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Short-term and long-term health impacts of air pollution reductions from COVID-19 lockdowns in China and Europe: a modelling study

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Summary

Background Exposure to poor air quality leads to increased premature mortality from cardiovascular and respiratory diseases. Among the far-reaching implications of the ongoing COVID-19 pandemic, a substantial improvement in air quality was observed worldwide after the lockdowns imposed by many countries. We aimed to assess the implications of different lockdown measures on air pollution levels in Europe and China, as well as the short-term and long-term health impact.

Methods For this modelling study, observations of fine particulate matter (PM$_{2.5}$) concentrations from more than 2500 stations in Europe and China during 2016–20 were integrated with chemical transport model simulations to reconstruct PM$_{2.5}$ fields at high spatiotemporal resolution. The health benefits, expressed as short-term and long-term avoided mortality from PM$_{2.5}$ exposure associated with the interventions imposed to control the COVID-19 pandemic, were quantified on the basis of the latest epidemiological studies. To explore the long-term variability in air quality and associated premature mortality, we built different scenarios of economic recovery (immediate or gradual resumption of activities, a second outbreak in autumn, and permanent lockdown for the whole of 2020).

Findings The lockdown interventions led to a reduction in population-weighted PM$_{2.5}$ of 14·5 µg m$^{-3}$ across China (${-29.7\%}$) and 2·2 µg m$^{-3}$ across Europe (${-17.1\%}$), with unprecedented reductions of 40 µg m$^{-3}$ in bimonthly mean PM$_{2.5}$ in the areas most affected by COVID-19 in China. In the short term, an estimated 24 200 (95% CI 22 380–26 010) premature deaths were averted throughout China between Feb 1 and March 31, and an estimated 2190 (1960–2420) deaths were averted in Europe between Feb 1 and May 17. We also estimated a positive number of long-term avoided premature fatalities due to reduced PM$_{2.5}$ concentrations, ranging from 76 400 (95% CI 62 600–86 900) to 287 000 (233 700–328 300) for China, and from 13 600 (11 900–15 300) to 29 500 (25 800–33 300) for Europe, depending on the future scenarios of economic recovery adopted.

Interpretation These results indicate that lockdown interventions led to substantial reductions in PM$_{2.5}$ concentrations in China and Europe. We estimated that tens of thousands of premature deaths from air pollution were avoided, although with significant differences observed in Europe and China. Our findings suggest that considerable improvements in air quality are achievable in both China and Europe when stringent emission control policies are adopted.

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Introduction

The risk of pandemics has increased over the past century due to the increase in global travel and drastic changes to the natural environment. The current outbreak of COVID-19, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which was first detected in Wuhan, China, in December, 2019, is poised to become the most disruptive viral event since the 1918–19 influenza pandemic a century ago. On March 11, 2020, WHO declared COVID-19 a pandemic; as of Sept 21, 216 countries and territories have been affected, with more than 30·6 million confirmed cases and more than 950 000 registered deaths. However, the official figures probably underestimate the actual death toll of the pandemic, as many cases remain undetected and a considerable number of unexplained excess deaths have been observed that might be related to unrecorded COVID-19 deaths and the strain on health-care systems. The societal impacts are far reaching: travel restrictions, quarantine, and social distancing are now enforced to slow the spread of SARS-CoV-2, and face masks are mandatory in most affected countries for the limited time spent outdoors or in public spaces.

Although the effects of COVID-19 are undeniably devastating for society and the global economy, the severe lockdown interventions implemented first in China, and gradually in the rest of the world, have resulted in an abrupt decrease in anthropogenic
emissions in the atmosphere, leading to substantially improved air quality in highly polluted areas of China and Europe (figure 1; appendix p 2), with unprecedented societal implications.

This study aimed to investigate the effectiveness of control measures, such as those implemented during the COVID-19 pandemic, in reducing the mortality burden due to air pollution, which remains the leading environmental cause of death to date. Specifically, this investigation focused on fine particulate matter (PM$_{2.5}$), which is both directly emitted by human activities and formed through chemical reactions in the atmosphere. Although recent studies have shown that appreciable reductions in aerosol concentrations have been achieved after the implementation of strict lockdown measures, especially in China, the large-scale implications of such improvements in air quality on human health are still uncertain. We searched PubMed and Google Scholar for studies connecting premature deaths associated with air quality and with the COVID-19 pandemic, published in English from database inception until July 14, 2020. We used a combination of search terms, including “COVID-19”, “air quality”, “PM$_{2.5}$”, “fine particulate matter”, “premature deaths”, “air pollution”, “emission scenarios”, and “pandemic”. A few previous studies have assessed the mortality burden due to changes in air quality in China, focusing mostly on specific cities and ground-based observations. To our knowledge, no scientific study has linked the large-scale impacts of lockdown interventions associated with COVID-19 to global improvements in air quality and compared the respective mortality burdens in key areas such as China and Europe.

Added value of this study

To the best of our knowledge, this is the first comprehensive modelling study to investigate the effect of stringent lockdown interventions adopted to control the spread of COVID-19 on air quality and human health at a large scale. We made use of observations of fine particulate matter concentrations from more than 2500 measuring sites in Europe and China during 2016–20, and integrated them with chemical transport model simulations as well as the latest epidemiological studies to quantify the avoided premature deaths in the short term and long term during the COVID-19 pandemic. The findings presented here contribute to the existing literature by analysing the large-scale implications of the different lockdown measures on human health in Europe and China, providing crucial information for policy makers focused on preserving both environmental quality and public health. Our results show that stringent lockdown measures resulted in tens of thousands of avoided premature deaths from air pollution, with significant differences observed in Europe and China.

Implications of all the available evidence

Our results indicate that substantial improvements in air quality are achievable in both China and Europe when interventions are adopted to control air pollution. Compared to the mortality from COVID-19, the avoided premature deaths are far larger in China and lower in Europe. Furthermore, because most of the pre-existing respiratory and pulmonary conditions increasing the risk of death from COVID-19 are enhanced by exposure to fine particulate matter, improving air quality could also reduce mortality in a viral pandemic. We suggest that the difference in risk perception associated with an environmental versus health crisis originates from the spatiotemporal characteristics of the associated death rates, as a compelling sense of urgency is felt by society only to the extent that a disaster is highly localised in space and time. The response to the COVID-19 pandemic thus offers a unique lesson on the importance of communicating risk and the urgency of political interventions to effectively mitigate air pollution and climate change.

Methods

PM$_{2.5}$ concentrations

We combined model simulations and ground-based observations of PM$_{2.5}$ concentrations from more than 2500 sites in Europe and China to estimate PM$_{2.5}$ concentration fields on a daily basis, from Jan 1, 2016, to June 30, 2020. The Weather Research and Forecasting model with Chemistry (WRF-Chem) was used to provide baseline PM$_{2.5}$ concentrations. The model was run at
27 km for the year 2016 using the set-up in the appendix (p 12), which showed good skills in reproducing spatiotemporal patterns of PM$_{2.5}$ in China.12 We integrated the baseline WRF-Chem simulation, which represents an underlying spatial field for each point in the specified domain, with observed in-situ data, which provide up-to-date and direct information on PM$_{2.5}$ concentrations (for details see the appendix pp 2–3). This approach helps to overcome issues related to purely observation-based studies (ie, data sparsity) as well as purely model-based studies (eg, lack of WRF-Chem-ready emission inventories for the COVID-19 outbreak period).

Emission scenarios of future economic recovery
We explored the sensitivity of avoided premature deaths in different scenarios of economic recovery. We defined the average daily PM$_{2.5}$ concentrations during 2016–19 as typical concentrations and defined the lockdown period (ie, the period after the start of the outbreak) as Feb 1 to March 31, for China, and Feb 21 to May 17, for Europe. We considered four emission scenarios (detailed in the appendix p 3). The first scenario was immediate resumption: we assumed that strict lockdown interventions are implemented only during the lockdown period in the first part of the year and that all human and social activities return to their original status on April 1 in China and on May 18 in Europe. The second scenario was gradual resumption: this scenario considered a progressive recovery in human activities, and thus a 3-month-long proportional increase in PM$_{2.5}$ concentrations during April 1 to June 30, in China, and during May 18 to Aug 18, in Europe. This intermediate scenario accounted for the time needed for the economy and society to adjust to different operational conditions and lifestyles. The third was a second outbreak scenario: this scenario accounted for a possible seasonality of COVID-19 and considered a second outbreak during October to December. The fourth scenario was a permanent lockdown: the extreme scenario of a permanent lockdown for the whole of 2020 was considered in the absence of evidence of effective control strategies or vaccines. Typical PM$_{2.5}$ concentrations in this scenario are thus decreased by the reduction coefficient calculated during the lockdown period for the remainder of the year.

Mortality estimates
The short-term mortality burden avoided during the lockdown period was computed for each day by use of an exposure response function based on 110 peer-reviewed epidemiological short-term time-series studies of daily mortality and hospital admissions.10 The total mortality burden ($M$) in each grid cell and day was computed as follows, as done by Apte and colleagues:13

$$M = B_d \times P \times \frac{RR - 1}{RR}$$

where $B_d$ is the daily, country-specific baseline risk of deaths from non-communicable diseases, obtained from the Global Burden of Diseases, Injuries, and Risk Factors Study 2017 (GBD 2017).14 $P$ is the total population in each grid cell from the 2017 LandScan global population data at 30 arc-seconds resolution (approximately 1 km at the equator) and RR is the relative risk defined as:

$$RR = \exp(\gamma \times (PM_{d,2020} - PM_{d,avg}))$$

where $PM_{d,2020}$ is the daily mean PM$_{2.5}$ concentration (in µg m$^{-3}$) for 2020 and $PM_{d,avg}$ is the average for 2016–19. $\gamma$ is the excess mortality per unit increase in
PM$_{2.5}$, which was estimated to be 0.00104 (95% CI 0.00052–0.00156). The long-term premature mortality associated with lung cancer, ischaemic heart disease, stroke, and chronic obstructive pulmonary diseases, for individuals older than 25 years with 5-year groupings (eg, 25–30 years, 31–35 years, and so on) was estimated on the basis of the annual mean PM$_{2.5}$ concentrations for 2016–19 and different concentration scenarios for 2020. We adopted relative risk functions from cause-specific Global Exposure Mortality Models (GEMMs), which specifically encompass only cohort studies of outdoor air pollution and have been recently applied to estimate mortality trends over China. Within GEMMs, RR is defined as:

$$RR = \exp\left(\frac{\theta \log(\frac{\bar{z}}{\alpha} + 1)}{1 + \exp(-\frac{z-\mu}{\nu})}\right)$$

where $\theta$, $\alpha$, $\mu$, and $\nu$ are the age-specific and disease-specific parameters estimated by Burnett and colleagues, including a Chinese male cohort, and $\bar{z}$ is the difference between the yearly average PM$_{2.5}$ concentration ($\mu$ g m$^{-3}$) and the counterfactual concentration (2.4 g m$^{-3}$), below which no health impacts are assumed to occur.

The comparison between total averted mortality due to PM$_{2.5}$ and deaths related to COVID-19 was based on the above calculations and data from the European Centre for Disease Prevention and Control (ECDC).

Role of the funding source
There was no funding source for this study. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results
The COVID-19 outbreak forced many countries into an almost total cessation of productive activities, which led to a considerable reduction in anthropogenic emissions and thus an improvement in air quality, as indicated by the air quality index and satellite observations of nitrogen dioxide (appendix p 5).

PM$_{2.5}$ concentrations, which are responsible for much of the health burden from air pollution both in Europe and in China, also showed a relevant decrease after the COVID-19 outbreak, although considerable differences were observed between Europe and China (figure 1). Although a widespread reduction in PM$_{2.5}$ concentrations was observed in China, especially around the epicentre (Hubei province), contrasting patterns were found for different areas in Europe.

According to our analysis, more than 80% of the Chinese territory had a reduction in PM$_{2.5}$ concentrations during February to March, 2020, compared to the average in the same period in 2016–19. The mean reduction in the country was $-11.3\%$ ($-4.03$ µg m$^{-3}$), with the largest decreases in populated areas and peaks of $-50\%$ seen in the regions most affected by COVID-19. Unprecedented decreases of almost $-40$ µg m$^{-3}$ in bimonthly mean PM$_{2.5}$ concentrations were observed in the areas most affected by COVID-19 (figure 1). In Europe, the mean reduction in PM$_{2.5}$ concentrations during the lockdown period (from Feb 21, with Italy’s first restrictive measures on schools and public buildings, to May 17, when most restrictions were lifted) was larger than the reduction in China in relative terms ($-20.4\%$), but the actual reduction in PM$_{2.5}$ concentrations was much smaller (with an average of $-1.82$ µg m$^{-3}$ and peaks of $-6.6$ µg m$^{-3}$ during the lockdown period). Nonetheless, small improvements and even increases in PM$_{2.5}$ concentrations were observed for some countries in Europe (appendix p 13), which were partly attributable to the more heterogeneous responses of different countries to COVID-19. Furthermore, the lockdown measures drastically affected emissions from industry and traffic, but only had a partial impact on agricultural and residential emissions, the contribution of which is predominant during winter time, especially in some European countries. Meteorology also has an important role in dictating airborne concentrations of particulate matter. However, our additional analyses (appendix p 18) suggest that the observed decrease in PM$_{2.5}$ concentrations throughout China cannot be ascribed to meteorological variations alone, whereas in Europe the meteorological fluctuations had a more important role in influencing PM$_{2.5}$ concentrations during the lockdown period.

The improved air quality during the lockdown period was expected to reduce short-term premature deaths associated with PM$_{2.5}$ concentrations, particularly in the weeks after strict control measures were implemented. In China, a systematic reduction in premature deaths was apparent over the whole country for the entire period after the outbreak (February to March). During this time span, an estimated 24 200 (95% CI 22 380–26 010) premature deaths were avoided throughout China in the short term (figure 2), compared to the reported 3309 fatalities from COVID-19, during this period. Interestingly, the majority of fatalities related to COVID-19 occurred in Hubei province, whereas benefits from improvements in air quality were widespread across China because of extended lockdown measures. Avoided premature deaths in Hubei province only account for approximately 6% of the total (24 200) whereas more than 96% of COVID-19 fatalities occurred in that province. This finding suggests that the adoption of strict lockdown measures drastically reduced PM$_{2.5}$ concentrations far beyond Hubei province, including the populated provinces of Henan, Hebei, and Shandong, among others (appendix p 15), and thus contributed to a substantial reduction in premature mortality compared with previous years.
The same analysis also indicates that premature fatalities were systematically averted in Europe during the lockdown period, with an estimated 2190 avoided deaths (95% CI 1960–2420) compared to the 2016–19 averages (figure 2). As mentioned above, this result can be only partially attributable to the lockdown measures in Europe, since meteorology also played an important role in dictating PM$_{2.5}$ concentrations during the lockdown period. The number of avoided deaths in the short term due to improvements in air quality was far smaller than the number of fatalities due to COVID-19 in Europe (154,041 up to May 17). Mortality due to COVID-19 was substantially higher in Europe than in China, especially when considering the number of fatalities per capita (approximately 130 times higher than China up to May 17). Furthermore, Europe typically has substantially lower PM$_{2.5}$ concentrations than China (approximately three times lower on average in the first quarter of 2020), so the magnitude of the attainable improvements following reductions in PM$_{2.5}$ concentrations is also substantially smaller (figure 1). Highly populated and industrial countries, such as Germany and France, had the largest benefits in terms of prevented short-term mortality. Surprisingly, the countries most affected by COVID-19 (Italy and Spain) achieved smaller improvements in PM$_{2.5}$ concentrations during the same period, since PM$_{2.5}$ concentrations did not drop sharply (appendix p 13), as discussed above.

The long-term effects of worsening air quality are traditionally associated with an increased risk of contracting lung cancer, chronic obstructive pulmonary diseases, ischaemic heart disease, and stroke, and the magnitude of the risk depends on the annual mean PM$_{2.5}$ concentrations that the population is exposed to. We defined four scenarios to quantify the long-term effects of improved air quality from the lockdown based on possible future pathways of economic recovery. These scenarios aimed to explore the full extent of variability that could be derived from different recovery pathways rather than making accurate predictions of the future socioeconomic response to the COVID-19 pandemic.

Assuming that all activities resumed immediately starting on April 1 in China and May 17 in Europe, we estimated that 76,400 (95% CI 62,600–86,900) fatalities in China and 13,600 (11,900–15,300) in Europe related to long-term impacts of PM$_{2.5}$ concentrations would be avoided (table), due to reductions in emissions in the lockdown period. Results from this conservative scenario are intended to provide a lower bound of the long-term effects, as an immediate resumption of all activities is highly unlikely to have occurred, especially in Europe. Our findings indicate that, for both China and Europe, a gradual resumption of activities was instead more likely (appendix pp 6, 14, 16), although the likelihood of a second wave in autumn remains unpredictable. Conversely, when we considered an extreme scenario where lockdown measures are adopted for the entire year, we obtained an estimate for the upper bound of 287,000 avoided fatalities due to reduced PM$_{2.5}$ concentrations in China and 29,500 in Europe. Two intermediate scenarios were designed to include a 3-month-long gradual resumption of activities and a second COVID-19 outbreak in the autumn, which would result in new lockdown measures in the second part of the year. For these two intermediate scenarios, we estimated that the mean avoided premature mortalities would vary between 111,700 (95% CI 91,250–127,000) and 160,300 (130,900–182,400) in China and between 16,400 (14,300–18,400) and 21,000 (18,400–23,700) in Europe. Long-term health effects are not uniformly distributed in the two regions (figure 3). As COVID-19 control measures have affected mostly industrial and...
traffic sources of PM$_{2.5}$ emissions, locations where the emissions from such sectors are predominant will evidently experience the largest improvements. In China, there was indeed a strong correlation between the provinces most affected by COVID-19 and the resulting positive health impact (appendix p 9), as a substantial fraction of PM$_{2.5}$ emissions in the country is of industrial origin. In Europe, the correlation between reduced PM$_{2.5}$ concentrations and avoided fatalities was still significant, although there were a few relevant outliers (eg, Italy and Spain) due to the larger variability in the predominant emission sector (appendix p 9).

Discussion

Among the far-reaching implications of the ongoing COVID-19 pandemic, a substantial worldwide improvement in air quality has been observed as a result of the abrupt decrease in anthropogenic emissions due to the stringent lockdowns adopted by many countries. Although controlled emission scenarios have never occurred on a global scale, evidence from shutdowns of industrial plants and construction sites and reduced traffic mobility when preparing for the 2008 Olympic Games in Beijing suggested a strong dependence between the decrease in emissions and a decrease in the mortality burden from diseases related to poor air quality.

| Table: Short-term and long-term health impacts due to the COVID-19 pandemic and governments’ response in China and European countries |
|---|---|
| COVID-19 mortality |  |
| **Lockdown period** | -3309 (95% CI) | -154 041 (95% CI) |
| Short-term premature deaths averted due to reduced PM$_{2.5}$ concentrations |  |
| **January to March** | 24 200 (22 380–26 010) | 2190 (1960–2420) |
| Long-term yearly premature deaths averted due to reduced PM$_{2.5}$ concentrations |  |
| **Immediate resumption** | 7 640 (6 260–8 090) | 13 600 (11 900–15 300) |
| **Gradual resumption** | 111 700 (91 250–127 000) | 16 400 (14 300–18 400) |
| **Fall outbreak** | 160 300 (130 900–182 400) | 21 000 (18 400–23 700) |
| **Permanent lockdown** | 287 000 (233 700–328 300) | 29 500 (25 800–33 300) |

*Avoided premature deaths due to reduced PM$_{2.5}$ in the short term are shown from Feb 1 to March 31, 2020, in China and from Feb 21 to May 17, 2020, in Europe. Positive numbers indicate avoided deaths, whereas negative numbers indicate additional deaths.

(Figure 3 continues on next page)
In this analysis we used the control interventions adopted in response to COVID-19 in China and Europe as a proxy for the reduction in emissions that is achievable in the existing system of environment–human interactions and developed a range of scenarios where only a fraction of current emissions are controlled over different time frames. We estimated that 24,200 premature deaths due to air pollution were avoided in China and 2190 in Europe during the lockdown period, and that at least 76,400 premature deaths in China and at least 13,600 in Europe would be avoided over 2020, considering long-term effects. Overall, although the final numbers will depend on the future pathways to full recovery, our analysis highlights that large improvements in health are indeed achievable with aggressive air pollution mitigation. Interestingly, the scale of the attainable improvements is similar to the order of magnitude of the reported COVID-19 health burden, although official COVID-19 mortality figures possibly underestimate the actual death toll. Moreover, it should be noted that although COVID-19 mortality was evidently contained by the stringent lockdown interventions, especially in China, other economical, societal, and health-care hardships related to COVID-19 entail an additional mortality burden that currently remains unaccounted for.

Nonetheless, the full implications of lockdown interventions in terms of long-term positive health impacts are also expected to be greater than the estimated numbers reported here. Exposure to PM$_{2.5}$ leads to a non-negligible increase in the risk of other non-communicable diseases, thus the total avoided fatalities are likely to be higher than our estimates, particularly in Europe where other non-communicable diseases contribute substantially to the total fatalities linked to PM$_{2.5}$ concentrations. Moreover, we only focused on the health effects related to PM$_{2.5}$ concentrations, whereas the substantial reductions in emissions from nitrogen oxides would also contribute to reducing the mortality burden from respiratory diseases. Recent estimates have shown that 9000 short-term fatalities were avoided because of the drop in nitrogen

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**Figure 3: Long-term health impacts**
Avoided premature deaths per 100,000 inhabitants due to changes in air quality (variations in PM$_{2.5}$ concentrations) under four different scenarios for China and Europe: an immediate resumption of anthropogenic activities, a gradual resumption of economic activities, total lockdown in the autumn following a second outbreak, and permanent lockdown until the end of 2020.
Articles

Articles

pp 17–18). Additional insights into the contribution from concentrations observed after the outbreak suggest a magnitude of the results.

Other studies have recently estimated the short-term health implications of improvements in air quality in China, using measured nitrogen oxide and PM$_{2.5}$ data from 367 Chinese cities$^{24}$ and comparing PM$_{2.5}$ concentrations between locked down and non-locked down cities.$^{25}$ Here, we further expanded such analyses by developing detailed bottom-up emission inventories for the lockdown period, once sector-specific activity data related to the COVID-19 response are released. Although future studies are needed to further investigate these aspects, when more data become available, the assumptions made here are not likely to influence the overall order of magnitude of the results.

Other studies have recently estimated the short-term health implications of improvements in air quality in China, using measured nitrogen oxide and PM$_{2.5}$ data from 367 Chinese cities$^{24}$ and comparing PM$_{2.5}$ concentrations between locked down and non-locked down cities.$^{25}$ Here, we further expanded such analyses by integrating 6 months of data from more than 2500 measuring stations across China and Europe with a chemical transport model simulation, which allowed us to discuss and interpret drivers of the differences between impacts in Europe and China. The short-term impacts found in this study are consistent with the results of He and colleagues$^{25}$ and larger than those reported by Chen and colleagues, reflecting a sharper drop in population-weighted PM$_{2.5}$ concentrations (–14.5 µg m$^{-3}$ compared to 2016–19 averages) when taking into account the spatial variability of concentrations across the whole of China. Furthermore, we discussed the long-term impacts entailed by lockdown measures to provide guidance on the improvements in air quality and human health that could be attainable with strict policy measures.

We show that the environmental response, measured as the reduction in PM$_{2.5}$ concentrations due to implementation of similar control strategies, varies according to the dominant emission sectors and systems in each country and because of the different role played by meteorology. To date, interventions to control the COVID-19 outbreak represent the largest single global experiment to reduce traffic and industrial emissions, and this study suggests that although some regions have achieved unprecedented improvements in air quality, other areas have only experienced a marginal improvement despite the lockdowns. This finding implies that policies targeted to reduce only industrial and traffic emissions will not be uniformly effective worldwide and ad hoc policies might be required to achieve substantial improvements in air quality in some regions (eg, by changing fuel types for residential heating$^{26}$).

Our results also suggest that continuous air pollution mitigation strategies might help in reducing mortality not only during the ongoing COVID-19 pandemic but also in future pandemics related to respiratory diseases, as people exposed to poor air quality are more likely to have pre-existing respiratory or pulmonary conditions that could make them more vulnerable to infectious diseases and ultimately increase the death rate. Controlling a pandemic is highly challenging$^{27,28}$ and the political interventions adopted so far are having drastic economic and social consequences.$^{27,28}$ Alternative options, such as digital contact tracing$^{11}$ to prevent a long and unsustainable lockdown, are urgently needed and under investigation.

Although this investigation shows heterogeneous results for China and Europe due to, among other reasons, the sources of PM$_{2.5}$, meteorology, and population demographics, the cessation of anthropogenic activities had an undeniable positive effect on the mortality burden due to poor air quality. The results presented here therefore raise questions about comparative risk perception and the effect of perceived risk in facilitating policy responses. The public understandably sees the COVID-19 pandemic as posing a massive, global risk to public health and consequently accepts as necessary equally drastic and sudden changes in lifestyles, law, the economy, work life, transportation, and education.$^{29,30}$ By contrast, the public perceives only a low risk to public health posed by activities that inject particulate matter into the atmosphere, even though the cumulative threat to public health can be, in the long term, greater than that posed by the COVID-19 pandemic, and there is comparatively low public support for large-scale changes in energy production, manufacturing, transportation, and other activities that produce PM$_{2.5}$ emissions.$^{11}$

The spatial and temporal scale of the COVID-19 pandemic, and the visual effect of hospitals worldwide being strained with insufficient intensive care units, face masks, and hand sanitiser have created in the public a compelling sense of the necessity of making drastic changes to their lifestyle. Events such as air pollution and climate change could be even more devastating than COVID-19 in the long term, yet there is comparatively little support to take action to mitigate their risks, because the effects of air pollution and climate change are being diluted in time and space, and hence their impact is largely only reported in terms of numbers and statistics; by contrast, the images of the impact and consequences of COVID-19 on society and the economy have been far more visible and distressing. We thus argue that if interventions of a similar scale to those adopted to address
the COVID-19 pandemic were widely and systematically adopted, substantial progress towards solving the most pressing environmental and health crisis of our time could be achieved, and reinforce ongoing efforts to develop an emission control policy in China as well as other countries affected by poor air quality.

Contributors

PG, PC, and SC designed the study and developed the analysis plan. PG and WH downloaded and processed the observational datasets. AA did the chemical transport model simulation. PG did all the analyses. PG, PC, and SC wrote most of the manuscript. DH analysed the social implications and contributed to the writing of the Discussion section. All authors contributed to the interpretation of the results.

Declaration of interests

We declare no competing interests.

Data sharing

The data that support the findings of this study are available upon request from the authors.

Acknowledgments

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Editorial note: the contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 2015; 525: 367–71.

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