ENVIRONMENTAL HEALTH

Santé publique France

IMPACT OF AMBIENT AIR POLLUTION ON MORTALITY IN METROPOLITAN FRANCE

Reduction related to Spring 2020 lockdown and new data for total burden of impact for the period 2016-2019

KEY POINTS

- The benefits resulting from the decreases in ambient air pollution observed during the first lockdown in France in Spring 2020 can be estimated at around 2,300 postponed deaths associated with a decrease in the population's exposure to particulate matter, and around 1,200 postponed deaths associated with a decrease in exposure to nitrogen dioxide (NO_2).
- These results, occurring in an unprecedented context certainly not desirable for improving air quality in the long term, once again confirm that public interventions appear to have a significant impact on health through reductions in air-pollution levels. Some learnings can already be leveraged in terms of public action and behavioural changes (teleworking, travel modes, etc.) that will likely be lasting in French society.
- In a broader, long-term perspective, each year nearly 40,000 deaths could be attributed to population exposure to fine particles ($PM_{2.5}$), and 7,000 deaths to population exposure to NO_2, representing respectively 7% and 1% of total annual mortality.
- This study serves as a reminder that the total burden of air pollution on health remains a relevant risk factor in France. And that efforts to reduce ambient air pollution must be pursued lastingly for all sources of air pollution with suitably adapted but ambitious policies.

WHY CONDUCT A NEW QUANTITATIVE HEALTH IMPACT ASSESSMENT OF AMBIENT AIR POLLUTION?

To limit the spread of the SARS-CoV-2 virus causing the COVID-19 pandemic, national authorities took drastic, totally unprecedented measures with the Spring 2020 lockdown in France. These measures led to a massive slowdown in activity and population mobility with negative consequences for society and the economy. The measures also had positive consequences, however, including local improvements in air quality and reductions in urban noise [1, 2].

In France's largest urban areas, a study by Atmo France[1] showed a decrease in average concentrations of nitrogen oxides (NO_x) from 1 to 31 March 2020 observed at monitoring stations measuring pollution from road traffic. At the same time, the French National Institute for Industrial Environment and Risks (Ineris) took these observations into account for its modelling at a national level, and also found significant decreases in NO_2 concentrations, whose sources are mainly road traffic, but more moderate decreases in particulate matter (PM_{10} and $PM_{2.5}$),

1. Study carried out by the French Air Quality Monitoring Network (AASQA).

which provide an indicator of background pollution from multiple sources. These lesser decreases indicate that some emission sources such as heating on cold days at the beginning of the epidemic, and spring agricultural spraying, were not (or only slightly) impacted by the lockdown.

With the work that follows Santé publique France wanted to study the consequences of the COVID-19 health crisis beyond its surveillance of the epidemic. The goal was to contribute to thinking about the resumption of activities, and to enhance understanding of ambient air pollution and its long-term consequences for the population's health.

WHAT ARE THE STUDY'S TWO OBJECTIVES?

Santé publique France conducted a new quantitative health impact assessment (QHIA) of the impact of ambient air pollution on mortality in metropolitan France with two objectives. The first was to determine whether the reduction in ambient air pollution levels, and therefore the reduction in the population's exposure to PM and NO_2 linked to the drastic decrease in human activities during the Spring 2020 lockdown, had an impact on mortality. At the same time, ambient air pollution remains a major health risk factor in France. For this reason, as the second objective an assessment of its impact on long-term mortality in metropolitan France for the period 2016-2019 was also performed to update the estimates produced for the period 2007-2008 and published in 2016 [3].

This two-pronged study was conducted under the French Surveillance Program on Air Pollution and Health (Psas) in collaboration with Ineris and with the French Technical Reference Center for Air Pollution and Climate Change (Citepa), the French Air Quality Monitoring Network (AASQA) and the Ile-de-France Regional Observatory (ORS Ile-de-France).

WHAT ARE THE MAIN FINDINGS?

What were the impacts on mortality of the reduction in ambient air pollution during the Spring 2020 lockdown?

Short-term impact of lockdown

For the period of tight lockdown (16 March to 11 May 2020), on average the decrease between the estimated PM_{10} levels and their baseline without lockdown varied between –8.6 µg/m³ and –0.1 µg/m³ depending on the municipality. For NO_2, this decrease varied between –30.8 µg/m³ and –0.3 µg/m³. For these two pollutants, the decrease is greater in more urbanised areas **(Figure 1)**. In this scenario of a tight lockdown, in the short term 243 deaths would have been postponed from reductions in NO_2 and 61 deaths from reductions in PM_{10} concentrations, representing respectively 0.3% and 0.08% of total annual mortality. About half of these postponed deaths were concentrated in urban units totalling more than 100,000 inhabitants.

The gradual lifting of lockdown (11 May to 22 June 2020) saw a smaller decrease in pollutant concentrations than during the tight lockdown with an even more pronounced rural/urban exposure gradient for NO_2 than for PM_{10}. In this scenario of gradual lifting of lockdown, 39 deaths would have been postponed from reductions in NO_2 concentrations and 8 deaths from reductions in PM_{10} concentrations, representing respectively 0.1% and 0.01% of total annual mortality. About half of these postponed deaths were again concentrated in urban units totalling more than 100,000 inhabitants.

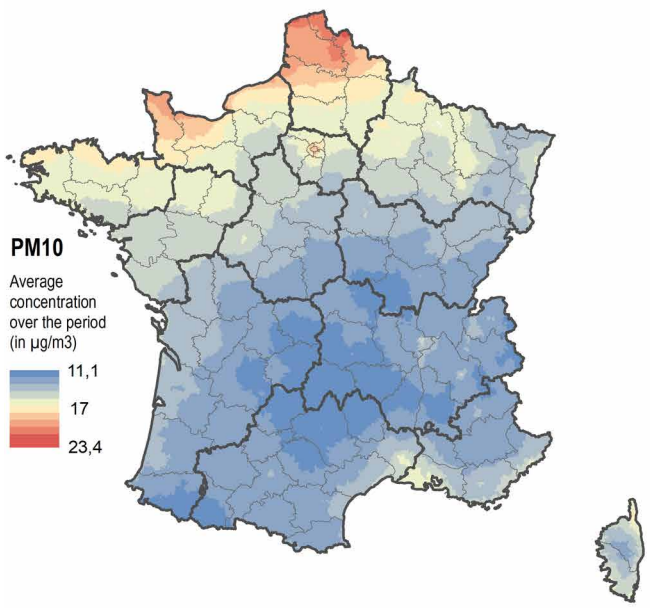
Thus, in the short term the estimated decreases in PM_{10} and NO_2 concentrations between 16 March and 22 June 2020 would in total have postponed respectively around 70 and 280 deaths associated with the short-term effects of ambient air pollution (exacerbation of chronic pathologies).

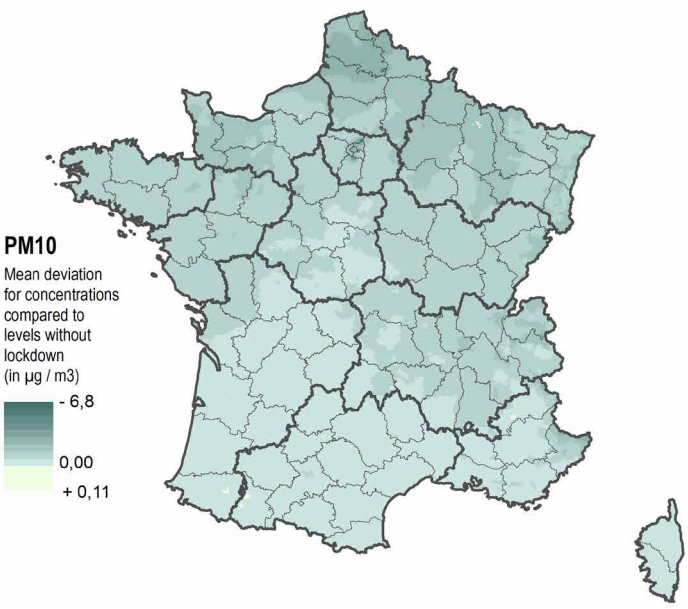
It should be noted that the respective estimates of deaths postponed by decreases in each pollution indicator (NO_2 and PM_{10}) cannot be added together since some of these deaths can be attributed to exposure to both pollutants.

Longer-term impact of lockdown

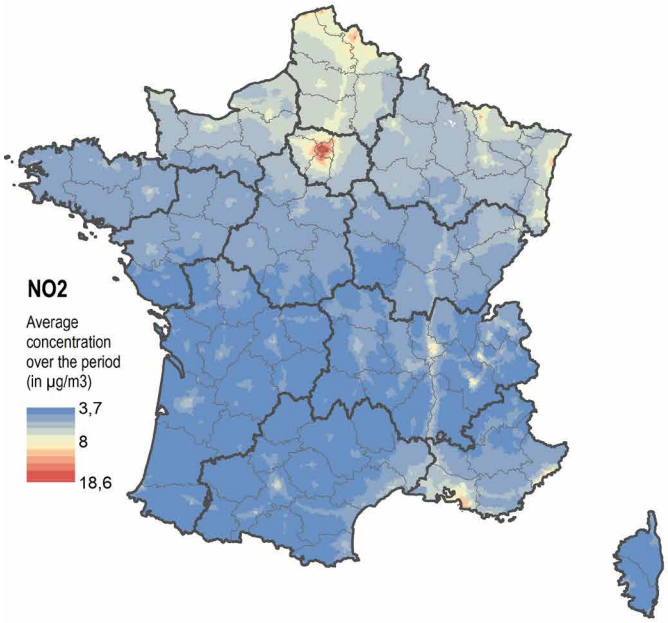
For the period from 1 July 2019 to 30 June 2020, on average the decrease in annual average $PM_{2.5}$ levels in metropolitan France varied between –0.9 µg/m³ and 0.01 µg/m³ depending on the town. For NO_2, this decrease varied between –7.0 µg/m³ and –0.04 µg/m³ **(Figure 2)**. In this scenario, 2,274 deaths would have been postponed from reductions in $PM_{2.5}$ concentrations, and 893 deaths from the drop in concentrations in NO_2 in metropolitan France, accounting respectively for 0.4% and 0.2% of total annual mortality. About half of these postponed deaths were again concentrated in urban units totalling more than 100,000 inhabitants **(Figure 3)**.

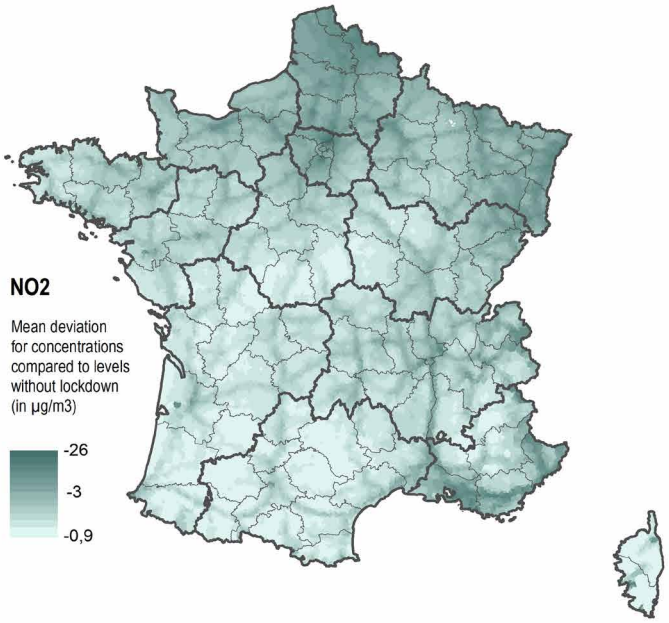
FIGURE 1 | Distribution of average pollutant concentrations (PM_{10} and NO_2) estimated during lockdown (left) and modelled average difference in concentrations between lockdown and non-lockdown levels (right)





Source: ADMIN-EXPRESS - Ign, 2018; Ineris, Chimère, adjusted data taking into account the reduction of emissions during lockdown, concentration averages over the period from 16/03 to 22/06/2020. Santé publique France, 2020

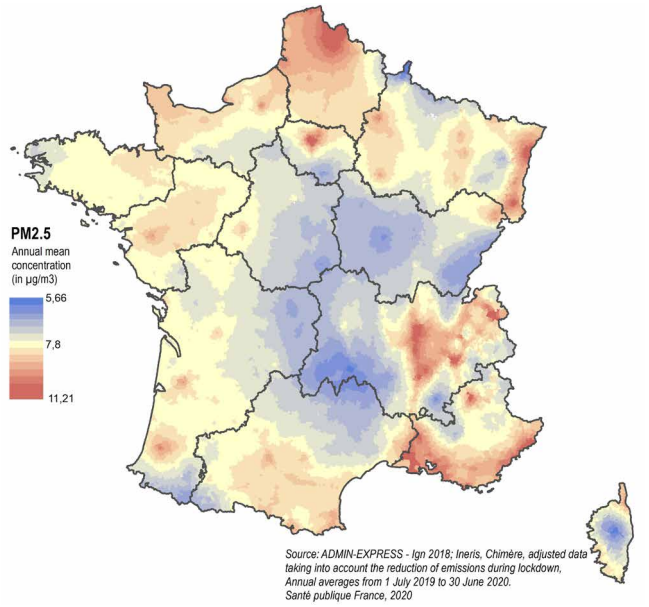




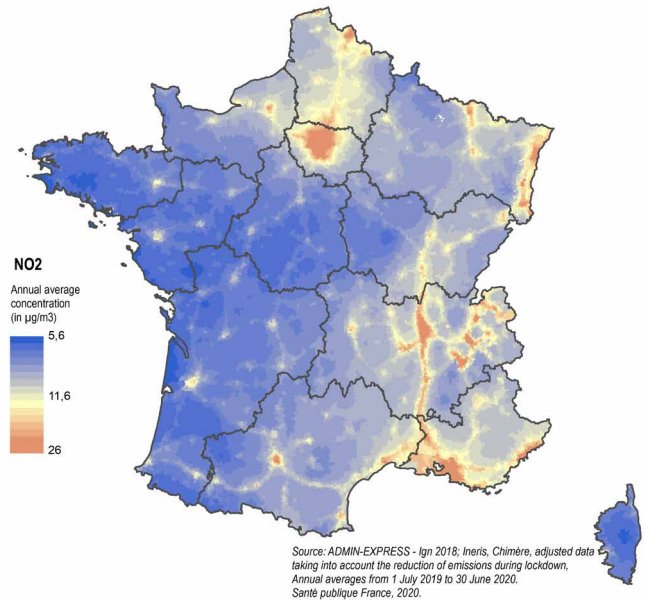
Source: ADMIN-EXPRESS - Ign, 2018; Ineris, Chimère, adjusted data taking into account the reduction of emissions during lockdown, concentration averages for the period from 16/03 to 22/06/2020. Santé publique France, 2020

FIGURE 2 | Distribution of mean concentrations of $PM_{2.5}$ (left) and NO_2 (right) by municipality from 1 July 2019 to 30 June 2020

CHIMERE modelling, data adjustment taking into account the reduction of emissions during lockdown

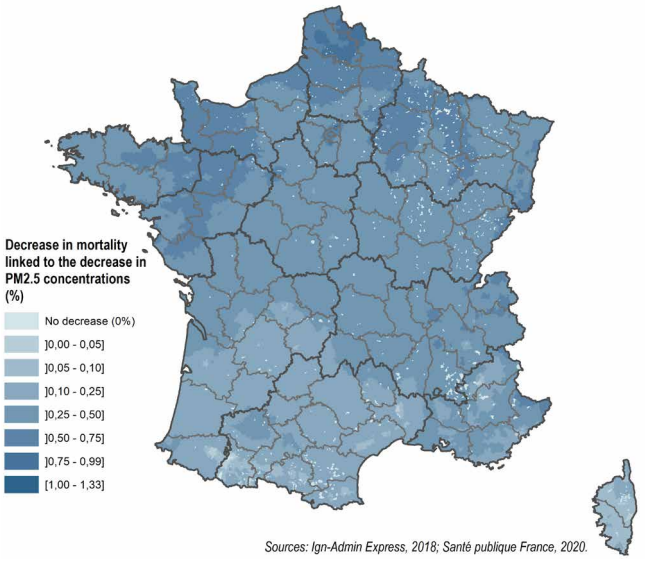


Source: ADMIN-EXPRESS - Ign 2018; Ineris, Chimère, adjusted data taking into account the reduction of emissions during lockdown, Annual averages from 1 July 2019 to 30 June 2020. Santé publique France, 2020

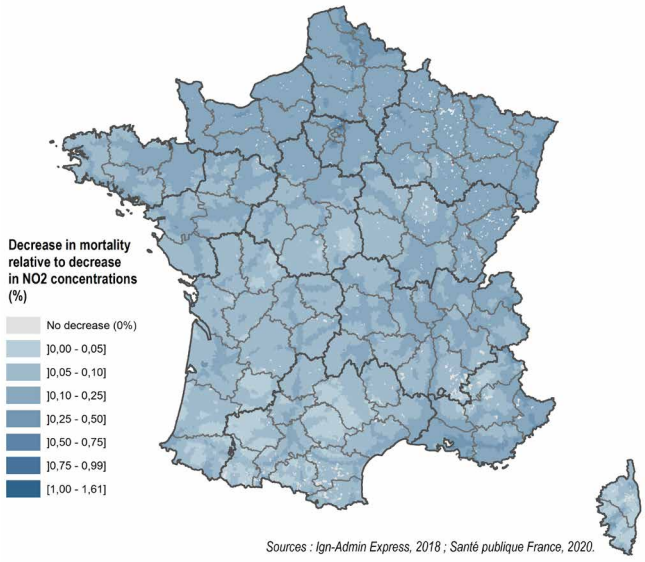


Source: ADMIN-EXPRESS - Ign 2018; Ineris, Chimère, adjusted data taking into account the reduction of emissions during lockdown, Annual averages from 1 July 2019 to 30 June 2020. Santé publique France, 2020.

FIGURE 3 | Impact of the decrease in $PM_{2.5}$ and NO_2 concentrations on annual mortality from 1 July 2019 to 30 June 2020 at the municipal level in metropolitan France (in %)



Sources: Ign-Admin Express, 2018; Santé publique France, 2020.



Sources : Ign-Admin Express, 2018 ; Santé publique France, 2020.

It should again be noted that the respective estimates of deaths postponed by decreases in each pollution indicator (NO_2 and $PM_{2.5}$) cannot be added together since some of these deaths can be attributed to exposure to both pollutants.

In total during the first lockdown in Spring 2020 the mean reduction in PM_{10} concentrations was 8.3%, with values ranging from –1.8% to 39.8% depending on the municipality. For NO_2 concentrations, the mean reduction was 29.0%, with values ranging from 3.5% to 187.8% depending on the municipality. Moreover, the exposure-reduction gradient from rural to urban areas was larger for NO_2 than for PM_{10} and $PM_{2.5}$. The short- and longer-term benefits of these decreases can be estimated at around 2,300 deaths postponed from a decrease in the population's exposure to particulate matter, and around 1,200 deaths postponed from a decrease in the population's exposure to NO_2.

These benefits are mainly due to longer-term effects (reduction in the contribution of air pollution to the development of pathologies leading to death), and to a lesser extent to short-term effects (exacerbation of chronic pathologies).

What was the total long-term mortality burden of ambient air pollution between 2016 and 2019?

To frame the results of the concentration reduction scenarios relative to the Spring 2020 lockdown, a QHIA of **the total long-term burden of ambient air pollution on mortality** in metropolitan France was conducted for the period from 1 January 2016 to 31 December 2019. This QHIA aimed to update the estimates published in 2016 by Santé publique France for the period 2007-2008 [3].

Depending on the municipality, the annual average concentrations of $PM_{2.5}$ for the study period varied from 6.6 µg/m³ to 14.4 µg/m³, and from 7.4 µg/m³ to 34.3 µg/m³ for NO_2 **(Figures 4 and 5)**.

Taking the same concentration-response function or relative risk (RR) (1.15 [1.05-1.25]) and the same threshold of 5 µg/m³ for $PM_{2.5}$ as a reference for anthropogenic pollution (linked to human activities) as those used in 2016, and a threshold of 10 µg/m³ for NO_2, each year nearly 40,000 deaths could be attributed to population exposure to $PM_{2.5}$, and 7,000 deaths to exposure to NO_2, representing respectively 7% and 1% of total annual mortality **(Figure 6)**. This equates to an average loss of life expectancy of 7.6 months from $PM_{2.5}$ exposure and 1.6 months from NO_2 exposure for people 30 years and over.

It should again be noted that the respective estimates of deaths postponed by decreases in each pollution indicator (NO_2 and $PM_{2.5}$) cannot be added together since some of these deaths can be attributed to exposure to both pollutants.

These results can be compared with those published in 2016 estimating that 48,000 deaths per year are attributable to exposure to $PM_{2.5}$ by the population in metropolitan France for the period 2007-2008 with identical scenarios and RR values. The differences between the two estimates can be partly explained by a decrease in ambient air pollution since 2007-2008 [18], and partly by the use of different exposure models that are more consistent and robust for urban areas than for rural areas.

about 40,000

DEATHS ATTRIBUTABLE TO POPULATION EXPOSURE TO $PM_{2.5}$ EACH YEAR FOR PEOPLE AGED 30 YEARS AND OVER

nearly 8 months

OF LIFE EXPECTANCY LOST ON AVERAGE DUE TO EXPOSURE TO $PM_{2.5}$ FOR PEOPLE AGED 30 YEARS AND OVER

around 7%

OF TOTAL ANNUAL MORTALITY ATTRIBUTABLE TO $PM_{2.5}$ EXPOSURE FOR PEOPLE AGED 30 YEARS AND OVER

Interpretation of results

When interpreting the results of all QHIAs, the choice of exposure models, the anthropogenic pollution reference threshold and the RR greatly affect the results. This influence is discussed in detail in the study report and peer-reviewed article [19-20]. Moreover, in this QHIA the exceptional situation created by the lockdown must also be taken into account, since it modified population exposure to ambient air pollution, in particular from a reduction in mobility, more time spent in indoor environments, changes in lifestyle and behaviour, and postponements of medical treatment. Our analysis could not quantify the influence of these exceptional factors due to a lack of hindsight and available data, but they are discussed qualitatively in the study report.

FIGURE 4 | **Distribution of annual average $PM_{2.5}$ concentrations during the period from 1 January 2016 to 31 December 2019**

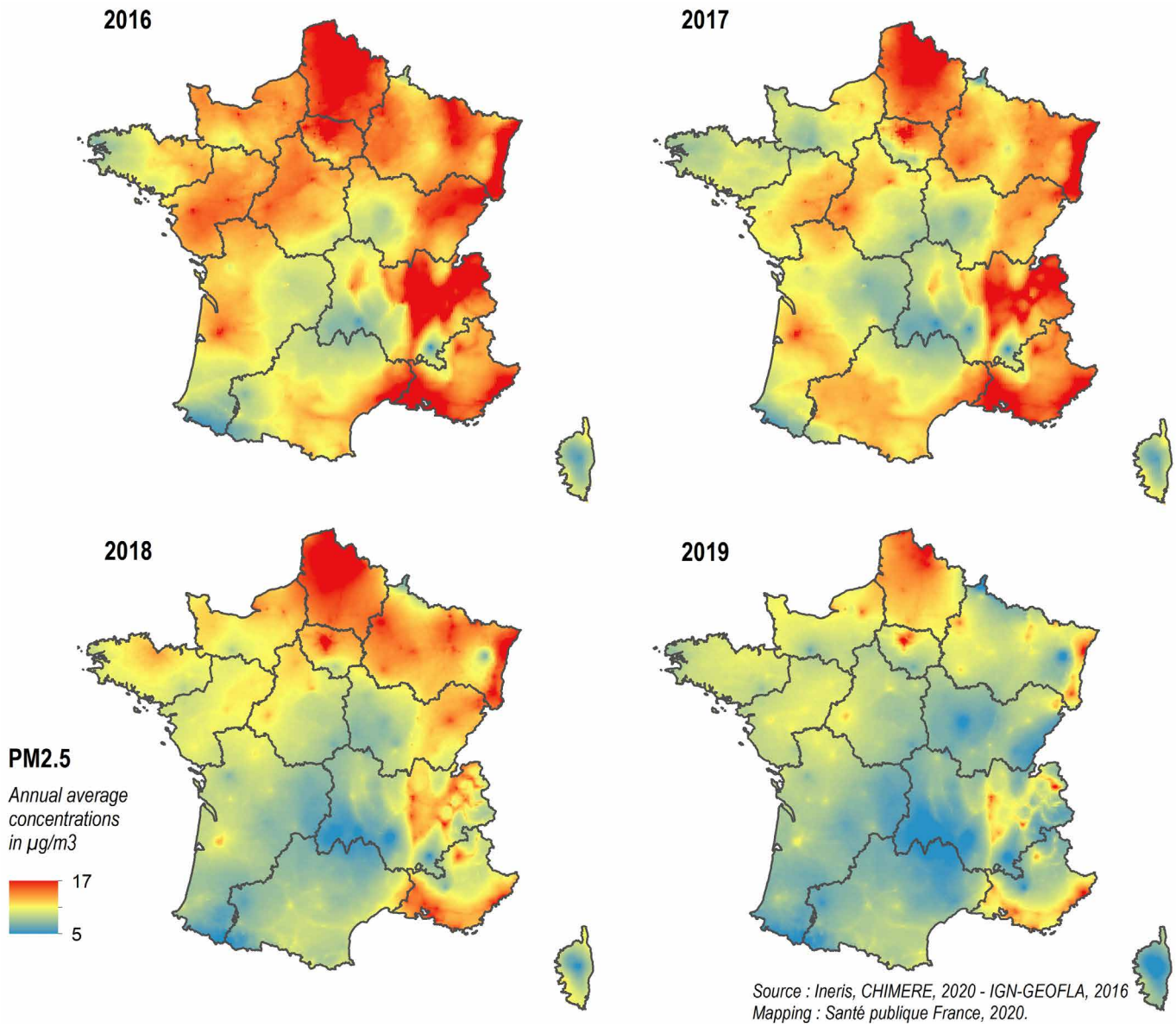


FIGURE 5 | **Distribution of annual average NO_2 concentrations during the period from 1 January 2016 to 31 December 2019**

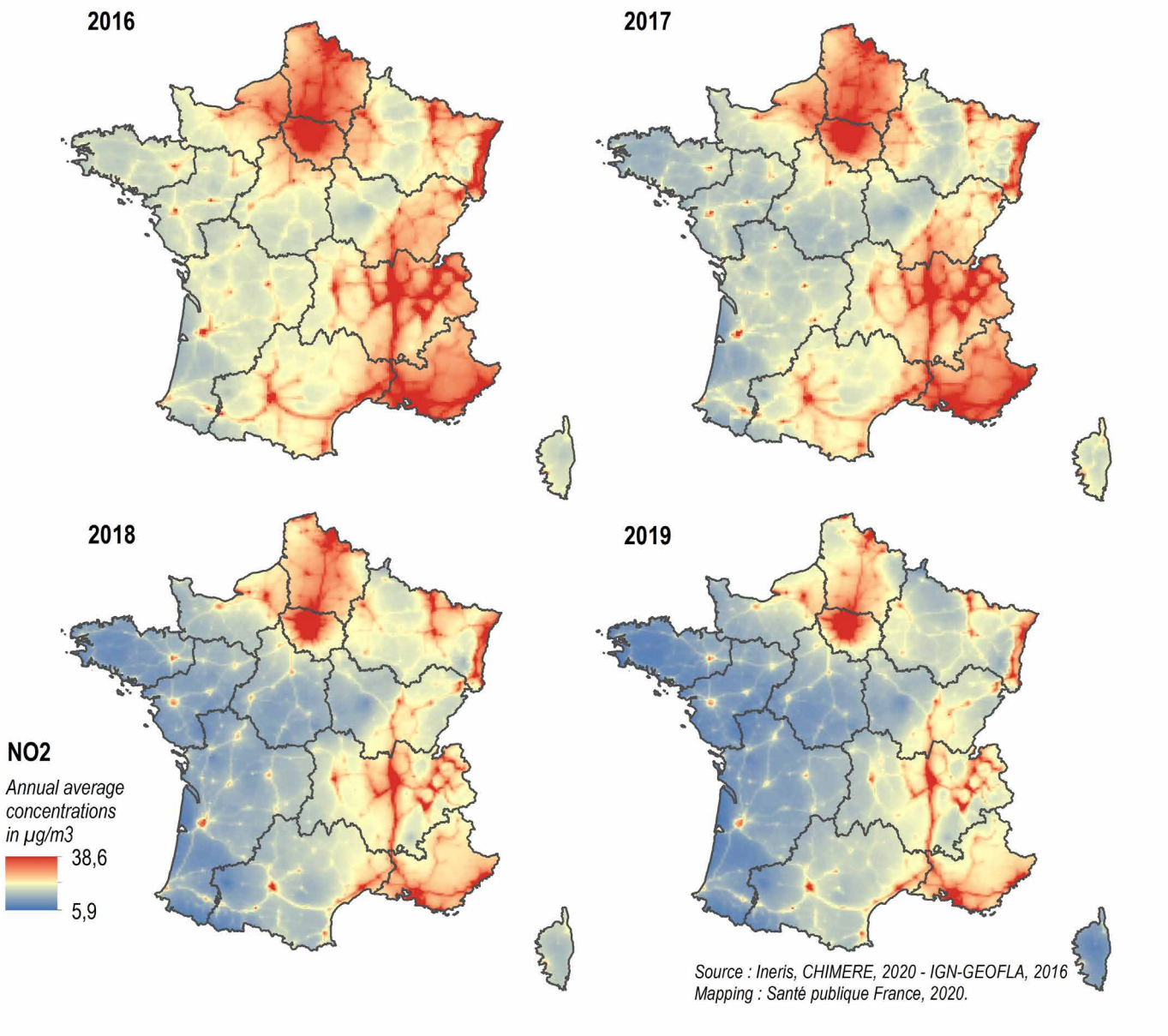
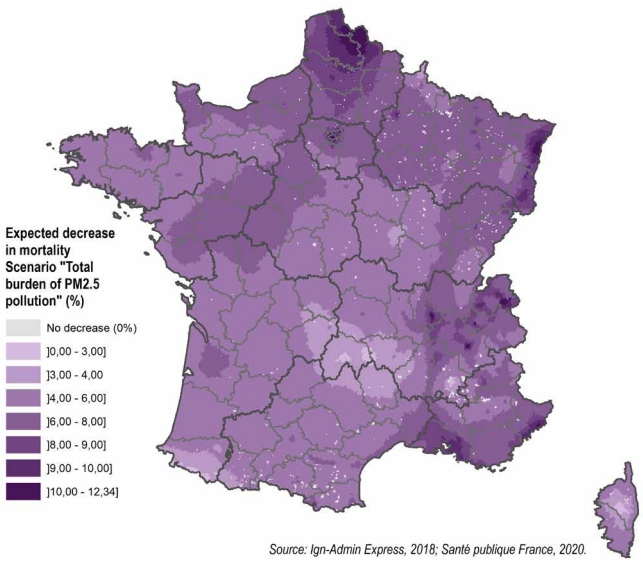
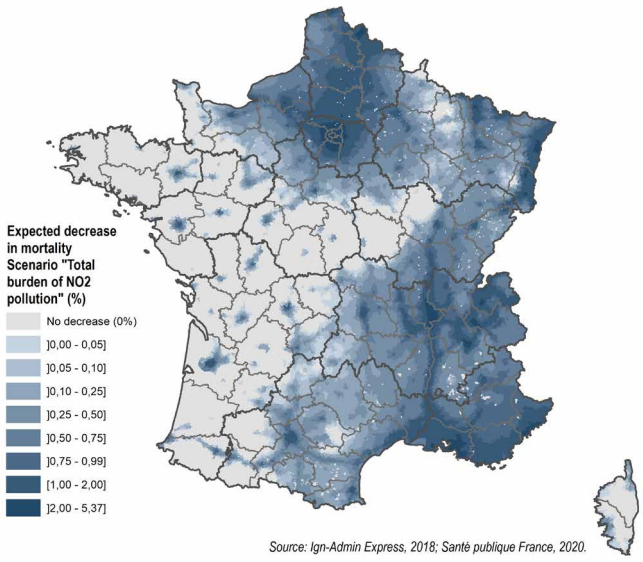


FIGURE 6 | Total burden of long-term exposure to $PM_{2.5}$ (left) and NO_2 (right) on mortality of the population aged 30 years and over at municipal level in metropolitan France from 1 January 2016 to 31 December 2019



Source: Ign-Admin Express, 2018; Santé publique France, 2020.



Source: Ign-Admin Express, 2018; Santé publique France, 2020.

SIGNIFICANCE OF THE STUDY'S RESULTS

- The study estimates the consequences for mortality of the decreases in ambient air pollution observed during the first lockdown in Spring 2020 in metropolitan France. The results highlight that temporary reductions in air pollution levels like those observed in Spring 2020 are associated with significant health benefits.

- The results, while occurring in an unprecedented context certainly not desirable for improving air quality in the long term, once again confirm that public interventions appear to significantly reduce air-pollution levels, population exposure and the resulting impact on health in a rapid, measurable manner. This period thus provided a unique opportunity to rethink sustainable interventions on sources of air-pollution emissions in France. Some learnings can already be leveraged in terms of public action and behavioural changes (teleworking, travel modes, etc.) that will likely be lasting in French society.

- In addition, in a broader and long-term perspective this study serves as a reminder that the total burden of air pollution on health remains a relevant risk factor in France. And that efforts to reduce ambient air pollution must be pursued lastingly for all sources of air pollution with suitably adapted but ambitious policies.

- Finally, the lockdown restrictions had other consequences for the population's health both positive (reduction in noise and road accident deaths) and negative (mental health problems, reduced or delayed screening and access to health care, reduced physical activity and increased sedentary behaviour, etc.). These consequences highlight the need to conduct more integrated assessments of health impacts that include the multisectoral consequences of interventions, particularly in terms of population compliance, behaviour, mental health and, more broadly, climate change.

METHOD: HOW WERE THESE HEALTH IMPACTS OF AMBIENT AIR POLLUTION ESTIMATED?

What are the principles of a QHIA?

The quantitative health impact assessment (QHIA) is a method developed by the World Health Organisation (WHO) to illustrate the impact of ambient air pollution on population health. It is used to estimate the benefits that can be achieved in different air quality improvement scenarios [4].

The pertinence of conducting a QHIA is based on the assumption of a causal link between exposure to air pollution and its health effects.

This link is based, among other things, on:

- **the concentration-response relationship:** *the higher the pollution levels, the greater the health effect and/or its probability*
- **the temporal relationship:** *exposure to the risk factor precedes the health effect*
- **the consistency of the association:** *its repetition in time and space*
- and above all, **the notion of biological plausibility:** *the association between exposure to outdoor air pollution and health effects is consistent with knowledge of the relevant biological mechanisms [5].* This plausibility is confirmed by numerous mechanistic, toxicological and epidemiological studies [6-12].

This QHIA was conducted in accordance with the QHIA guidelines on air pollution and health (QHIA-AP) developed by Santé publique France [4].

Which periods were studied?

The analyses were carried out at the municipal level. To study the short-term effects (occurring within a few days of exposure) of lockdown, several periods corresponding to the implementation of restrictive measures were examined. For longer-term effects (occurring several months after exposure), a period of one year was studied from July 2019 to June 2020. Finally, for the total burden four years were studied during which no exceptional health or environmental events were recorded **(Table 1)**.

Which "pollutant-health" pairs were studied?

In accordance with the recommendations of the QHIA-AP guidelines for mortality, the study focused:

- for the short-term impacts on PM_{10}[2] or NO_2[3] and non-accidental mortality
- for the long-term impacts on $PM_{2.5}$[4] or NO_2 and all-cause mortality in the 30+ age group.

Which concentration-response functions were chosen?

The concentration-response functions, or relative risk (RR), represent the relationship between an indicator of population exposure to ambient air pollution and a health indicator. They are estimated by epidemiological studies and are necessary for conducting a QHIA. These RRs are expressed with a central value and a 95% confidence interval [95% CI].

This confidence interval expresses the random error and variability attributed to the heterogeneity of the RRs from the epidemiological studies. The choice of the RR among those available in the literature was based on the criteria of the QHIA-AP guidelines **(Table 2)**.

TABLE 1 | **Study periods**

	Objectives	Study period
Impacts on mortality associated with lower air-pollutant concentrations caused by COVID-19-related activity restrictions in Spring 2020	Scenario 1 Short-term impact on mortality	**Tight lockdown:** 16 March to 11 May 2020 **Gradual lifting of lockdown*:** 11 May to 22 June 2020 **Total period:** 6 March to 22 June 2020
	Scenario 2 Longer-term impact on mortality	1 July 2019 to 30 June 2020
Total long-term burden of ambient air pollution between 2016 and 2019 (excluding the context of measures taken to limit the spread of COVID-19)		1 January 2016 to 31 December 2019

* Gradual lifting of lockdown refers to a gradual resumption of economic activity following tight lockdown.

2. Suspended particles with an aerodynamic diameter of less than 10 microns

3. Nitrogen dioxide

4. Suspended particles with an aerodynamic diameter of less than 2.5 microns

TABLE 2 | Choice of relative risks

	Objectives	Mortality indicator	Age groups	Relative risks (RR)	References
Impacts on mortality associated with lower air-pollutant concentrations caused by COVID-19-related activity restrictions in Spring 2020	Scenario 1 Short-term impact on mortality	Non-accidental mortality Code-ICD-10: A00-R99	All ages	PM_{10} : 1.0030 [1.0013-1.0047]	Liu *et al.* 2019, meta-analysis of 340 cities* [13]
				NO_2 : 1.0075 [1.0040-1.011]	Corso *et al.* 2020, meta-analysis of 18 French cities [14]
	Scenario 2 Longer-term impact on mortality	Total mortality Code ICD-10: A00-Y98	⩾ 30 years	$PM_{2.5}$: 1.15 [1.05-1.25]	Pascal *et al.* 2016, meta-analysis of European studies (22 ESCAPE project cohorts and one French Gazel'Air cohort) [3]
				NO_2 : 1.023 [1.008-1.037]	COMEAP 2018, meta-analysis of 11 Western studies [15]
Total long-term burden of ambient air pollution between 2016 and 2019		Total mortality Code ICD-10: A00-Y98	⩾ 30 years	$PM_{2.5}$: 1.15 [1.05-1.25]	Pascal *et al.* 2016 [3]
				NO_2 : 1.023 [1.008-1.037]	COMEAP 2018 [15]

** Compared to the study referred to, the RRs reported here only take into account in the meta-analysis those of Western countries (Canada, Czech Republic, Estonia, Finland, France, Germany, Greece, Italy, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States) not all the countries in the study.*

How were the pollution indicators modelled?

The concentrations of the pollutants in the air were modelled by Ineris using an adaptation of national emissions during the lockdown periods done by Citepa. This modelling was done on a 4 km × 4 km grid covering France [16].

Daily and annual municipal exposure was estimated on the basis of modelled concentrations using population-weighted averages.

For the first objective of the QHIA, the model estimated the decrease in daily concentrations of NO_2 and of PM_{10}/$PM_{2.5}$ attributable to the lockdown measures, based on assumptions about the impact of these measures on air-pollutant emissions.

For the short-term impact, the difference between the actual exposure of the population during the periods of tight lockdown and gradual lifting and the exposure that would have occurred in the absence of these lockdown measures was calculated for PM_{10} and NO_2.

For the longer-term assessment, we compared the impacts when the population would have been exposed to the estimated annual average concentrations of $PM_{2.5}$ and NO_2 without the lockdown (i.e., the annual average concentrations on each day from 1 July 2019 to 30 June 2020 if the lockdown had not been implemented) and when the population would have been exposed to the estimated annual average concentrations with the lockdown (i.e., the annual average concentrations observed on the non-lockdown days and the concentrations observed on the lockdown days from 1 July 2019 to 30 June 2020).

For the second objective of calculating the total burden of ambient air pollution in the long term, NO_2 and $PM_{2.5}$ annual average concentrations over the period 2016-2019 were used.

Which reference thresholds were used to estimate the total burden of ambient air pollution in metropolitan France?

In the absence of data to estimate the share of anthropogenic pollution[55] in France, the reference thresholds to which the scenarios were compared were 5 µg/m³ for $PM_{2.5}$ and 10 µg/m³ for NO_2. For $PM_{2.5}$, this value is very close to the value used in the previous QHIA by Santé publique France for mainland France, which had used a reference of 4.9 µg/m³ corresponding to the values estimated in French mountainous areas and in theory free of major anthropogenic particle pollution [3]. For NO_2, the value chosen corresponds to the level chosen for the sensitivity analysis carried out by the European Environment Agency (EEA), based on the publication by Raaschou -Nielsen et al. [17].

The exposure level considered in the QHIA was the difference between the estimated annual average exposure during the period 2016-2019 and the selected threshold (this difference being zero if the concentration is already below the threshold).

5. Share of ambient air pollution attributable to human activities

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Santé publique France

12 rue du Val d'Osne, 94415 Saint-Maurice Cedex France
www.santepubliquefrance.fr

ISSN: 2609-2174 – ISBN-NET: 979-10-289-0707-5 – CREATION: GROUPE JOUVE – LEGAL SUBMISSION: MAY 2021

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ACKNOWLEDGEMENTS

We would like to extend our thanks to **Atmo Grand Est** (Emmanuel Rivière, Florent Vasbien, Maxime Alter) and **AtmoFrance** (Charlotte Lepitre) for their contribution to the environmental data, to the protocol and to proofreading the report; and to the Center for Epidemiology on the Medical Causes of Death (Centre d'épidémiologie sur les causes médicales de décès - Cépidc) for the mortality data provided. We also thank Sylvie Cassadou (**CREA-ORS Occitanie**), Aymeric Ung (**DMNTT, Santé publique France**) and Guillaume Boulanger (**DSET, Santé publique France**) for their careful review and suggestions. Lastly, our thanks to Michael Saklad for his editorial input and support for the English version of the report.

MOTS CLÉS
COVID-19
QHIA
AMBIENT AIR POLLUTION
MORTALITY
FRANCE

Suggested citation : *Impact of ambient air pollution on mortality in metropolitan France: Reduction related to Spring 2020 lockdown and new data for total burden of impact for the period 2016-2019.* Saint-Maurice: Santé publique France; 2021: 12 p. Available at: http://www.santepubliquefrance.fr