2020) suggest that different air quality strategies should be applied in inland and coastal cities, e.g., coastal cities also need start bio aerosol risk alarm during moderate pollution when severe pollution occurs in inland cities. Guo *et al.,* (2019) argue that in recent years, haze pollution is a serious environmental problem affecting cities, proposing implications for urban planning to improve public respiratory health. In short, the long-term benefits of sustainable economic development are basic for the improvement of environment, atmosphere, air quality and especially health of populations (Blackaby, 1978; Bluestone & Harrison, 1982; Pike, 2009).

Overall, the, these findings here are consistent with correlational studies and indicate that health effects of air pollution exposure can span decades and extend beyond cardiopulmonary systems affecting diffusion of epidemics similar to COVID-19. Hence, it is important to reinforce evidence related to air pollution and inter-related factors of the transmission dynamics of virus similar to COVID-19, and helps policy makers to develop proactive regulations for the control of environment, air pollution, polluting industrialization and prevention of the diffusion of viral infectivity. The complex problem of epidemic threats has to be treated with an approach of dissolution: it means to redesign the strategies and protocols to cope with future epidemics in such way as to eliminate the conditions that caused accelerated diffusion of COVID-19, thus enabling advanced nations to do better in the future than the best it can do today (Ackoff & Rovin, 2003, pp.9-10; Bundy *et al.,* 2017). This study revels interesting results of transmission dynamics of COVID-19 given by the mechanism of air pollution-to-human transmission that in addition to human-to-human transmission seems to have accelerated diffusion of epidemics in Italy. However, these conclusions are tentative. There are several challenges to such studies, particularly in real time. Sources may be incomplete, or only capture certain aspects of the on-going outbreak dynamics; there is need for much more research in to the relations between viral infectivity, air pollution, meteorological factors and other determinants, when the COVID-19 outbreak is over. Overall, then, in the presence of polluting industrialization of cities and air pollution -to-human transmission of viral infectivity, this study must conclude that a comprehensive strategy to prevent future epidemics similar to COVID-19 has also to be designed in environmental and socioeconomic terms, that is in terms of sustainability science and environmental science, and not only in terms of biology, healthcare and health sector.

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