

SHORT-LIVED CLIMATE POLLUTANTS SPECIAL EDITION RESEARCH DIGEST

Covid-19 and Air Pollution

The SAP and the Secretariat have prepared this special edition of the SLCP research digest for the purpose of informing the Climate and Clean Air Coalition partnership of the latest and on-going research and potential links between covid-19 and air pollution and SLCPs. The SAP has not evaluated the content of the publications.

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CLIMATE &
CLEAN AIR
COALITION
TO REDUCE SHORT-LIVED
CLIMATE POLLUTANTS

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REPORTING ON EMERGING RESEARCH

COVID-19 Could Help Solve Climate Riddles: Pollution declines from pandemic shutdowns may aid in answering long-standing questions about how aerosols influence climate

Levy, Adam. COVID-19 Could Help Solve Climate Riddles. *Scientific American* (17 April 2020) <https://www.scientificamerican.com/article/covid-19-could-help-solve-climate-riddles1/>.

CHANGES IN EMISSIONS DUE TO COVID-19 RESPONSE

COVID-19 as a factor influencing air pollution?

Journal pre-proof

At the end of 2019, the first cases of pneumonia associated with coronavirus (COVID-19) were reported in Wuhan, China (Huang et al., 2020). Thereafter, the number of infected people increased rapidly and, a month later, the outbreak turned into a national crisis, with infected individuals diagnosed all over the country (CDC, 2020; Chan et al., 2020; World Health Organization, 2020a; 2020b). Chinese authorities shut down transportation and travel in and out of Wuhan. They also curtailed and reduced local business travel, closed down schools, colleges and universities in order to reduce the spread of the disease and established numerous quarantines (Wilder-Smith and Freedman, 2020). The maps in Fig. 1 show the nitrogen dioxide (NO₂) concentrations, resulting primarily from the burning of fossil fuels (He et al., 2020a,b), prior to and following the quarantine, with a massive reduction observed in concentrations after the corona virus outbreak (NASA, 2020). The data were collected by the Tropospheric Monitoring Instruments (TROPOMI) on-board ESA's Sentinel-5 satellite. A related sensor, the Ozone Monitoring Instrument (OMI) on-board NASA's Aura satellite, recorded similar atmospheric changes. NO₂ is a common tracer of air pollution/industrial activity, associated with morbidity and mortality (He et al., 2020a,b). NASA scientists have commented that the reduction in NO₂ pollution was first apparent near Wuhan, but spread across the rest of the country, and eventually worldwide (NASA, 2020). In Central China, NO₂ emissions were reduced by as much as 30% (NASA, 2020). CO₂ emissions, another common tracer of air pollution (Hanaoka and Masui, 2019), decreased by 25% in China and by 6% worldwide (CarbonBrief, 2020). Air pollution is responsible for many deaths and increased incidences of respiratory disease (Brauer, 2010). According to the World Health Organization, 4.6 million individuals die annually from diseases and illnesses directly related to poor air quality (Cohen et al., 2017). Poor air quality is responsible for more deaths each year than motor vehicle accidents (European Environment Agency, 2005). The impact of air pollution is a global problem and includes developed countries, such as the European nations where 193,000 people died in 2012 from airborne particulate matter (Ortiz et al., 2017). Air pollution associated deaths include but are not limited to aggravated asthma, bronchitis, emphysema, lung and heart diseases, and respiratory allergies (Brauer, 2010). China, where the COVID-19 epidemic started, is also a country severely affected by air pollution (He et al., 2020a,b).

Air pollution in China was responsible for 4000 preventable deaths each day i.e. 1.6 million fatalities in 2016 (Rohde and Muller, 2015; Wang et al., 2012). Several models predict mortality due to air pollution (Hoek et al., 2013), with an increase of all-cause mortality ranging from 0.13% per 10µg/m³ of NO₂ per day (He et al., 2020a,b) to 2% per 10µg/m³ of NO₂ on a 5 day period (Chiusolo et al., 2011), or a global hazard ratio of 1.052 (95 confidence intervals 1.045 to 1.059) per increase of 8.1 ppb in NO₂ (Crouse et al., 2015). In a hypothetical scenario in which the impact of air pollution on mortality was underestimated using the aforementioned models, and in which we considered a time period of two months with a decrease in NO₂ air pollution in China, macabre predictions could postulate a 6% reduction in mortality due to air pollution (i.e. around 100 000 life's saved, just in China). Similar calculations could be applied to

other countries. At the time of writing this, there are 3,158 reported deaths from COVID-19 in China and 4,607 worldwide. Considering the huge decrease in air pollution following the quarantine (China's CO₂ emissions decreased by a quarter), the COVID-19 pandemic might paradoxically have decreased the total number of deaths during this period, by drastically decreasing the number of fatalities due to air pollution. Moreover, in addition to the reduced number of deaths due to air pollution, the reduction in air pollution itself could also have positive benefits in reducing preventable non communicable diseases (Chen and Bloom, 2019; Neira et al., 2018).

Frédéric Dutheil, Julien S.Baker, Valentin Navel. "COVID-19 as a factor influencing air pollution?" Environmental Pollution 263(Part A) (August 2020). <https://www.sciencedirect.com/science/article/pii/S0269749120316468?via%3Dihub>

COVID-19, City Lockdown, and Air Pollution Evidence from China

The rapid spread of COVID-19 is a global public health challenge. To prevent the escalation of its transmission, China locked down one-third of its cities and strictly restricted human mobility and economic activities. Using timely and comprehensive air quality data in China, we show that these counter-COVID-19 measures led to remarkable improvement in air quality. Within weeks, the Air Quality Index and PM_{2.5} concentrations were brought down by 25%. The effects are larger in colder, richer, and more industrialized cities. We estimate that such improvement would avert 24,000 to 36,000 premature deaths from air pollution on a monthly basis.

He, Guojun, Yuhang Pan, and Takanao Tanaka. "COVID-19, City Lockdown, and Air Pollution: Evidence from China." medRxiv (2020).

Good in The Worst: Covid-19 Restrictions and Ease in Global Air Pollution

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), known to cause 2019-coronavirus disease (COVID-19) pandemic is a zoonotic coronavirus and crosses species to infect human populations, where an efficient transmission of virus occurs human-to-human. Nationwide lockdown is being adopted to stop public transport, keep people at their homes and out of their work, and maintain social distancing. In turn, large geographic areas in the world (including China, Italy, Spain, and USA) has been almost halted. This temporary halt is significantly slashing down the air pollution (air pollutants and warming gases) in most cities across the world. This paper: (i) introduces both COVID-19 and air pollution; (ii) overviews the relation of air pollution with respiratory/lung diseases; (iii) compiles and highlights major data appeared in media and journals reporting lowering of air pollution in major cities those have been highly impacted by the COVID-19; and also (iv) lists the way forward in the present context. Because COVID-19 is an ongoing pandemic and currently far from over, strong conclusions could not be drawn with very limited data at present. The temporary slashed down global air pollution as a result of COVID-19 restrictions are expected to stimulate the researchers, policy makers and governments for the judicious use of resources; thereby minimise the global emissions, and maintain their economies once the pandemic eases. On the other, lifting of the nationwide lockdown and eventual normalisation of the temporarily halted sectors may also reverse the currently COVID-19 pandemic-led significantly slashed down global air pollution that could make the future respiratory health crisis grimmer.

Anjum, N.A. Good in The Worst: COVID-19 Restrictions and Ease in Global Air Pollution. Preprints 2020, 2020040069 (doi: 10.20944/preprints202004.0069.v1). <https://www.preprints.org/manuscript/202004.0069/v1>

Severe air pollution events not avoided by reduced anthropogenic activities during Covid-19 outbreak

Due to the pandemic of coronavirus disease 2019 in China, almost all avoidable activities in China are prohibited since Wuhan announced lockdown on January 23, 2020. With reduced activities, severe air pollution events still occurred in the North China Plain, causing discussions regarding why severe air pollution was not avoided. The Community Multi-scale Air Quality model was applied during January 01 to February 12, 2020 to study PM_{2.5} changes under emission reduction scenarios. The estimated emission

reduction case (Case 3) better reproduced PM_{2.5}. Compared with the case without emission change (Case 1), Case 3 predicted that PM_{2.5} concentrations decreased by up to 20% with absolute decreases of 5.35, 6.37, 9.23, 10.25, 10.30, 12.14, 12.75, 14.41, 18.00 and 30.79 $\mu\text{g}/\text{m}^3$ in Guangzhou, Shanghai, Beijing, Shijiazhuang, Tianjin, Jinan, Taiyuan, Xi'an, Zhengzhou, Wuhan, respectively. In high-pollution days with PM_{2.5} greater than 75 $\mu\text{g}/\text{m}^3$, the reductions of PM_{2.5} in Case 3 were 7.78, 9.51, 11.38, 13.42, 13.64, 14.15, 14.42, 16.95 and 22.08 $\mu\text{g}/\text{m}^3$ in Shanghai, Jinan, Shijiazhuang, Beijing, Taiyuan, Xi'an, Tianjin, Zhengzhou and Wuhan, respectively. The reductions in emissions of PM_{2.5} precursors were ~2 times of that in concentrations, indicating that meteorology was unfavorable during simulation episode. A further analysis shows that benefits of emission reductions were overwhelmed by adverse meteorology and severe air pollution events were not avoided. This study highlights that large emissions reduction in transportation and slight reduction in industrial would not help avoid severe air pollution in China, especially when meteorology is unfavorable. More efforts should be made to completely avoid severe air pollution.

Wang, Pengfei, et al. "Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak." Resources, Conservation and Recycling 158 (2020): 104814.

The Effects of Outdoor Air Pollution Concentrations and Lockdowns on Covid-19 Infections in Wuhan and Other Provincial Capitals in China

Background: Covid-19 was first reported in Wuhan, China in Dec 2019. Since then, it has been transmitted rapidly in China and the rest of the world. While Covid-19 transmission rate has been declining in China, it is increasing exponentially in Europe and America. Although there are numerous studies examining Covid-19 infection, including an archived paper looking into the meteorological effect, the role of outdoor air pollution has yet to be explored rigorously. It has been shown that air pollution will weaken the immune system, and increase the rate of respiratory virus infection. We postulate that outdoor air pollution concentrations will have a negative effect on Covid-19 infections in China, whilst lockdowns, characterized by strong social distancing and home isolation measures, will help to moderate such negative effect.

Methods: We will collect the number of daily confirmed Covid-19 cases in 31 provincial capital cities in China during the period of 1 Dec 2019 to 20 Mar 2020 (from a popular Chinese online platform which aggregates all cases reported by the Chinese national/provincial health authorities). We will also collect daily air pollution and meteorology data at the city-level (from the Chinese National Environmental Monitoring Center and the US National Climatic Data Center), daily inter-city migration flows and intra-city movements (from Baidu). City-level demographics including age distribution and gender, education, and median household income can be obtained from the statistical yearbooks. City-level co-morbidity indicators including rates of chronic disease and co-infection can be obtained from related research articles. A regression model is developed to model the relationship between the infection rate of Covid-19 (number of confirmed cases/population at the city level) and outdoor air pollution at the city level, after taking into account confounding factors such as meteorology, inter- and intra-city movements, demographics, and co-morbidity and co-infection rates. In particular, we shall study how air pollution affects infection rates across different cities, including Wuhan. Our model will also study air pollution would affect infection rates in Wuhan before and after the lockdown. Expected findings: We expect there be a correlation between Covid-19 infection rate and outdoor air pollution. We also expect that reduced intra-city movement after the lockdowns in Wuhan and the rest of China will play an important role in reducing the infection rate. Interpretation: Infection rate is growing exponentially in major cities worldwide. We expect Covid-19 infection rate is related to the air pollution concentration, and is strongly dependent on inter- and intra-city movements. To reduce the infection rate, the international community may deploy effective air pollution reduction plans and social distancing policies.

Han, Yang, et al. "The Effects of Outdoor Air Pollution Concentrations and Lockdowns on Covid-19 Infections in Wuhan and Other Provincial Capitals in China." (2020).

Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic

Lockdown measures came into force in Spain from March 14th, two weeks after the start of the SARS-CoV-2 epidemic, to reduce the epidemic curve. Our study aims to describe changes in air pollution levels during the lockdown measures in the city of Barcelona (NE Spain), by studying the time evolution of atmospheric pollutants recorded at the urban background and traffic air quality monitoring stations. After two weeks of lockdown, urban air pollution markedly decreased but with substantial differences among pollutants. The most significant reduction was estimated for BC and NO₂ (-45 to -51%), pollutants mainly related to traffic emissions. A lower reduction was observed for PM₁₀ (-28 to -31.0%). By contrast, O₃ levels increased (+33 to +57% of the 8 h daily maxima), probably due to lower titration of O₃ by NO and the decrease of NO_x in a VOC-limited environment. Relevant differences in the meteorology of these two periods were also evidenced. The low reduction for PM₁₀ is probably related to a significant regional contribution and the prevailing secondary origin of fine aerosols, but an in-depth evaluation has to be carried out to interpret this lower decrease. There is no defined trend for the low SO₂ levels, probably due to the preferential reduction in emissions from the least polluting ships. A reduction of most pollutants to minimal concentrations are expected for the forthcoming weeks because of the more restrictive actions implemented for a total lockdown, which entered into force on March 30th. There are still open questions on why PM₁₀ levels were much less reduced than BC and NO₂ and on what is the proportion of the abatement of pollution directly related to the lockdown, without meteorological interferences.

Tobías, Aurelio, et al. "Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic." Science of The Total Environment (2020): 138540.

Abrupt declines in tropospheric nitrogen dioxide over China after the outbreak of COVID-19

China's policy interventions to reduce the spread of the coronavirus disease 2019 have environmental and economic impacts. Tropospheric nitrogen dioxide indicates economic activities, as nitrogen dioxide is primarily emitted from fossil fuel consumption. Satellite measurements show a 48% drop in tropospheric nitrogen dioxide vertical column densities from the 20 days averaged before the 2020 Lunar New Year to the 20 days averaged after. This is 20% larger than that from recent years. We relate to this reduction to two of the government's actions: the announcement of the first report in each province and the date of a province's lockdown. Both actions are associated with nearly the same magnitude of reductions. Our analysis offers insights into the unintended environmental and economic consequences through reduced economic activities.

Liu, Fei, et al. "Abrupt declines in tropospheric nitrogen dioxide over China after the outbreak." arXiv.2004.06542.

Biomass use and COVID-19: A novel concern

Evidence supports the link between air pollution and COVID-19 and thus it is likely that exposure to biomass smoke is associated with COVID-19. The poor, including refugees and migrant workers staying in fragile conditions, are most vulnerable. An outbreak of COVID-19 in a place where the concept of physical distancing is next to impossible could easily overwhelm the public health system. It is thus essential to understand the consequences of being exposed to smoke in relation to COVID-19 infection.

Thakur, Megha, et al. "Biomass use and COVID-19: A novel concern." Environmental Research (2020): 109586.

A preliminary assessment of the impact of COVID-19 on environment – A case study of China

The coronavirus disease (COVID-19) is seriously threatening world public health security. Currently, >200 countries and regions have been affected by the epidemic, with the number of infections and deaths still increasing. As an extreme event, the outbreak of COVID-19 has greatly damaged the global economic growth and caused a certain impact on the environment. This paper takes China as a case study, comprehensively evaluating the dynamic impact of COVID-19 on the environment. The analysis results indicate that the outbreak of COVID-19 improves China's air quality in the short term and significantly

contributes to global carbon emission reduction. However, in the long run, there is no evidence that this improvement will continue. When China completely lifts the lockdown and resumes large-scale industrial production, its energy use and greenhouse gas (GHG) emissions are likely to exceed the level before the event. Moreover, COVID-19 significantly reduces the concentration of nitrogen dioxide (NO₂) in the atmosphere. The decline initially occurred near Wuhan and eventually spread to the whole country. The above phenomenon shows that the decreasing economic activities and traffic restrictions directly lead to the changes of China's energy consumption and further prevent the environment from pollution. The results in this study support the fact that strict quarantine measures can not only protect the public from COVID-19, but also exert a positive impact on the environment. These findings can provide a reference for other countries to assess the influence of COVID-19 on the environment.

Wang, Qiang, and Min Su. "A preliminary assessment of the impact of COVID-19 on environment—A case study of China." Science of The Total Environment (2020): 138915.

Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China

The novel coronavirus pneumonia, namely COVID-19, has become a global public health problem. Previous studies have found that air pollution is a risk factor for respiratory infection by carrying microorganisms and affecting body's immunity. This study aimed to explore the relationship between ambient air pollutants and the infection caused by the novel coronavirus. Daily confirmed cases, air pollution concentration and meteorological variables in 120 cities were obtained from January 23, 2020 to February 29, 2020 in China. We applied a generalized additive model to investigate the associations of six air pollutants (PM_{2.5}, PM₁₀, SO₂, CO, NO₂ and O₃) with COVID-19 confirmed cases. We observed significantly positive associations of PM_{2.5}, PM₁₀, NO₂ and O₃ in the last two weeks with newly COVID-19 confirmed cases. A 10- $\mu\text{g}/\text{m}^3$ increase (lag₀₋₁₄) in PM_{2.5}, PM₁₀, NO₂, and O₃ was associated with a 2.24% (95% CI: 1.02 to 3.46), 1.76% (95% CI: 0.89 to 2.63), 6.94% (95% CI: 2.38 to 11.51), and 4.76% (95% CI: 1.99 to 7.52) increase in the daily counts of confirmed cases, respectively. However, a 10- $\mu\text{g}/\text{m}^3$ increase (lag₀₋₁₄) in SO₂ was associated with a 7.79% decrease (95% CI: -14.57 to -1.01) in COVID-19 confirmed cases. Our results indicate that there is a significant relationship between air pollution and COVID-19 infection, which could partially explain the effect of national lockdown and provide implications for the control and prevention of this novel disease.

Yongjian, Zhu, et al. "Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China." Science of The Total Environment (2020): 138704.

Does lockdown reduce air pollution? Evidence from 44 cities in northern China

Responding to the ongoing novel coronavirus (agent of COVID-19) outbreak, China implemented "the largest quarantine in human history" in an attempt to prevent the spread of the virus on 23 January 2020. Human mobility and relevant production and consumption activities have since decreased significantly. As a likely side effect of this decrease, many regions have recorded significant reductions in air pollution. We employed daily air pollution data and Intracity Migration Index (IMI) data from Baidu between 1 January and 21 March 2020 for 44 cities in northern China to examine whether, how, and to what extent travel restrictions affected air quality. On the basis of this quantitative analysis, we reached the following conclusions: (1) The reduction of air pollution was strongly associated with travel restrictions during this pandemic—on average, the air quality index (AQI) decreased by 7.80%, and five air pollutants (i.e., SO₂, PM_{2.5}, PM₁₀, NO₂, and CO) decreased by 6.76%, 5.93%, 13.66%, 24.67%, and 4.58%, respectively. (2) Mechanism analysis illustrated that the lockdowns of 44 cities reduced human movements by 69.85%, and a reduction in the AQI, PM_{2.5}, and CO was partially mediated by human mobility, and SO₂, PM₁₀, and NO₂ were completely mediated. (3) Our findings highlight the importance of understanding the role of green production and consumption.

Rui, Bao and Achen Zhang. "Does lockdown reduce air pollution? Evidence from 44 cities in northern China." Science

of *The Total Environment* (2020): 139052

Exploring Dependence of COVID-19 on Environmental Factors and Spread Prediction in India

The pandemic of “Corona Virus Disease 2019” or COVID-19 has taken the world by storm. Majority of nations of the world have been challenged by the novel coronavirus, which is supposedly of zoonotic origin and is known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The present work attempts to evaluate the spread of COVID-19 in India. The methodology of assessment uses SEIR (Susceptible-Exposed-Infectious-Removed) model to establish the impact of socio-behavioural aspect, especially social distancing, affecting the numbers of COVID-19 cases per day. The lockdown initiated by Government of India (GoI) scenario is weighed against a scenario with a possible initiation of community spread due to crowded gatherings in India. The resultant changes, as against the lockdown scenario, has been reported in terms of the increase in the number of cases and stretch of the timeline to mitigate the COVID-19 spread. Impact of environmental factors like temperature and relative humidity have also been analyzed using statistical methods, including Response Surface Methodology (RSM) and Correlation. It has been found that the spread of cases is dependent on environmental conditions, i.e. temperature and relative humidity. This study is expected to help the policymakers and stakeholders to devise an improved action plan to alleviate the COVID-19 spread, especially in India.

Bherwani, H., et al. "Exploring Dependence of COVID-19 on Environmental Factors and Spread Prediction in India." (2020).

AIR POLLUTION COVID-19 HEALTH LINK

Exposure to air pollution and COVID-19 mortality in the United States

This article is a preprint and has not been certified by peer review. It reports new medical research that has yet to be evaluated and so should not be used to guide clinical practice.

Background: United States government scientists estimate that COVID-19 may kill between 100,000 and 240,000 Americans. The majority of the pre-existing conditions that increase the risk of death for COVID-19 are the same diseases that are affected by long-term exposure to air pollution. We investigate whether long-term average exposure to fine particulate matter (PM_{2.5}) increases the risk of COVID-19 deaths in the United States. **Methods:** Data was collected for approximately 3,000 counties in the United States (98% of the population) up to April 04, 2020. We fit zero-inflated negative binomial mixed models using county-level COVID-19 deaths as the outcome and county level long-term average of PM_{2.5} as the exposure. We adjust by population size, hospital beds, number of individuals tested, weather, and socioeconomic and behavioral variables including, but not limited to obesity and smoking. We include a random intercept by state to account for potential correlation in counties within the same state.

Results: We found that an increase of only 1 µg/m³ in PM_{2.5} is associated with a 15% increase in the COVID-19 death rate, 95% confidence interval (CI) (5%, 25%). Results are statistically significant and robust to secondary and sensitivity analyses.

Conclusions: A small increase in long-term exposure to PM_{2.5} leads to a large increase in COVID-19 death rate, with the magnitude of increase 20 times that observed for PM_{2.5} and all-cause mortality. The study results underscore the importance of continuing to enforce existing air pollution regulations to protect human health both during and after the COVID-19 crisis.

Xiao Wu, Rachel C. Nethery, Benjamin M. Sabath, Danielle Braun, Francesca Dominici, "Exposure to air pollution and COVID-19 mortality in the United States." medRxiv (2020). <https://www.medrxiv.org/content/10.1101/2020.04.05.20054502v1>

Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy?

This paper investigates the correlation between the high level of Severe Acute Respiratory Syndrome CoronaVirus 2 (SARS-CoV-2) lethality and the atmospheric pollution in Northern Italy. Indeed, Lombardy and Emilia Romagna are Italian regions with both the highest level of virus lethality in the world and one of Europe's most polluted area. Based on this correlation, this paper analyzes the possible link between pollution and the development of acute respiratory distress syndrome and eventually death. We provide evidence that people living in an area with high levels of pollutant are more prone to develop chronic respiratory conditions and suitable to any infective agent. Moreover, a prolonged exposure to air pollution leads to a chronic inflammatory stimulus, even in young and healthy subjects. We conclude that the high level of pollution in Northern Italy should be considered an additional co-factor of the high level of lethality recorded in that area.

Conticini, Edoardo, Bruno Frediani, and Dario Caro. "Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy?." Environmental Pollution (2020): 114465.

Does Air Pollution Influence COVID-19 Outbreaks?

SARS-CoV-2 is highly transmissible (with more than 1.3 million people infected in the world at the time of this writing) and lethal (more than 76,000 reported deaths at present). Exposure to air pollution could increase vulnerability and have detrimental effects on the prognosis of patients affected by the COVID-19. However, the relative weight of air pollution, compared to other confounders, is still to be determined.

Caution should be used in translating high values of conventional metrics, such as PM_{2.5} and PM₁₀ concentrations, into a direct measure of vulnerability. Airborne transmission mediated by virus-laden aerosols emitted during expiration and speech is plausible in specific environments. Current knowledge indicates a low probability in outdoor environments and an increase in probability in specific indoor environments, like hospitals and areas where patients are quarantined. In these environments, it is advisable to mitigate the risk for vulnerable people via using periodic ventilation of environments, decontaminations of surfaces and air conditioning systems, and appropriate technologies for mechanical ventilation/conditioning in order to limit the circulation of virus-laden bioaerosols in air.

The stakes for the world are enormous, and the results of robust research studies are urgently needed in order to provide information that could help in developing strategies for facing the current pandemic as well as future pandemics. Our recommendations for future research focus on (but are not limited to) the investigation, both outdoors and indoors, of airborne transmission routes, lifetimes and dynamics, dosimetry and infection thresholds within the human body, and the physical, chemical, biological, toxicological, virological properties of virus-laden bioaerosol particles, with all of these factors properly adjusted for a wide number of potential confounders. This research should come from a multidisciplinary approach involving a strong collaboration between traditionally distinct disciplines of science, and in particular, virologists, epidemiologists, toxicologists, physicians, aerobiologists, aerosol scientists, and meteorologists.

Contini, D.; Costabile, F. Does Air Pollution Influence COVID-19 Outbreaks? Atmosphere 2020, 11, 377.

Evaluation of the potential relationship between Particulate Matter (PM) pollution and COVID-19 infection spread in Italy

In conclusion, the rapid COVID-19 infection spread observed in selected regions of Northern Italy is supposed be related to PM₁₀ pollution due to airborne particles able to serve as carrier of pathogens. As already highlighted in previous studies, it is recommended to take into account PM₁₀ contribution and make policymakers aware of the need to take direct actions for pollution control.

Piazzalunga-Expert, Andrea. Evaluation of the potential relationship between Particulate Matter (PM) pollution and COVID-19 infection spread in Italy. mimeo, 2020.

Assessing nitrogen dioxide (NO₂) levels as a contributing factor to coronavirus (COVID-19) fatality

Nitrogen dioxide (NO₂) is an ambient trace-gas result of both natural and anthropogenic processes. Long-term exposure to NO₂ may cause a wide spectrum of severe health problems such as hypertension, diabetes, heart and cardiovascular diseases and even death. The objective of this study is to examine the relationship between long-term exposure to NO₂ and coronavirus fatality. The Sentinel-5P is used for mapping the tropospheric NO₂ distribution and the NCEP/NCAR reanalysis for evaluating the atmospheric capability to disperse the pollution. The spatial analysis has been conducted on a regional scale and combined with the number of death cases taken from 66 administrative regions in Italy, Spain, France and Germany. Results show that out of the 4443 fatality cases, 3487 (78%) were in five regions located in north Italy and central Spain. Additionally, the same five regions show the highest NO₂ concentrations combined with downwards airflow which prevent an efficient dispersion of air pollution. These results indicate that the long-term exposure to this pollutant may be one of the most important contributors to fatality caused by the COVID-19 virus in these regions and maybe across the whole world.

Ogen, Yaron. "Assessing nitrogen dioxide (NO₂) levels as a contributing factor to the coronavirus (COVID-19) fatality rate." Science of The Total Environment (2020): 138605.

Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China

The novel coronavirus pneumonia, namely COVID-19, has become a global public health problem. Previous studies have found that air pollution is a risk factor for respiratory infection by carrying microorganisms and affecting body's immunity. This study aimed to explore the relationship between ambient air pollutants and the infection caused by the novel coronavirus. Daily confirmed cases, air pollution concentration and meteorological variables in 120 cities were obtained from January 23, 2020 to February 29, 2020 in China. We applied a generalized additive model to investigate the associations of six air pollutants (PM_{2.5}, PM₁₀, SO₂, CO, NO₂ and O₃) with COVID-19 confirmed cases. We observed significantly positive associations of PM_{2.5}, PM₁₀, NO₂ and O₃ in the last two weeks with newly COVID-19 confirmed cases. A 10- $\mu\text{g}/\text{m}^3$ increase (lag0–14) in PM_{2.5}, PM₁₀, NO₂, and O₃ was associated with a 2.24% (95% CI: 1.02 to 3.46), 1.76% (95% CI: 0.89 to 2.63), 6.94% (95% CI: 2.38 to 11.51), and 4.76% (95% CI: 1.99 to 7.52) increase in the daily counts of confirmed cases, respectively. However, a 10- $\mu\text{g}/\text{m}^3$ increase (lag0–14) in SO₂ was associated with a 7.79% decrease (95% CI: -14.57 to -1.01) in COVID-19 confirmed cases. Our results indicate that there is a significant relationship between air pollution and COVID-19 infection, which could partially explain the effect of national lockdown and provide implications for the control and prevention of this novel disease.

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Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID

This study has two goals. The first is to explain the geo-environmental determinants of the accelerated diffusion of COVID-19 in Italy that is generating a high level of deaths. The second is to suggest a strategy to cope with future epidemic threats having accelerated viral infectivity in society. Using data on N = 55 Italian province capitals, and data of infected individuals at as of April 7th, 2020, results reveal that the accelerate and vast diffusion of COVID-19 in North Italy has a high association with air pollution of cities measured with days exceeding the limits set for PM₁₀ (particulate matter 10 μm or less in diameter) or ozone in previous years. In particular, hinterland cities with average higher number of days exceeding the limits set for PM₁₀ (and a low intensity of wind speed) have a very high number of infected people on 7th April 2020 (arithmetic mean about 2200 infected, with average polluted days greater than 80), than coastal cities also having days of exceeding the limits set for PM₁₀ or ozone but with high intensity of wind speed (arithmetic mean about 944.70 infected individuals, with about 60 average polluted days); moreover, cities having more than 100 days of air pollution (exceeding the limits set for PM₁₀), they have a very high average

number of infected people (about 3350 infected individuals, 7th April 2020), whereas cities having less than 100 days of air pollution, they have a lower average number of infected individuals (about 1014). The findings here also suggest that to minimize the impact of future epidemics similar to COVID-19, the maximum number of days per year in which Italian provincial capitals can exceed the limits set for PM10 or for ozone, considering their meteorological conditions, is about 48 days. Moreover, results here reveal that the explanatory variable of air pollution in cities under study seems to be a more important predictor in the initial phase of diffusion (on 17th March 2020, $b_1 = 1.27$, $p < 0.001$) than interpersonal contacts ($b_2 = 0.31$, $p < 0.05$). In the second phase of maturity of the transmission dynamics of COVID-19, air pollution reduces intensity (on 7th April 2020 with $b'_1 = 0.81$, $p < 0.001$) also because of indirect effect of lockdown, whereas coefficient of transmission by interpersonal contacts has stability ($b'_2 = 0.31$, $p < 0.01$). This result reveals that accelerated transmission dynamics of COVID-19 is due to mainly to the mechanism of "air pollution-to-human transmission" rather than "human-to-human transmission". Overall, then, transmission dynamics of viral infectivity, such as COVID-19, is due to systemic causes: general factors that are the same for all regions (e.g., biological characteristics of virus, incubation period, etc.) and specific factors which are different for each region (e.g., complex interaction between air pollution, meteorological conditions and biological characteristics of viral infectivity) and health level of individuals (habits, immune system, age, sex, etc.). Lessons learned for COVID-19 in the case study of Italy suggest that a proactive strategy to cope with future epidemics is to also apply especially an environmental and sustainable policy based on reduction of levels of air pollution mainly in hinterland and polluting cities- having low wind speed, high percentage of moisture and fog days-that seem to have an environment that may damage immune system of people and foster a fast transmission dynamics of viral infectivity in society. Hence, in the presence of polluting industrialization in regions that can trigger the mechanism of air pollution-to-human transmission dynamics of viral infectivity, this study must conclude that a comprehensive strategy to prevent future epidemics similar to COVID-19 has to be also designed in environmental and socioeconomic terms, that is also based on sustainability science and environmental science, and not only in terms of biology, healthcare and health sector.

Coccia, Mario. "Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID." Science of The Total Environment (2020): 138474.