**Has the Spring 2020 lockdown modified the relationship between air pollution and COVID-19 mortality in Europe?**

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Studies conducted in countries around the world have reported significant associations between air pollution and COVID-19 severity and death1,2. Air pollution decreases airways permeability, thus facilitating the penetration of the SARS-CoV-2 virus responsible for COVID-19 and contributing to the development of chronic illnesses, including cardiovascular, metabolic and neurodegenerative diseases, all known to increase the risk of suffering from severe forms COVID-19 leading to death1. This observation has led to the hypothesis that air pollution diminution during lockdowns may have engendered a reduction in COVID-19 severity and mortality.

Regrettably, available data show that results on air pollution diminution and related benefit during lockdown were contradictory. Using national monitoring station assessments, the European Environmental Agency showed that lockdown measures in 2020 have resulted in air pollution modifications in air pollutants concentrations, though with notable differences among air pollutants, cities and countries and sometimes not significantly3. Similarly, among other examples, gaseous and particulate matter (PM) concentrations diminished during the 2020 spring lockdown in forty-four cities in northern China due to reduced human activity and travel restrictions4. However, during the same period in the UK, after an initial abrupt reduction, nitrogen dioxide (NO2) increased gradually, suggesting that the return of vehicles to the road during early lockdown had already offset much of the temporary air quality improvement5. Regarding health impact, the risk of mortality during lockdown diminished alongside major air pollutants in Delhi, India6, but not in Mexico City, Mexico, where an inverse relationship was found in the case of fine particulate matter7. Furthermore, no reduction in COVID-19 deaths was associated with lockdowns as defined by social isolation (staying at home) in 87 regions and countries in the world8.

We used the Spring 2020 lockdown as a natural experiment to understand what happened to the COVID-19 syndemic in terms of mortality when air pollution was abruptly lowered in the European region, providing a distinct look at short-term health impacts of lockdown to compare against the long-term health impacts observed in studies relating air pollution exposure to COVID-19 in highly polluted zones1. COVID-19 provides a choice criterion for such a comparison because it is a specific disease, which was the same in each country at the start of the epidemics with similar immunity for everyone.

To this extent, we compared the impact of restrictions on air quality during the first lockdown and the first phase of unlocking with respect to COVID-19 mortality in 33 sovereign states of the European region. The analysis timespan for each country ranged from the date of the first day of lockdown until July 20th, 2020 (the cut-off date for the analysis). Daily COVID-19 mortality data (deaths per million people) were obtained from the Johns Hopkins Coronavirus Resource Centre9. Air temperature, humidity, particulate matter of 10 µm of diameter (PM10) and NO2 were assessed through the CHIMERE chemistry transport model provided by INERIS10 at various resolutions, with a broader coverage than the monitoring station assessments. Lockdown periods were found in the websites of the Health Authorities in the considered countries.

## The relationship between each air pollutant and mortality rates per million inhabitants on a daily basis was analysed by a Generalized Additive Model (GAM) using a Distributed Nonlinear Lag Model (DNLM) framework, which assumes a quasi-Poisson distribution of the mortality rates. The covariates adjusted for were daily average temperature and daily average relative humidity; a 3-day moving average was applied to each of these meteorological variables, with natural (cubic) smoothing splines of 6 and 3 degrees of freedom in the GAM. The associations were expressed as Risk Ratios (RR) with 95% confidence intervals. Only the maximum RRs were retained.

## Averaged levels as obtained through the dispersion model were lower during the lockdown than during the unlocking only in 8 (Algeria, Armenia, Greece, Israel, Lebanon, Lithuania, Morocco, Tunisia) for NO2 and in 7 countries (Bulgaria, Israel, Lebanon, Lithuania, Morocco, Spain, Turkey) for and PM10 respectively. No decreases were seen elsewhere.

## Overall, the relationship between air pollution levels and death rates during and after the lockdown varied from one country to another (Figure 1). In Ireland, Poland, Portugal, Serbia and Switzerland, NO2, PM10 or both levels were significantly associated with COVID-19 mortality in the post-lockdown period but not during the lockdown, thus suggesting that air pollution diminution during the lockdown might be protective. In France and Germany, PM10, levels were significantly related to a higher risk of COVID-19 death both during and after the lockdown. The association was significant with NO2 during and after the lockdown in Turkey. Conversely, in the UK, a significant relationship was seen for both PM10 and NO2 during the lockdown, but not after. Lastly, in five countries (Bosnia and Herzegovina, Estonia, Macedonia, The Netherlands and Slovakia) that did not adopt lockdown restrictions at the beginning of epidemic and for which the entire timespan was considered, the COVID-19 mortality risk was significantly higher only for PM10 for all the countries, except Estonia where a significantly increased COVID-19 mortality risk was seen only for NO2. No significant relationship was observed in the other countries whether or not they adopted a lockdown.

Altogether, our national observations are not conclusive on whether the first lockdown modified the relationship between air pollution and COVID-19 mortality in Europe throughout the COVID-19 pandemic. Only the results obtained in five countries sustain the beneficial effect of the lockdown, but this is small. In three additional countries, air pollution was related to a higher COVID-19 death risk both during and after the lockdown.

The observed differences could possibly be explained by the variation in the duration (from 4 (Turkey) to 156 days (UK) days, with a large proportion of countries not having adopted the lockdown) and the type of lockdown among the countries. Lockdown restrictions ranged from strict stay-at-home to curfew during some hours of the day and included different limitations of activities and working procedures. The heterogeneity of air pollution exposure could also help to understand the results as we considered national data through a dispersion model. Moreover, indoor air pollution might have increased during the lockdown, as people spent more time indoors and burnt more fuel for cooking and heating.

**Figure 1:** Relationship of air pollution to COVID-19 mortality during and after the lockdown in the Spring and Summer 2020 in the Europe.

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Our mixed results suggest that sharp, but short-term effects, of air pollution reduction may not be as important in mitigating immediate health impacts as the longer-term effects. Indeed, it is the long-term, sustained impacts of air pollution that contribute most to the risk of COVID-19 severity and mortality1,2. The strongest links our study found between air pollution concentrations and COVID-19 outcomes during and after the lockdown where observed in countries where air quality impacts are severe and prolonged.

Our findings must be interpreted cautiously as we adopted an ecological approach at the country level. Individual-level data with exposure and contagion outcomes information are needed to adequately address whether the reduction of air pollution emissions during the lockdown did or did not contribute to a diminution of COVID-19 mortality.

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