Supplementary Material

# Supplementary Data-Presentation of the CHIMERE model

The CHIMERE model is a numerical model that brings together a set of equations representing the transport and transformation of chemical species and allows the quantification of the evolution of a pollutant plume as a function of time over different domains (from urban to continental). From meteorological and emission flow data, CHIMERE allows the calculation of hourly three-dimensional fields of pollutant concentrations in the atmosphere. Due to the input data used, the number of equations to be solved and the physico-chemistry represented in it, CHIMERE is a mesoscale model, i.e. it simulates the troposphere (from the surface to 200 hPa or approximately 10km in altitude) for a horizontal resolution of 1 to 100 km and over study areas ranging from the city to the continent. The CHIMERE model integrates a chemical scheme comprising more than a hundred chemical reactions. It can model the formation and evolution of atmospheric particles from a few nanometers to 20 µm. The aerosols in CHIMERE are made up of primary species emitted directly by human activities, but also of secondary aerosols produced in the atmosphere: sulphate, nitrate, ammonium and secondary organic species, in addition to natural sources such as sea salts or desert dust. More than a hundred gaseous compounds are modeled including ozone, nitrogen oxides, sulfur dioxide.

Re-analyzed PREVAIR concentrations are generated each day for the previous day by combining forecasts developed using the CHIMERE model and observation data from measures implemented on the national territory by the AASQA. More information on the methodology for the elaboration of these data is available in Beauchamp *et al.* (2018) (6) and Beauchamp *et al*. (2017) (7).

Simulations with and without lockdown effect were performed over the study period on a domain covering France at about 4 km resolution with the CHIMERE version 2017β (8). Several input data were used to perform the simulations:

* Meteorological data: meteorology is an essential input to the model. In the case of this study, data from the IFS (Integrated Forecast System) model of the European Centre for Medium-Range Weather Forecasts (ECMWF) were used.
* The boundary conditions: CHIMERE being a regional model it is necessary to constrain the model to the boundaries of the domain. To do this, the domain over France is constrained by a simulation over Europe (at a resolution around 25 km) which itself takes into account the effect of confinement on emissions as provided by the Copernicus service. The concentrations at the boundaries of the European domain are themselves constrained by meteorological data from global Copernicus European Atmospheric Monitoring Service (CAMS) simulations.
* Emissions: the CAMS-REG emissions inventory for the year 2015 covering all Europe at a resolution of 0.1°x0.05° was used. As these emissions do not take into account the effect of the lockdown, emission abatement factors were applied on each day of the period. These abatement factors are based on CAMS data and adapted by French regions by CITEPA

# Supplementary Data-Calculation of emissions from CAMS data and by Citepa for the French emissions

The calculation of emissions is based on the daily emissions variations proposed by CAMS for the main sectors of activity (3). Guevara et al (2020) quantify the primary emission reductions due to lockdown measures in Europe. Their estimates are provided in the form of a dataset of reduction factors varying by country and by day that will allow modelling and identification of the associated impacts on air quality. The reduction factors resolved by country and on a daily basis are provided for each sector of activity: energy industry (power plants), manufacturing industry, road traffic and aviation (landing and take-off cycle). They have calculated the reduction factors based on open access and activity data measured in near real time from a wide range of information sources (Google, Apple, etc...). They performed a machine-learning model with meteorological data to derive weather-standardized electricity consumption reductions. The period covered is from February 21, when the first European localized lockdown was implemented in the Lombardy region (Italy), to April 26, 2020. The calculated reduction factors were combined with the European emission inventory of the Copernicus air monitoring service using adjusted emission time profiles to derive time-resolved emission reductions by country and pollutant sector.

For France, CITEPA has performed a finer calculation of emission variations by region for road traffic emissions and a first estimate for the residential sector.

Road traffic

CEREMA (French center for studies and expertise on risks, environment, mobility and planning) data were used; they give, by region, the evolution compared to a reference situation an index reflecting the volume of vehicles in circulation. The index is constructed by comparing current traffic to “pre-crisis” traffic. For this reference to be as specific as possible, it is calculated on the average daily flow from January 13 to February 2, 2020 to avoid the school holidays effects and the start of confinement. These indicators are determined from traffic data from more than 1200 metering stations. Two indices are proposed: an all-vehicle index (ITV) and a heavy vehicle index (IPL) allowing us to add further refinement to the calculation by introducing a variation factor per pollutant. CEREMA provides an index constructed so that “0” represents a “before crisis” situation.

The principle is to first calculate a new variation index for light vehicles (AVL) and heavy goods vehicles (APL) such that 100 represents the pre-crisis value. As set here below, VKTvl and VKTpl are the average driven kilometers of HGV and light vehicles (including utility vehicles) respectively in France.

VKTvl=560.3 and VKTpl=32.1

The following coefficient are then calculated:

$a=\frac{VKTvl}{VKTvl+VKTpl} et b=1-a$

$$APL=100+IPL$$

$$AVL=\frac{100+ITV}{a}+\frac{b}{a}APL$$

The APL and IVL coefficients are normalized for each day i, we will call them APLn and AVLn for the 7 types of days j = [Monday-… -Sunday] from January 13 to March 5 so that the pre-processors of CHIMERE can always affect his classic temporal profiles.

$$AVLn\_{i}=\frac{AVL\_{i}}{\overbar{AVL\_{j\in [13 January-5 March]}}}$$

$$APLn\_{i}=\frac{APL\_{i}}{\overbar{APL\_{j\in [13 January-5 March]}}}$$

An underlying assumption is that the pre-crisis monthly variation is negligible which is a reasonable assumption for road traffic.

From the last available national inventory (2018), we use the total emissions in France of each of the pollutants from road traffic, distinguishing between light vehicles and heavy vehicles (EVL and EPL).

|  |  |  |
| --- | --- | --- |
| **Polluants** | **EVL** | **EPL** |
| CO | 214.05 | 24.20 |
| NH3 | 3.71 | 0.15 |
| NMVOC | 21.1 | 2.65 |
| NOX | 330.14 | 87.20 |
| PM10 | 10.53 | 1.16 |
| PM2.5 | 10.53 | 1.16 |
| SOX | 0.634 | 0.184 |

The final calculation of the index VARtrap,i as defined by Guevara et al. (2020) is done by region for each day i and pollutant p :

$$VAR\_{tra}^{p,i}=AVLn\_{i}×α\_{p}+APLn\_{i}×β\_{p}-100$$

with :

$$α\_{p}=\frac{EVL\_{p}}{EVL\_{p}+EPL\_{p}} et β\_{p}=1-α\_{p}$$

Residential emissions

In this study one considered that household electricity consumption was an adequate proxy for calculating the impact of lockdown on residential heating emissions regardless of the heating method. In summer 2020, consumption data was not available to us, we tried to estimate it from more aggregated data.

Daily electricity consumption data in MW from 2016 to summer 2020 by region from RTE the public French Technical Center of Electric Network Management. To unbias these data to remove the temperature effect we also have the daily average temperatures by region. These data also make it possible to define a minimum climatological consumption located around summer by type of day j which we will call $C\_{min}^{j}$. The index $VAR\_{ene}^{i}$ as defined by Guevara et al. (2020) is the variation in the estimated household electricity consumption for a day I that will be applied to the residential sector, it is calculated as follows:

$$VAR\_{ene}^{i}=100×\left(\frac{C\_{t}^{i}}{∝\_{j}^{i}×C}-r×\left(\frac{1}{∝\_{j}^{i}}-1\right)-1\right)$$

With :

$$∝\_{j}^{i}=\frac{C^{i}-r×C\_{min}^{j}}{C^{i}}$$

r represents the decline in industrial production estimated based on national figures (INSEE) likely to impact industrial energy production. This coefficient is assumed to be constant over the 4 periods of lockdown management.

|  |  |
| --- | --- |
| **r** | **Period** |
| 1.00 | < 20200318 |
| 0.65 | 20200317 - 20200511 |
| 0.75 | 20200512 - 20200601 |
| 0.88 | >20200602 |

$C^{i}$ is the electric consumption of the region and $C\_{t}^{i}$ the temperature corrected electric consumption based on a 4-year historical database (2016-2019).

# Supplementary Table 1. Daily mean differences [min; max] using surface-weighted concentrations by period and area in France from March 16 to June 22, 2020 and from July 1, 2019 to June 30, 2020

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Strict lockdown**(March 16 to May 11, 2020) | **Gradual lifting**(May 11 to June 22, 2020) | **Total period**(March 16 to June 22, 2020) | **Annual**(July 1, 2019 to June 30, 2020) |
| **PM10 (µg.m-3)** | Rural areas(< 2,000 inhabitants) | -2.4[-4.9 ; -0.1] | -0.4[-1.7 ; 0.6] | -1.5[-3.3 ; 0.07] | / |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | -2.4[-4.6 ; -0.1] | -0.4[-1.3 ; 0.4] | -1.5[-3.0 ; 0.1] | / |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | -2.4[-4.7 ; -0.1] | -0.4[-1.4 ; 0.4] | -1.5[-3.0 ; 0.1] | / |
| Areas belonging to urban units of more than 100,000 inhabitants  | -2.7[-8.6 ; -0.1] | -0.4[-4.4 ; 0.6] | -1.7[-6.7 ; 0.1] | / |
| **Metropolitan France** | **-2.4****[-8.6 ; -0.1]** | **-0.4****[-4.4 ; 0.6]** | **-1.5****[-6.7 ; 0.1]** | **/** |
| **NO2 (µg.m-3)** | Rural areas(< 2,000 inhabitants) | -3.0[-18.4 ; -0.3] | -0.5[-10.3 ; 0.1] | -1.9[-14.9 ; -0.2] | -0.5[-4.0 ; -0.04] |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | -3.5[-11.8 ; -0.3] | -0.6[-4.2 ; 0.1] | -2.3[-8.3 ; -0.2] | -0.6[-2.2 ; -0.05] |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | -3.8[-10.4 ; -0.9] | -0.7[-3.5 ; 0.02] | -2.5[-7.4 ; -0.6] | -0.7[-2.0 ; -0.2] |
| Areas belonging to urban units of more than 100,000 inhabitants  | -5.1[-28.9 ; -1.2] | -1.04[-18.3 ; -0.04] | -3.3[-24.3 ; -0.8] | -0.9[-6.6 ; -0.2] |
| **Metropolitan France** | **-3.2****[-28.9 ; -0.3]** | **-0.6****[-18.3 ; 0.1]** | **-2.1****[-24.3 ; -0.2]** | **-0.6****[-6.6 ; -0.04]** |
| **PM2.5 (µg.m-3)** | Rural areas(< 2,000 inhabitants) | / | / | / | -0.3[-0.6 ; -0.002] |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | / | / | / | -0.3[-0.6 ; 0.01] |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | / | / | / | -0.3[-0.6 ; 0.004] |
| Areas belonging to urban units of more than 100,000 inhabitants  | / | / | / | -0.3[-0.9 ; -0.002] |
| **Metropolitan France** | **/** | **/** | **/** | **-0.3****[-0.9 ; -0.008]** |

# Supplementary Table 2. Reductions in PM10 and NO2 and short-term impact on mortality in metropolitan France from March 16 to June 22, 2020 using the daily mean differences with the surface-weighted concentrations [95% CI]

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | **PM10** | **NO2** |
|  | **Study areas** | **Number of avoided deaths** | **Percentage of mortality over the study period (%)** | **Number of avoided deaths** | **Percentage of mortality over the study period** |
| **Strict lockdown**(March 16 to May 11, 2020) | Rural areas(< 2,000 inhabitants) | 13[6 ; 21] | 0.07 | 41[22 ; 60] | 0.2 |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | 12[5 ; 19] | 0.07 | 43[23 ; 63] | 0.2 |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | 9[4 ; 14] | 0.07 | 35[18 ; 51] | 0.3 |
| Areas belonging to urban units of more than 100,000 inhabitants  | 27[11 ; 43] | 0.09 | 124[66 ; 182] | 0.4 |
| **Metropolitan France** | **61****[26 ; 97]** | **0.08** | **243****[130 ; 356]** | **0.3** |
| **Gradual lifting**(May 11 to June 22, 2020) | Rural areas(< 2,000 inhabitants) | 2[0 ; 3] | 0.01 | 6[2 ; 9] | 0.04 |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | 2[0 ; 3] | 0.01 | 6[3 ; 9] | 0.1 |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | 1[0 ; 2] | 0.01 | 5[2 ; 8] | 0.1 |
| Areas belonging to urban units of more than 100,000 inhabitants | 3[0 ; 6] | 0.01 | 22[9 ; 35] | 0.1 |
| **Metropolitan France** | **8****[1 ; 14]** | **0.01** | **39****[17 ; 61]** | **0.1** |
| **Total period**(March 16 to June 22, 2020) | Rural areas(< 2,000 inhabitants) | 15[6 ; 24] | 0.04 | 47[24 ; 69] | 0.1 |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | 14[5 ; 22] | 0.04 | 49[25 ; 72] | 0.2 |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | 10[4 ; 16] | 0.04 | 40[21 ; 59] | 0.2 |
| Areas belonging to urban units of more than 100,000 inhabitants  | 31[11 ; 49] | 0.05 | 147[76 ; 217] | 0.3 |
| **Metropolitan France**  | **69****[27 ; 111]** | **0.05** | **282****[146 ; 418]** | **0.2** |

# Supplementary Table 3. Reductions in PM2.5 and NO2 and long-term impact on mortality in metropolitan France from July 1, 2019 to June 30, 2020 using the annual mean differences with the surface-weighted concentrations [95% CI]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Study areas** | **Number of avoided deaths** | **Percentage of annual mortality (%)**  | **Average gain in life expectancy at 30 (days)** | **Total number of years of life gained** |
| **PM2.5** | Rural areas(< 2,000 inhabitants) | 507[177 ; 811] | 0.39 | 12[4 ; 18] | 4,884[1,705 ; 7,798] |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | 461[161 ; 737] | 0.39 | 11[4 ; 18] | 3,607[1,259 ; 5,760] |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | 324[113 ; 518] | 0.37 | 12[4 ; 19] | 3,080[1,075 ; 4,919] |
| Areas belonging to urban units of more than 100,000 inhabitants  | 982[342 ; 1,571] | 0.45 | 14[5 ; 23] | 16,244[5,670 ; 25,937] |
| **Metropolitan France** | **2,275****[793 ; 3,637]** | **0.41** | **13****[5 ; 21]** | **27,815****[9,709 ; 44,414]** |
| **NO2** | Rural areas(< 2,000 inhabitants) | 150[52 ; 239] | 0.11 | 4[1 ; 6] | 1,489[522 ; 2,380] |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | 155[54 ; 248] | 0.13 | 4[1 ; 6] | 1,286[451 ; 2,380] |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | 126[44 ; 201] | 0.15 | 5[2 ; 7] | 1,231[431 ; 1,966] |
| Areas belonging to urban units of more than 100,000 inhabitants  | 461[161 ; 736] | 0.21 | 6[2 ; 10] | 7,272[2,548 ; 11,619] |
| **Metropolitan France** | **891****[312 ; 1,425]** | **0.16** | **5****[2 ; 8]** | **11,278****[3,956 ; 18,020]** |

# Supplementary Table 4. Influence of CRFs and reference values choices on the total burden of air pollution on mortality [95% CI]

|  |  |  |  |
| --- | --- | --- | --- |
| **CRFs** | **Reference values (μg.m-3)** | **Number of attributable deaths** | **Percentage of annual mortality (%)** |
| **1.15****[1.05 ; 1.25]** **(a)** | **5** | 39,541[14,160 ; 61,690] | 7.1 |
| **2.5** | 57,382[20,766 ; 88,680] | 10.3 |
| **0** | 74,610[27,293 ; 114,205] | 13.3 |
| **1.06****[1.04 ; 1.08]****(b)** | **5** | 16,866[11,413 ; 22,159]  | 3.0 |
| **2.5** | 24,707[16,757 ; 32,392] | 4.4 |
| **0** | 32,436[22,049 ; 42,429] | 5.8 |
| **1.07****[1.03 ; 1.11]****(c)** | **5** | 19,532[8,625 ; 29,819] | 3.5 |
| **2.5** | 28,582[12,678 ; 43,449] | 5.1 |
| **0** | 37,480[16,701 ; 56,729] | 6.7 |

# (a) Pascal, M., de Crouy Chanel, P., Wagner, V., Corso, M., Tillier, C., Bentayeb, M.,. et al. (2016). The mortality impacts of fine particles in France. *Sci. Total Environ*. 571:416-25. doi: 10.1016/j.scitotenv.2016.06.213.

# (b) WHO. (2013). “Health risks of air pollution in Europe - HRAPIE project - Recommandations for concentration-response functions for cost-benefits analysis of particulate matter, ozone and nitrogen dioxide”. (Copenhagen, Denmark: WHO Regional office for Europ.

# (c) Chen, J., and Hoek, G. (2020). Long-term exposure to PM and all-cause and cause-specific mortality: A systematic review and meta-analysis. *Environ. Int..* 143, 105974. doi: 10.1016/j.envint.2020.105974.

# Supplementary Table 5. Daily mean differences [min; max] using historical references by period and area in France from March 16 to June 22, 2020

We calculated the daily differences between the concentrations observed during the lockdown (from March 16 to June 22, 2020) and the daily average concentrations from March 16 to June 22, 2017-2019.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | **Strict lockdown**(March 16 to May 11, 2020) | **Gradual lifting**(May 11 to June 22, 2020) | **Total period**(March 16 to June 22, 2020) |
| **PM10 (µg.m-3)** | Rural areas(< 2,000 inhabitants) | 1.1[-3.3 ; 4.6] | -1.9[-7.0 ; 0.9] | -0.2[-4.8 ; 2.4] |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | 1.0[-3.1 ; 4.5] | -2.3[-7.0 ; 0.7] | -0.4[-4.6 ; 2.3] |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | 1.0[-3.0 ; 4.1] | -2.3[-7.5 ; 0.4] | -0.5[-4.6 ; 2.5] |
| Areas belonging to urban units of more than 100,000 inhabitants | 0.5[-3.8 ; 4.8] | -3.0[-7.6 ; 0.2] | -1.1[-5.4 ; 2.1] |
| **Metropolitan France** | **1.1****[-3.8 ; 4.8]** | **-2.0****[-7.6 ; 0.9]** | **-0.3****[-5.4 ; 2.5]** |
| **NO2 (µg.m-3)** | Rural areas(< 2,000 inhabitants) | -4.1[-9.7 ; -1.2] | -1.4[-6.0 ; 0.1] | -3.0[-7.7 ; -0.8] |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | -4.3[-9.5 ; -1.2] | -1.8[-7.9 ; 0.1] | -3.2[-7.6 ; -0.8] |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | -4.7[-8.8 ; -1.4] | -2.0[-5.5 ; -0.2] | -3.5[-7.3 ; -1.0] |
| Areas belonging to urban units of more than 100,000 inhabitants | -6.5[-15.8 ; -1.9] | -3.3[-11.4 ; -0.2] | -5.1[-13.8 ; -1.2] |
| **Metropolitan France** | **-4.3****[-15.8 ; -1.2]** | **-1.6****[-11.4 ; 0.1]** | **-3.1****[-13.8 ; -0.8]** |

# Supplementary Table 6. Average of daily differences [min; max] using historical references by quarter and area in France from July 1, 2019 to June 30, 2020

We calculated the daily differences between the concentrations observed from July 1, 2019 to June 30, 2020 and the daily average concentrations from July 1, 2016 to June 30, 2019.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | **3rd quarter 2019** | **4rd quarter 2019** | **1st quarter 2020** | **4th quarter 2020** | **Annual**(july 2019 to june 2020) |
| **PM2.5 (µg.m-3)** | Rural areas(< 2,000 inhabitants) | -0.8[-3.2 ; 0.8] | -3.4[-7.4 ; -1.0] | -2.8[-7.1 ; 2.2] | -1.1[-3.3 ; 0.7] | -2.0[-4.2 ; -0.07] |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | -0.8[-3.1 ; 1.0] | -3.5[-7.1 ; -1.1] | -2.9[-7.0 ; 2.4] | -1.2[-3.2 ; 0.8] | -2.1[-4.1 ; 0.09] |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | -0.9[-3.2 ; 0.9] | -3.6[-7.0 ; -1.0] | -3.0[-7.0 ; 2.5] | -1.2[-3.1 ; 0.8] | -2.1[-4.0 ; 0.2] |
| Areas belonging to urban units of more than 100,000 inhabitants | -1.1[-3.4 ; 1.4] | -4.1[-7.1 ; -0.9] | -3.6[-7.7 ; 1.4] | -1.5[-3.4 ; 0.9] | -2.6[-4.5 ; -0.3] |
| **Metropolitan France** | **-0.8****[-3.4 ; 1.4]** | **-3.5****[-7.4 ; -0.9]** | **-2.8****[-7.7 ; 2.5]** | **-1.1****[-3.4 ; 0.9]** | **-2.1****[-4.5 ; 0.2]** |
| **NO2 (µg.m-3)** | Rural areas(< 2,000 inhabitants) | -1.0[-4.3 ; 1.6] | -4.2[-9.4 ; -0.6] | -4.1[-9.7 ; -0.5] | -2.4[-6.4 ; -0.6] | -2.9[-6.7 ; -1.3] |
| Areas belonging to urban units of 2,000 to 20,000 inhabitants | -1.2[-9.3 ; 3.2] | -4.4[-9.9 ; 0.3] | -4.2[-9.4 ; 0.05] | -2.7[-6.6 ; -0.7] | -3.1[-7.4 ; 0.01] |
| Areas belonging to urban units of 20,000 to 100,000 inhabitants | -1.1[-4.4 ; 1.4] | -4.4[-9.3 ; -1.4] | -4.5[-8.7 ; 0.2] | -3.0[-6.4 ; -0.9] | -3.2[-6.1 ; -1.4] |
| Areas belonging to urban units of more than 100,000 inhabitants | -1.9[-11.0 ; 1.5] | -5.4[-15.2 ; -0.9] | -5.9[-14.3 ; 0.4] | -4.4[-13.4 ; -1.1] | -4.4[-13.2 ; -0.8] |
| **Metropolitan France** | **-1.1****[-11.0 ; 3.2]** | **-4.3** **[-15.2 ; 0.3]** | **-4.2****[-14.3 ; 0.4]** | **-2.6****[-13.4 ; -0.6]** | **-3.0****[-13.2 ; 0.01]** |