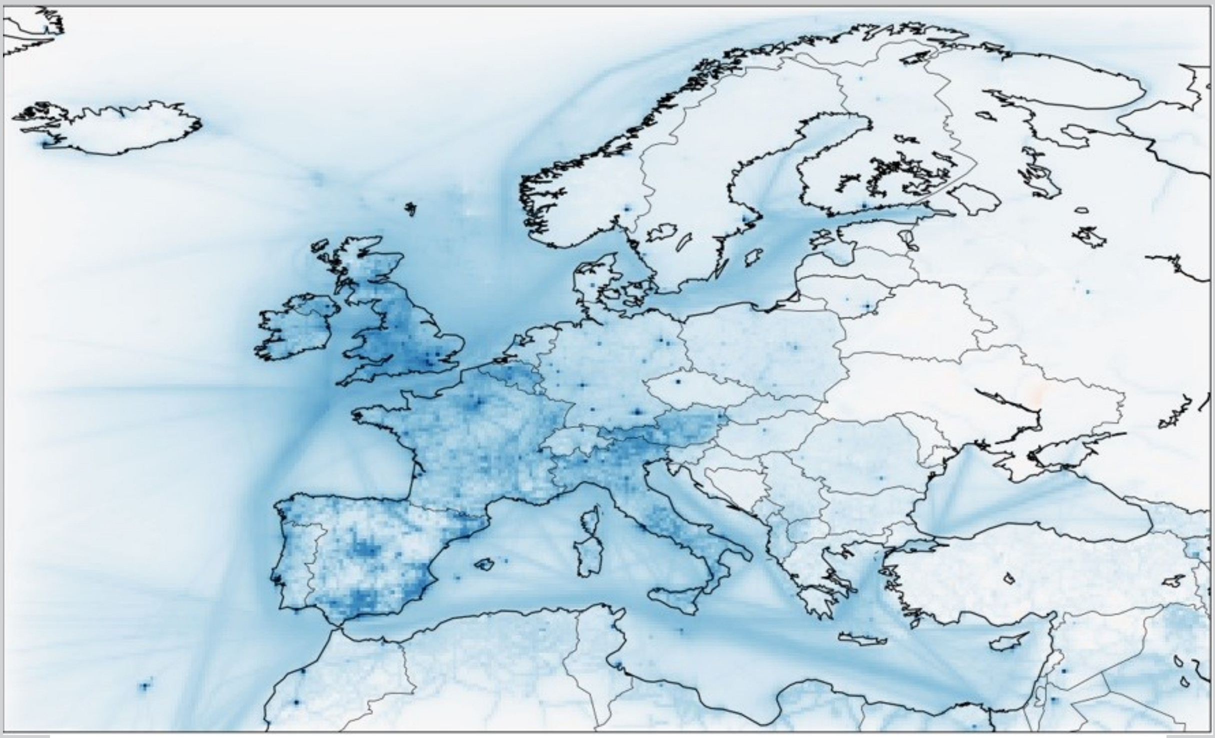
Eionet Report - ETC/ATNI 2021/16

# The Covid-19 pandemic and environmental stressors in Europe: synergies and interplays

April 2022



Estimated decrease in annual concentration of $NO_2$ due to lockdown measures (dark blue=25 %, white=0 %)

Authors:

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## Contents

## Summary

The restrictions imposed by governments in order to prevent the spreading of the SARS-CoV-2 virus in the population changed individual behaviour and all society. This unfortunate « natural experiment » may also provide insight into how our natural environment can change with such disruptive changes.

An initial analysis of impacts of the pandemic-related restrictions on air quality, based on data for the first months of 2020, was presented in the EEA Air quality report for 2020. Since then, longer time series of data are available and more analyses were published. The aim of this study is to expand on the analysis by including this new data and information for Europe, to include more pollutants and also to consider other related elements that are important to human health and wellbeing, namely, noise, air emission pressures, or urban environments.

Therefore, this report provides an overview of the potential impacts of Covid-19 restrictions, in particular, focusing on review and assessment of Covid-19 impacts on air quality, compliance with the National Emission reductions Commitments (NEC) Directive, noise, and the findings on identified changes in urban policies derived from lessons-learnt from the restrictions.

The air quality modelling is done by complementary approaches:

- The AirGAM is a sophisticated statistical model originally developed for trend analyses by ETC/ACM and ETC/ATNI. It analyses air quality monitoring data from Europe, and identifies trends and changes in concentrations.
- The Chimere chemical transport model is a European-wide model that allows prediction of air concentrations of both primary and secondary pollutants in relation to emission inventories. Emission inventories used were developed for two scenarios ("business as usual" and "lockdown").

The two modelling methods were already used for the short-term analysis of developments in nitrogen dioxide ($NO_2$) and particulate matter ($PM_{10}$) on data from March 2020 - April 2020, and are here used to generate results for the full year 2020 and for additional pollutants ($PM_{2.5}$ and ozone).

These original modelling studies are complemented by a case study using simple statistical analysis on $NO_2$ data from paired traffic and urban background monitoring stations in the Czech Republic, and by literature review of European studies on air quality developments during the periods with restriction measures, published before end November 2021.

The noise analysis is based on a literature review of papers published until June 2021.

As an important complement we also analyse a possible impact of the restriction measures on future compliance with the Directive (EU) (2016/2284/EU) on National Emission Reduction Commitments, which will have consequences for European air quality. The analysis is based in policies and measures reported by the countries in 2021 (covering the base year 2019).

Short-term analyses, available literature for air pollutants and noise clearly show that at the beginning of the restriction measures, in February 2020 - May 2020, there was a significant decrease in traffic-related pollutant levels. This is demonstrated for nitrogen dioxide ($NO_2$) and carbon oxides (CO), and for traffic-related noise. The same development is observed in the whole of Europe. A similar but much weaker pattern is seen for particulate matter (PM). As the period in question is part of the heating season in most European countries, the traffic reduction impact on PM concentratoins was most likely offset by increased local heating. This is attributed (at least partly) to restrictions that included working from home or other measures keeping the inhabitants in their homes. For secondary pollutants, i.e., ozone ($O_3$) and partly $PM_{2.5}$, such analysis is more difficult, but the results clearly indicate changes in atmospheric chemistry in urban areas leading to significant increase of $O_3$ levels.

Longer-term analyses were performed for the whole year 2020. The results show a less pronounced effects of the restrictions however similar tendencies and significant reductions of traffic-related pollutant $NO_2$. For both $NO_2$ and PM, a larger reduction is seen at traffic sites compared to rural and suburban/urban background sites, but the differences among the station types are not very large. The smaller size of the effect is due to an averaging effect: the restrictions were first imposed near simultaneously in all countries in the period covered by the shorter-term studies, and then gradually lifted and in varying degrees further imposed towards the end of the year. In most countries, the most stringent restrictions were implemented during March 2020 and were fully in place through April and parts of May of the same year. After that, the situation across Europe is more varied. This development is well captured by the stringency index for each country, which is used as one of the variables in the analyses.

For annual mean, the largest impact of Covid-19 related restrictions was found for $NO_2$ concentrations in 2020, especially for the countries that were strongly affected by the first wave of the restrictions. For the 10 EU27 countries where the impact is largest, the reduction is more than 10 % in both modelling approaches on European level. 11 % of the traffic stations considered in the study would have reported exceedance of the annual limit value for $NO_2$ if there had not been any Covid-19 restrictions in 2020. For the annual mean of $PM_{10}$, $PM_{2.5}$ and MDA8 $O_3$ a reduction is also found, but only of the order of 4-5 %.

Limited decreases for $PM_{10}$ and $PM_{2.5}$ annual concentrations, and for some ozone metrics, such as SOMO10 and the annual average of $O_3$ MDA8 (maximum daily running 8-h average), are estimated due to restrictions. For all these metrics, reductions are from below 1 % to below 5 %. These limited decreases are due to the ambivalent impact of restriction measures: traffic reductions lower NOx level which can increase or reduce $O_3$ depending on the days and locations. For PM, increases in residential heating can also compensate reductions in other sectors.

For $PM_{10}$ and $PM_{2.5}$, we estimate that 2 and 4 sites, respectively, dropped below the limit value in 2020 due the effects of the pandemic, whereas for $NO_2$ 11 % of the stations considered in the study fell below the limit value. Compared to the clear signal in $NO_2$ levels, very small changes are seen in PM data indicating that the air concentration of PM is dominated by other sources than road traffic. When averaged over individual countries, very good agreement between predicted and observed daily PM levels through 2020 are found both at rural, suburban/urban and traffic sites. This is a strong argument that restriction measures in Europe in 2020 had a very small impact on the atmospheric levels of $PM_{10}$ and $PM_{2.5}$.
The results regarding air quality are robust, and consistent also with literature. They are obtained by a wealth of methods, ranging from simple statistical approaches that do not require extensive sophisticated input data, to the most complex modelling that includes data from all available sources and observing platforms and uses advanced statistical and chemical transport modelling that requires multiple inputs on meteorology, air emissions and air quality observations.

An important factor in air quality management is compliance with the Directive (EU) 2016/2284 (NECD). In 2021, 19 Member States have been identified as being at risk of non-compliance with at least one of their 2030 NECD targets, using a base year of 2019. Of these, 12 reported additional measures which were analyzed for potential impacts due to the recovery after the Covid-19 pandemic. Additional measures related to emissions of $NH_3$ are expected to be impacted to the greatest extent, and four Member States (Estonia, Hungary, Luxemburg, and Slovakia) may be at greater risk of non-compliance with their $NH_3$ targets, since the travel restrictions and worker sickness caused by the Covid-19 might affect to a greater extent the agriculture sector.

Noise related to road traffic appears to have broadly similar development as for air quality, with decreases there where there was a decrease in traffic, and with some increases that can be explained by traffic increase. The studies considered in literature review address road traffic noise, and to minor extent, airport and port noise. They indicate a decrease in noise levels during the first restriction period

(March-June 2020), together with a possible reduction in the size of population exposed. The review has also led to proposing a possible assessment framework of Covid-19 mitigation strategies and noise.

Recognizing the importance of cities both for pollution pressures and for pollution governance, we have also reviewed literature that directly addresses the options cities have taken to reduce the spreading of the Covid-19 pandemics. The fragmentation of findings which are broadly consistent with the findings on air quality and noise, points to the need to develop an integrated assessment framework to capture the interplay of the most important factors and developments.

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## Acronyms and terms

| Acronym/term | Definition |
|---|---|
| 4DMA8 | The 4th highest 8-hour daily maximum $O_3$ concentration over the year, a metric representative of peak $O_3$ concentrations |
| ACTRIS | The Aerosol, Clouds and Trace Gases Research Infrastructure, part of the European Research Infrastructures, www.actris.eu |
| AirGAM | air quality trend and prediction model developed by ETC/ACM and ETC/ATNI over the years 2017-2021 |
| AOT40 | Accumulated exposure to ozone over a threshold value of 40 ppb (=80 µg/m$^3$). It represents the sum of the differences between hourly concentrations above 80 µg/m$^3$ and 80 µg/m$^3$ accumulated between 8:00 and 20:00 CET. |
| BAU | Business as Usual –A scenario for future patterns of activity which assumes that there will be no major changes in technology, economics, or policies, so that normal circumstances can be expected to continue unchanged. |
| BC | Black carbon |
| BSC | Barcelona Supercomputing Centre, www.bsc.es |
| CAMS | Copernicus Atmospheric Monitoring Services |
| CHIMERE | An open source multi-scale chemistry-transport model for atmospheric composition analysis and forecast, https://www.lmd.polytechnique.fr/chimere/ |
| CNRS | French National Council for Scientific Research |
| CO | Carbon monoxide, air pollutant mainly associated with combustion sources |
| Covid-19 | An infectious disease caused by the SARS-CoV-2 virus, the respiratory illness responsible for the Covid-19 pandemic delared by WHO as a global public health emergency on January 31, 2020. |
| ECMWF | European Centre for Medium-range Weather Forecasts |
| EMEP | Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (inofficially 'European Monitoring and Evaluation Programme' = EMEP), a scientifically based and policy driven programme under the Convention on Long-range Transboundary Air Pollution (CLRTAP) for international co-operation to solve transboundary air pollution problems. |
| ETC/ACM | European Topic Centre on Air Pollution and Climate Change, 2012-2018 |
| ETC/ATNI | European Topic Centre on Air pollution, Transport, Noise and Industrial pollution, 2019-2021 |
| ETC/CCA | European Topic Centre on European Topic Centre on Climate Change impacts, vulnerability and Adaptation, 2014-2018 |
| EU | European Union |
| IFS | Integrated Forecasting System |
| INERIS | French National Institute for Industrial Environment and Risks |
| MDA8 | Maximum daily running 8-h average |
| NECD | Directive (EU) (2016/2284/EU) on National Emission Reduction Commitments |
| $NH_3$ | Ammonia, an air pollutant mainly originating in relation to agricultural activities and biomass decay/burning |
| NMVOC | Non-methane volatile organic compounds, a group of air pollutants with very diverse sources |
| $NO_2$ | Nitrogen dioxide, an air pollutant mainly associated with vehicular transport |
| $NO_x$ | Nitrogen oxides, sum of nitrogen monoxide and nitrogen dioxide |
| $O_3$ | Ozone, a secondary air pollutant formed in the atmosphere |
| OxCGRT | Oxford Covid-19 Government Response Tracker |

| Acronym/term | Definition |
|---|---|
| PaMs | Air pollution policies and measures |
| PM | Particulate matter |
| $PM_{10}$ | A fraction of particulate matter, inhalable particles with a diameter of 10 micrometers and smaller |
| $PM_{2.5}$ | A fraction of particulate matter, inhalable particles with a diameter of 2.5 micrometers and smaller |
| PPB | Parts per billion |
| restrictions | In this report used to designate measures restricting the behaviour of inhabitants, implemented by (any level) authorities in relation to the Covid-19 pandemics, as for instance, lockdowns or quarantines. |
| SARS-CoV-2 | Severe acute respiratory syndrome coronavirus 2 |
| SOA | Secondary organic aerosol |
| SOMO10 | An indicator for health impact assessment recommended by WHO. Sum of the differences between maximum daily 8-hour running mean concentrations greater than 20 $\mu g/m^3$ (= 10 parts per billion) and 20 $\mu g/m^3$ |
| SOMO35 | It is the yearly sum of the daily maximum of 8-hour running average over 35 ppb (=70 $\mu g/m^3$). For each day the maximum of the running 8-hours average for $O_3$ is selected and the values over 35 ppb are summed over the whole year. |
| TNO | TNO, the Netherlands Organisation for applied scientific research, www.tno.nl |
| UNECE | United Nations Economic Commission for Europe |
| WAM | Emission scenario “With additional measures” |
| WM | Emission scenario “Without measures” |

# 1 Introduction

Starting the end of 2019, the novel SARS-CoV-2 coronavirus pandemic has brought about disruptive changes in our society. The restrictions imposed by governments in order to protect the population from the virus have led to changes to our daily lives that affected individual behaviour and all society, businesses and public sphere. While the pandemic has taken many lives and has led to significant human suffering, this unfortunate « natural experiment » may also provide data leading to insight into how our natural environment can be altered with disruptive changes to our human activities. Disruptive changes may be required in order to achieve the ambitious goals of the European Green Deal (EC, 2019) and the Zero Pollution Action Plan (EC, 2021).

Following the restrictions implemented by countries, pressures on the environment changed, and there were significant increased demands for some ecosystem services such as those provided by urban green areas. Some of these developments have already been studied, most importantly, air quality.

In 2020, EEA (in collaboration with ETC/ATNI and CAMS) included in the Air quality in Europe – 2020 report (EEA, 2020) a first analysis of the impacts of the restriction measures on air quality and a first overview of observed interrelationships between air quality and the health effects of the pandemic . This work, based on literature available at the time of the analysis and on assessment of air quality data for a limited period of time (February-April), has provided a first indication of the situation, and has concluded that for NOx, an overall significant reduction was observed in Europe, for PM the situation was more complex – while in most geographic areas there were significant reductions in concentrations, in other areas, an increase was observed.

Air concentrations and noise exposure respond immediately to changes in environmental stressors (e.g., emissions), but while the relation is immediate, it is not simple. Methodological approaches such as modelling allow an assessment, but they rely on input data including data on air emissions. Emission data are calculated based on statistical data, which typically become available in the year following the actual emission year.. Therefore, taking into account these initial statistical data for 2020, in the year 2021 (one year after the first EEA analysis), a wider analysis is possible, as we will show in this report.

This report expands the analysis of restriction measures done by EEA (2020) which addressed $NO_2$ and $PM_{10}$ and was based on comparison of the March 2020 - April 2020 restriction period compared to similar periods of 2015-2019. In this report, the impacts of restrictions related to the measures affecting air quality are based modeling studies on data for the whole of 2010 (compared to the years 2015-2019), and includes $NO_2$, $PM_{10}$, $PM_{2.5}$ and $O_3$. This is comlemented by assessment of future compliance with the National Emissions Ceiling Directive (EU) 2016/2284 (EU, 2016), and by literature reviews on air quality, noise and urban sustainability resp. urban planning. The overall aim is to bring together the first lessons learnt from the restriction periods, to inform potential future measures to improve air quality and noise levels and thus to . support achieving the ambitious goals of the European Zero Pollution Action Plan (EC, 2021).

In Chapter 2, we present two original Europe-wide studies on the relationship between the air quality and the Covid-19 related restrictions, one based on monitoring data, and one study based on chemical transport modeling using emission inventories developed for the studied period. Chapter 3 supplements these analyses with a simplified approach implemented in Czechia, which indicates how a simplified analysis of local data can be done. Chapter 4 looks in detail on countries' policies and measures to reduce air pollution, in the framework of the Directive (EU) 2016/2284 (EU, 2016). Noise as an environmental pressure and how the restrictions have affected it are summarized in Chapter 5. Chapter 6 supplements the above original analyses by two literature reviews, one on European studies on air quality published until November 2021, and a short complementary information on urban sustainability and urban planning as determinants of environmental pressures.

# 2 Developments in air quality under Covid-19 restrictions

In this chapter we assess the impact on air quality of restrictions implemented in order to prevent the spread of Covid-19 in Europe during 2020. Those restrictions induced a decrease of activity in several economic sectors (such as transport) and subsequent decrease in the related emissions; while for other sectors activity was unchanged or even increased. We combine two approaches: one based on statistical analysis of observed concentrations (monitoring data), and one based in chemical transport modelling.

The statistical AirGAM model (Walker et al., forthcoming) was originally developed for trend studies for EEA (ETC/ACM 2018; ETC/ACM 2019; ETC/ATNI 2020); but proved useful also for estimating the effect of the pandemic restriction measures in 2020 on the level of air pollutants (EEA 2020; Solberg et al. 2021).

The assessment of this impact also relies on the air quality model CHIMERE (v2020) (Menut et al. 2021). In order to quantify the change in pollution levels due to emissions changes because of the restriction measures, two different model simulations have been realized. The first simulation corresponds to a 'business as usual' (BAU) scenario for the year 2020 (Kuenen et al., 2021) which estimates emissions for the year 2020 based on the extrapolation of 2000-2018 emissions assuming that no lock-down restrictions happened. The second simulation is based on the ‘lockdown’ scenario using 2020 BAU emission data combined with specific Covid-19 reduction factors which are taking into account lock-down restrictions implemented by individual countries in Europe during 2020 (Guevara et al., forthcoming).

The two modelling approaches are complementary. The AirGAM is particularly suited and efficient to capture the impact of meteorological factors on air quality. Air quality models such as Chimere are designed to compute the ambient concentrations resulting from emissions changes (and other factors). In the present chapter, we take stock of this complementarity to discuss the robustness of our conclusions on the main impact of the 2020 restriction periods on air quality in Europe.

Key messages:

- The largest impact of Covid-19 related restrictions was found for annual mean $NO_2$ concentrations for 2020, especially for the countries that were strongly affected by the first wave of the restrictions. For the 10 EU27 countries where the impact is largest, the range of reduction is 13-19% in the AirGAM model, and 10-13.5% in the CHIMERE model.
- 11 % of the traffic stations considered in the study would have reported exceedance of the annual limit value for $NO_2$ if there had not been any Covid-19 restrictions in 2020, according to the AirGAM results.
- Limited decreases for $PM_{10}$ and $PM_{2.5}$ annual concentrations, for SOMO10 and the annual average of $O_3$ MDA8 (maximum daily running 8-h average) are estimated due to restrictions. For all these metrics, reductions are below 5% in the AirGAM model, or even below 1 % in CHIMERE. These limited decreases are due to the ambivalent impact of restriction measures: traffic reductions lower NOx level which can increase or reduce ozone depending on the days and locations. For PM, increases in residential heating can also compensate reductions in other sectors.
- Larger median reductions over EU27 were found for other ozone metrics: 8% for SOMO35 in the AirGAM, and 10% AOT40 in CHIMERE.

## 2.1 Impact of Covid-19 related restrictions on European air pollutant levels as calculated with the AirGAM statistical model

### *2.1.1 Overall findings for $NO_2$, $PM_{10}$, $PM_{2.5}$ and $O_3$*

AirGAM involves a statistical modelling approach based on generalized additive models and has been developed during the last years through various EEA tasks, originally aimed for long-term trend studies (ETC/ATNI, 2019; ETC/ACM, 2018; ETC/ACM, 2017). In 2020, the preliminary results with AirGAM were applied to the first restriction period (April) and presented in the Air Quality in Europe - 2020 Report (EEA, 2020).

The AirGAM model is designed to find relationships between various meteorological parameters and temporal metrics (day of week, season, long-term trend) on the one hand and the observed level of pollutants on the other. For details of the AirGAM model the reader is referred to other publications (ETC/ACM 2018; ETC/ACM 2019; ETC/ATNI 2020; Solberg et al. 2021). The main concept is that the response variable (the measured concentration or the logarithm of this value) is linked to a number of explanatory variables through a non-linear regression method where the relations are smooth functions and not constants as in the more common linear multiple regression methods. The meteorological parameters (temperature, relative humidity, absolute humidity, wind speed, wind direction, mixing height, cloud cover and precipitation) and the temporal metrics were used as explanatory variables. All calculations are performed on daily data, i.e. daily average concentrations of $NO_2$, $PM_{10}$ and $PM_{2.5}$ and MDA8 (maximum daily running 8-h concentrations) for $O_3$. At present AirGAM does not capture hourly data, so that it is not yet possible to compute indicators based on hourly concentrations, such as AOT40 for instance.

In the present study, the model was first trained on measurement data from monitoring stations during 2015–2019 and then applied to the same stations in 2020, providing predictions of expected concentrations in the absence of a restrictions but considering the actual meteorology of the year 2020. The difference between the modelled levels (the expected) and the actual measurements from 2020 was used to calculate the impact of the restriction measures adjusted for confounding effects, such as daily meteorology and a long-term temporal trend aimed to capture the gradual change in emissions and background concentrations.

In this work, the whole year 2020 was analyzed, as compared to previous studies looking into the periods with strongest restrictions only. The effect of the measures during the pandemic, when averaged over the whole year, will thus be substantially smaller than what was seen during e.g. April 2020 since the measures were gradually relaxed after the first restriction period. After the initial restriction measures in March-April 2020, individual countries introduced subsequent restriction periods throughout 2020,.

The following section presents the estimated effects of the restriction measures in 2020 for $NO_2$, $PM_{10}$, $PM_{2.5}$ and ozone MDA8 based on AirGAM modelling after screening the stations for data capture and model performance. The measurement data were extracted from EEA's web service by the end of September 2021, deadline for the official submission of validated 2020 data. In this way, most of the data (including those for 2020) were validated (E1a) data. We required a daily data capture of at least 75 % for each year in the period 2015-2020. Stations lacking data in some of the years were not used. The stations were grouped into three categories based on the station type and station area in the following way:

- Rural: Rural background sites
- Suburban: Suburban and urban background sites
- Traffic: All sites with type traffic (rural, suburban, and urban)

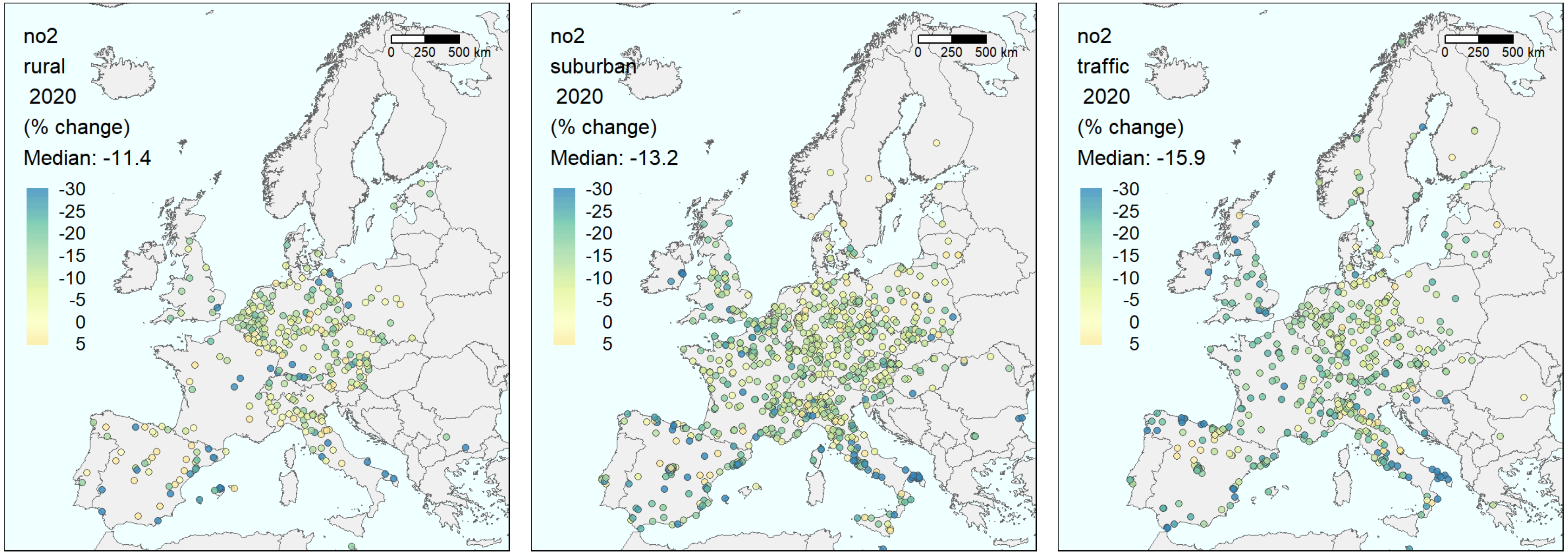
Statistical modelling can be strongly influenced by data that exhibit systematic or random features without relevance to the studied phenomena. For this reason, screening of input data was performed before the analysis. Data from industrial sites were not used as they were considered less suited in a GAM analysis due to their stronger inhomogeneity with respect to meteorological and time parameters. Furthermore, as in previous studies (Solberg et al., 2021), we applied a screening of stations based on model performance as given by the linear correlation coefficient, r. For $NO_2$ and $O_3$ we only used stations for which the correlation coefficient between daily modelled and measured data (2015-2019) was higher than 0.65. For $PM_{10}$ and $PM_{2.5}$ this criterion was relaxed to $r > 0.55$. The rationale behind this screening is further discussed in Solberg et al. (Solberg et al. 2021), and the main reasoning is that the AirGAM model fails for a certain fraction of the sites (of the order of 10-15 %).

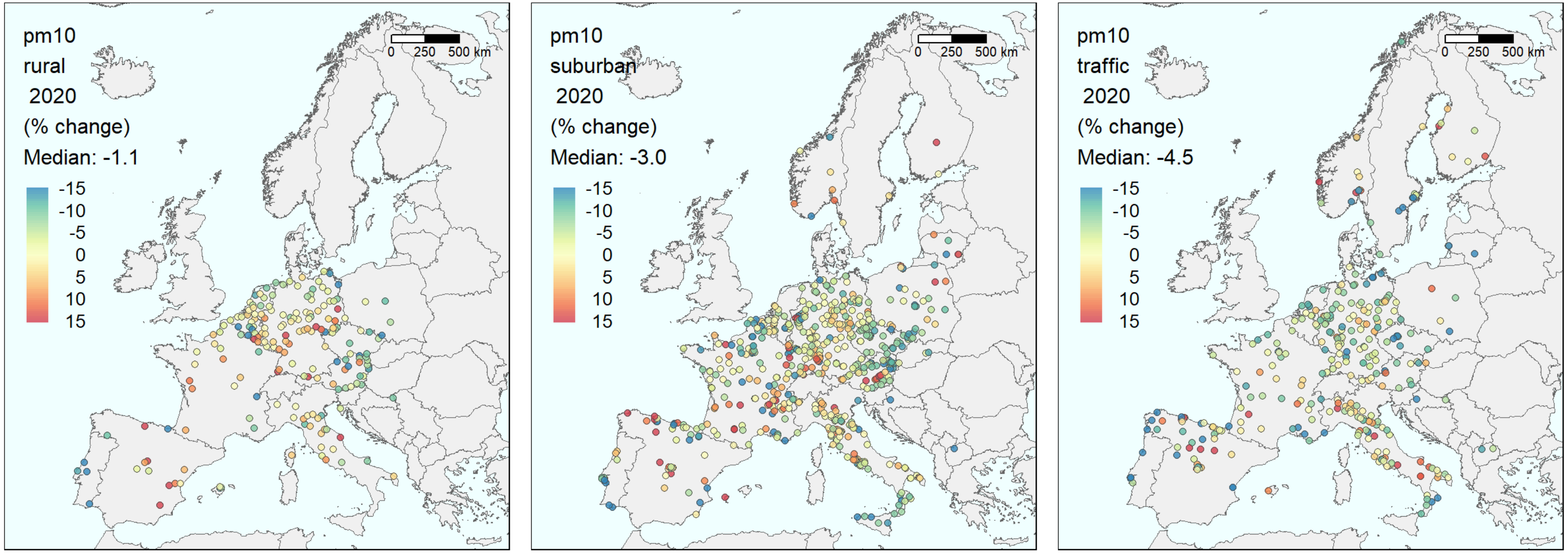
Daily modelled and measured time series during 2020 for each of the four species averaged over each country and each station type (traffic, suburban/urban background, and rural background) are given in Annex 8. These plots include confidence intervals for the daily data as well as indications of start and end of the various restriction periods for each country.

The relative difference in percentage between the observed and predicted annual mean values in 2020 for $NO_2$, $PM_{10}$, $PM_{2.5}$ and $O_3$ (annual mean of MDA8) for the three station categories is presented in Figure 2.1. For $NO_2$ a median reduction of more than 10 % relative to the predicted concentrations is found for the three station categories with the strongest signal for the traffic sites, as expected. The results indicate a higher number of sites with strong reductions in the south (Spain, Italy, France), although a mixed pattern is seen within individual countries. For $PM_{10}$ and $PM_{2.5}$ both positive and negative differences are found, and no clear geographical pattern is seen, although the median change for the three station categories is negative (1-6 % reduction). For sites in the suburban category, the $PM_{2.5}$ data indicate a larger number of stations with positive differences in France and Italy, implying an increase relative to the predicted values. The calculated median reductions in $PM_{10}$ are less than 5 % with slightly stronger negative changes for $PM_{2.5}$.

Figure 2.5 - Figure 2.7 show the percentage differences between measured and modelled annual mean statistics (annual mean for $NO_2$, $PM_{2.5}$ and $PM_{10}$ and annual mean of MDA8 for $O_3$ as well as SOMO10 and SOMO35 indicators) during 2015-2019 and in 2020 for each country, separately, as calculated by AirGAM. The mean relative differences for each country in 2020 are furthermore listed in Table 2.1.

*Figure 2.1 Difference between observed and predicted mean concentration (%) of $NO_2$, $PM_{10}$, $PM_{2.5}$, and $O_3$ in 2020 (100(obs-pred)/pred) as estimated by AirGAM for three categories of stations: i) rural background sites (left); ii) urban and suburban background (middle); iii) traffic (right). For $O_3$ the data are based on the mean of the daily max 8-h running mean*




pm10
rural
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(% change)
Median: -1.1
-15
-10
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pm10
suburban
2020
(% change)
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-15
-10
-5
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traffic
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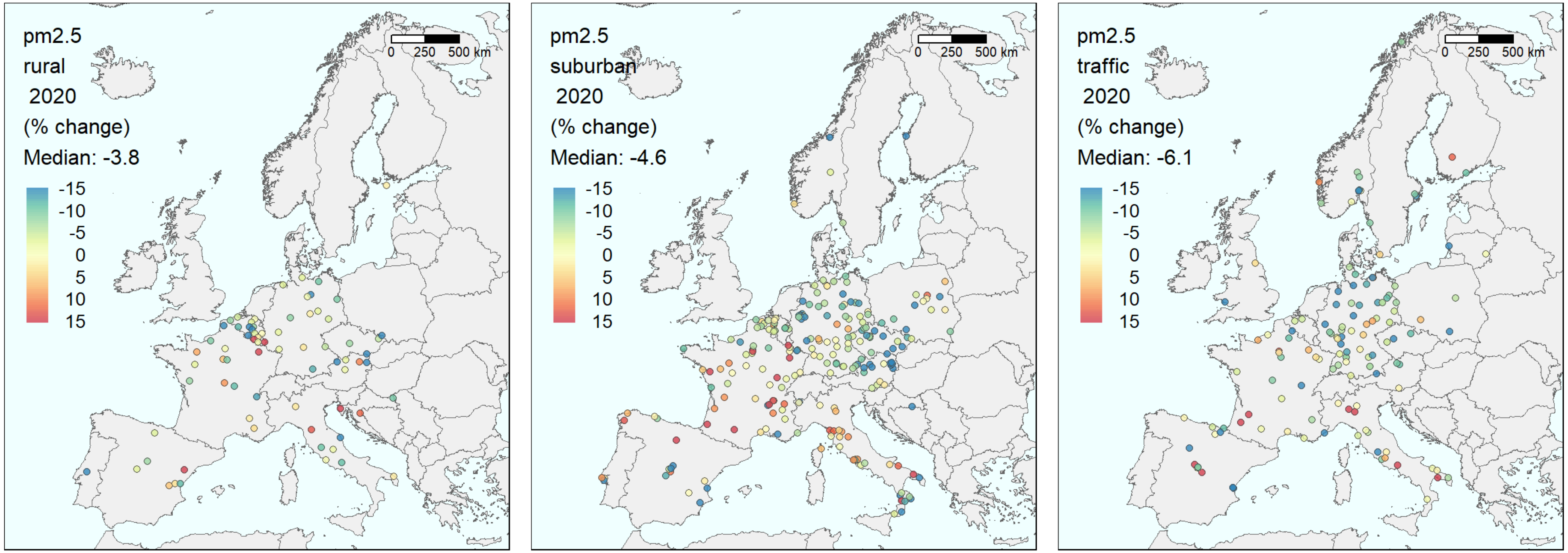
pm2.5
rural
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(% change)
Median: -3.8
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pm2.5
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Median: -4.6
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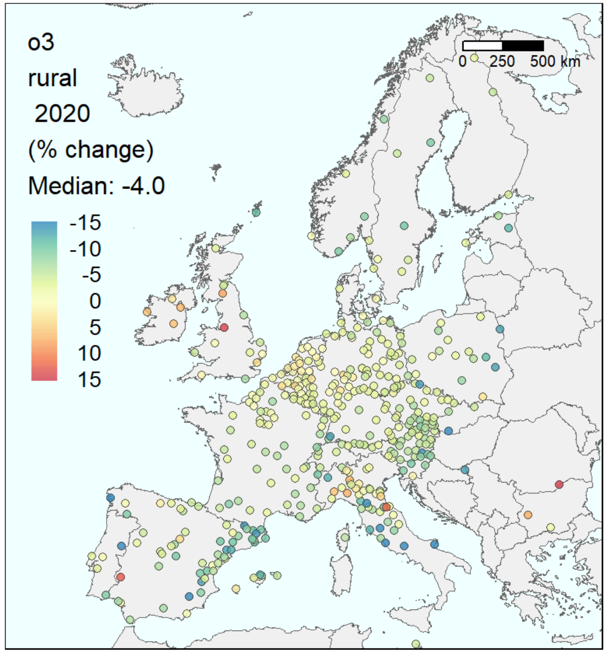
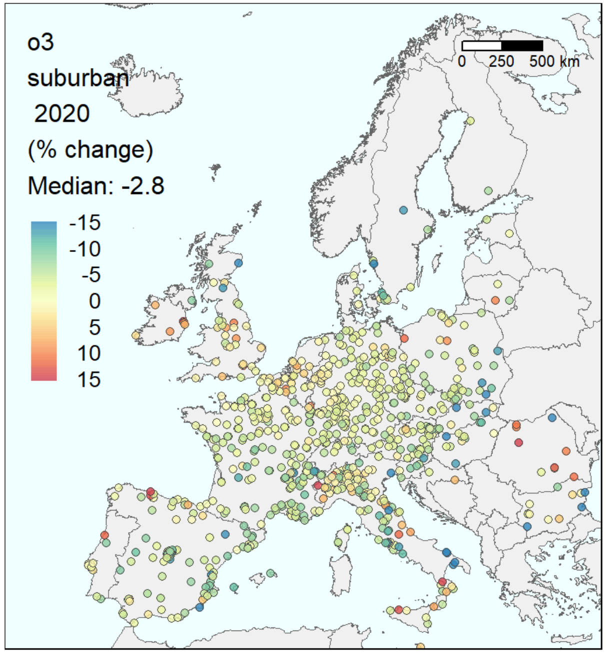
10
15
0 250 500 km
pm2.5
traffic
2020
(% change)
Median: -6.1
-15
-10
-5
0
5
10
15
0 250 500 km


o3
rural
2020
(% change)
Median: -4.0
-15
-10
-5
0
5
10
15
0 250 500 km


o3
suburban
2020
(% change)
Median: -2.8
-15
-10
-5
0
5
10
15
0 250 500 km

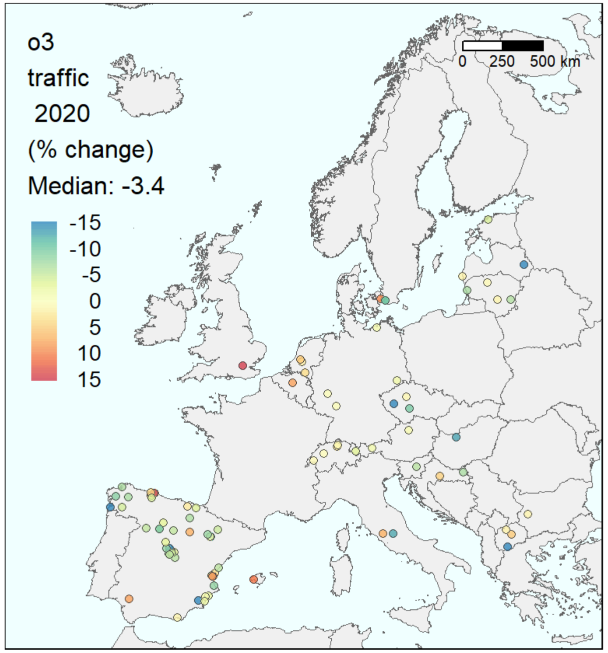

o3
traffic
2020
(% change)
Median: -3.4
-15
-10
-5
0
5
10
15
0 250 500 km

*Figure 2.2 Relative difference (percent) between measured and modelled annual mean $NO_2$ concentrations (100 x (measured-modelled)/modelled) as given by the AirGAM model for station data during 2015-2019 and 2020 for each country, separately. The boxes mark the 25 and 75 percentiles and the lines inside mark the medians. The upper whisker extends from the hinge to the highest value that is within 1.5 * IQR of the hinge, where IQR is the inter-quartile range, or distance between the first and third quartiles. The lower whisker extends from the hinge to the lowest value within 1.5 * IQR of the hinge. Data beyond the end of the whiskers are outliers and plotted as points. Only countries with at least 5 stations are shown*

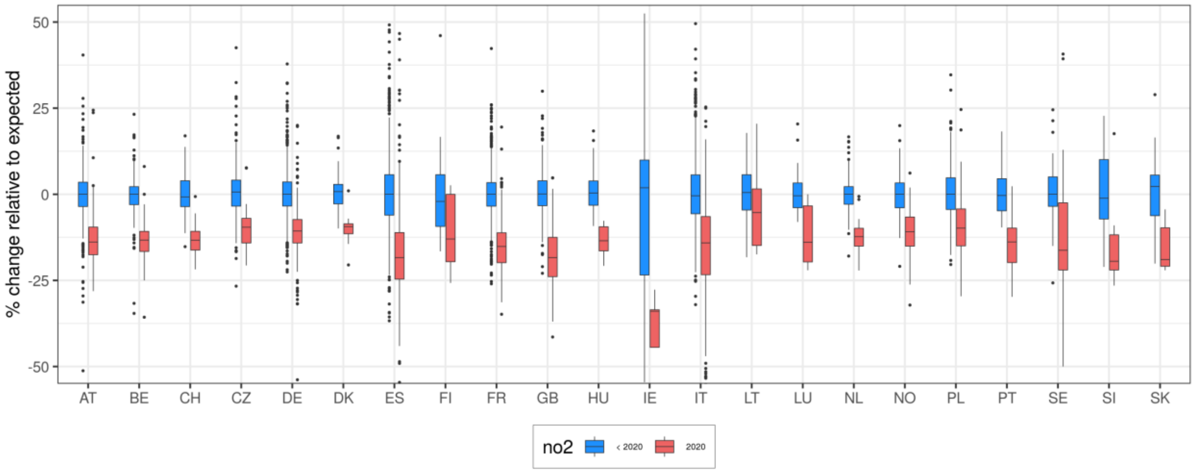



*Figure 2.3 Same as Figure 2.1 for $PM_{10}$*

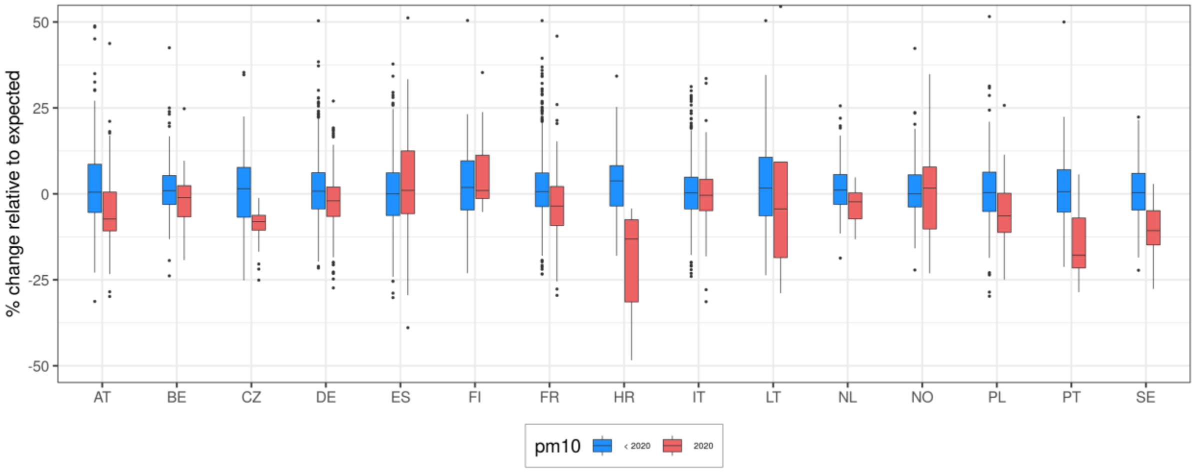


*Figure 2.4 Same as Figure 2.1 for $PM_{2.5}$*

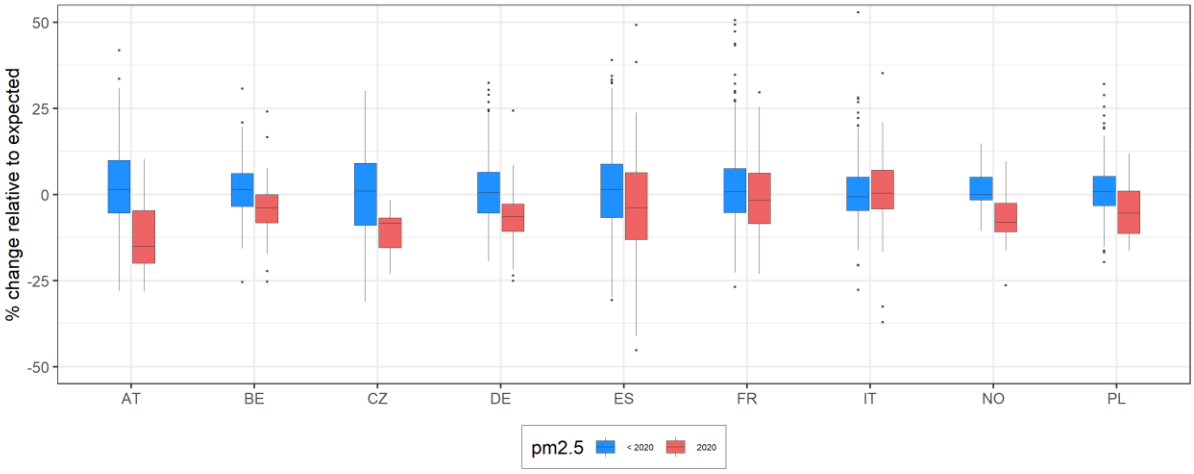



*Figure 2.5 Same as Figure 2.1 for the annual mean of MDA8 for $O_3$*

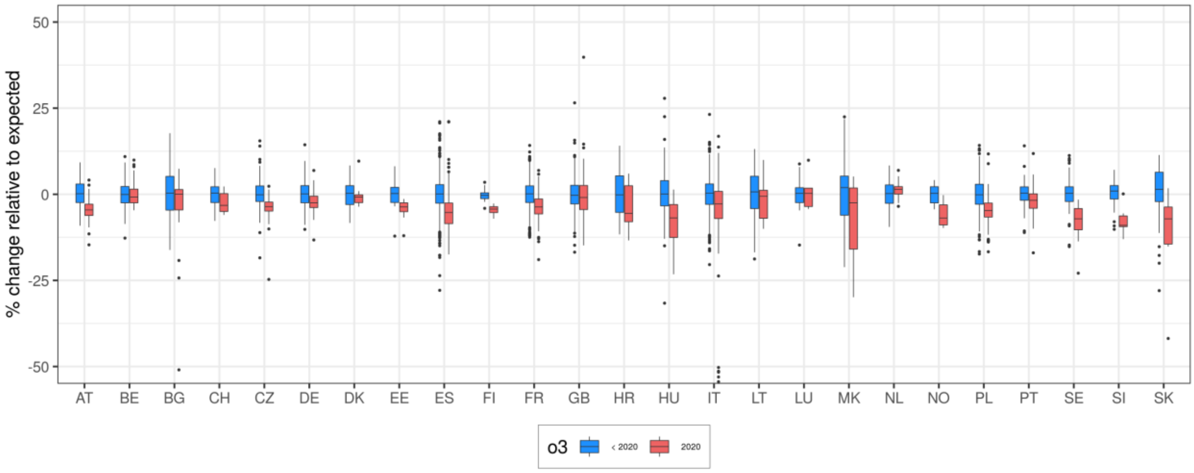



*Figure 2.6 Same as Figure 2.1 for SOMO10*

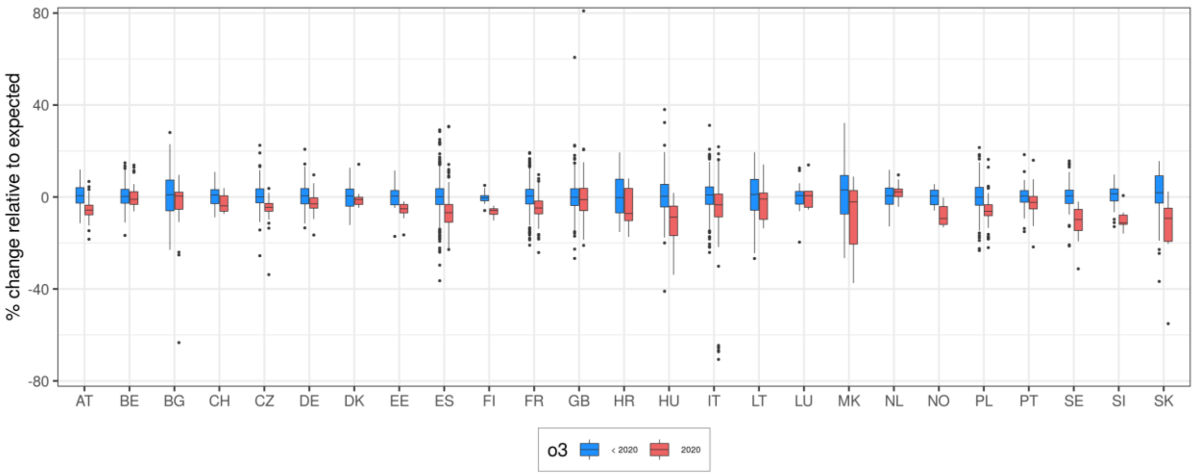
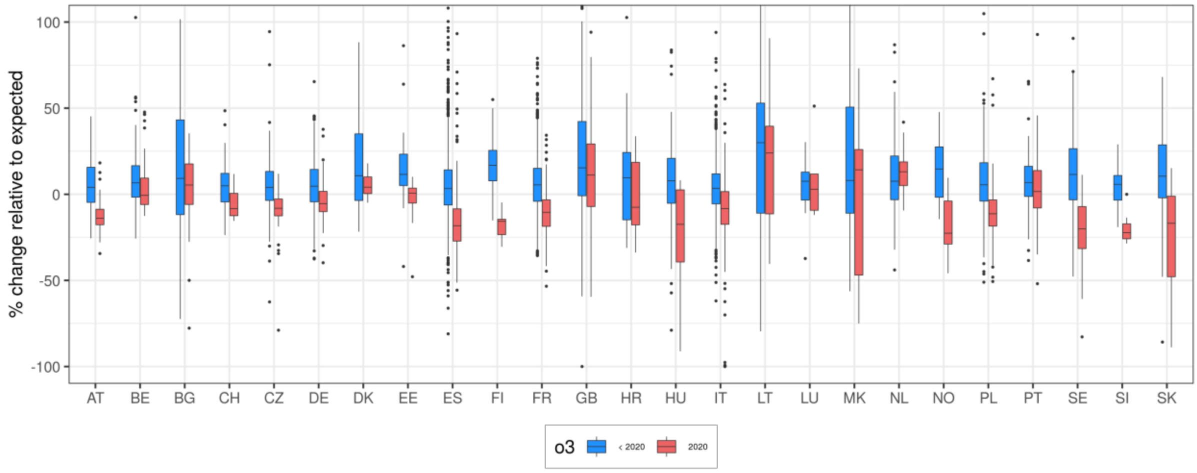


*Figure 2.7     Same as Figure 2.1 for SOMO35*




These results show clear reductions in the annual mean $NO_2$ concentrations in most countries. The results for annual mean $PM_{2.5}$, annual mean $PM_{10}$,annual mean MDA8 $O_3$ and SOMO10 do not show a clear spatial pattern. For SOMO35, large positive and negative deviations are found. A majority of the countries show levels of $PM_{10}$ and $PM_{2.5}$ slightly lower than expected in 2020 but the differences are small and not significant. Also for $O_3$ there are small differences between the modelled and measured data in 2020 when looking at the annual MDA8 means, and this is as expected since the effect of the reduced emissions during the restriction periods will presumably only be visible in $O_3$ during short-term episodes. For nearly all countries a reduction is seen (although not statistically significant) and this is an indication of slightly reduced levels of MDA8 in 2020 but the differences are within the uncertainty.

For a number of countries, we estimate a reduction in the annual mean $NO_2$ concentrations of 13 - 19 % in 2020 compared to the expected concentrations. Slovenia and Slovakia (19 %), Spain (18%), Sweden (16 %) and France (15 %) are countries with the strongest signal of reduction in $NO_2$. Ireland, however, show a substantially stronger reduction of 34 % but this is linked to the AirGAM estimating a strong upward trend during 2015-2019 caused by very low mean $NO_2$ levels in Ireland in 2015 combined with a minimum number of stations and thus we regard the estimated reduction in 2020 as an artefact. The strong reduction in $NO_2$ in Sweden is somewhat surprising, considering that this was a country with a very different approach to the pandemic than most European countries – the restriction measures were only “recommended”, not compulsory. As a median over the countries with at least five monitoring stations operating during 2015-2020, we estimate a reduction of 13.5 % in the annual $NO_2$ concentration.

For $PM_{10}$ and $PM_{2.5}$, a median reduction of the annual mean concentration of 4 % and 5 %, respectively, is calculated, but the number of countries with sufficient number of stations is very low, so these numbers should not be seen as any indicator for the European median. Most of the changes calculated for PM are negative, indicating that a small drop in the annual mean levels in 2020 occurred. For $O_3$ the analysis gets more difficult due to the complex and secondary nature of this species. In wintertime, $NO_x$ emissions tend to decrease the $O_3$ levels and in the summer season $NO_x$ emissions tend to lead to increased ozone concentrations. The first and most dramatic restriction period occurred in the transition period (March-April) whereas the restrictions were reduced when entering the main ozone season (end of May – early August). Thus, the estimated changes in the annual mean MDA8 are very small with a median reduction of 4 % only, presumably well within the uncertainties of these calculations. Also, for SOMO10 fairly small changes were found, amounting to a median reduction of 5 %. It should be noted, though, that for nearly all countries, a small reduction is estimated while nearly no countries are estimated to have increased these values.

For SOMO35, large negative and positive differences are calculated, both for 2020 and for the 2015-2019 period. This reflects that the level of 35 ppb is close to the mean level in many areas and thus only minor differences in the predicted daily levels could lead to substantial changes in the calculated SOMO35. SOMO35 is a therefore a difficult statistical metric for model evaluation based on station data and particularly when studying trends and changes in mean levels. To what extent the changes in SOMO35 shown in Figure 2.7 and Table 2.1 reflects real changes or are just reflecting uncertainties in the method is hard to evaluate. The basic way to read the boxplots in Figure 2.2 - Figure 2.7 is to compare the signal in 2020 with the spread in values in the previous period. For SOMO35 these are of the same order for many countries, implying that the estimated changes are not significant. Nevertheless, overall, a median reduction of 8 % over all countries with sufficient number of stations is found.

*Table 2.1 Mean relative differences (percent) in 2020 between measured and modelled annual mean concentrations (100 x (measured-modelled)/modelled) as given by the AirGAM model for all stations data in each country, separately. The table gives the values for annual means of $NO_2$, $PM_{10}$, $PM_{2.5}$, and MDA8 for $O_3$ as well as SOMO10 and SOMO35. Only countries with at least 5 stations were included*

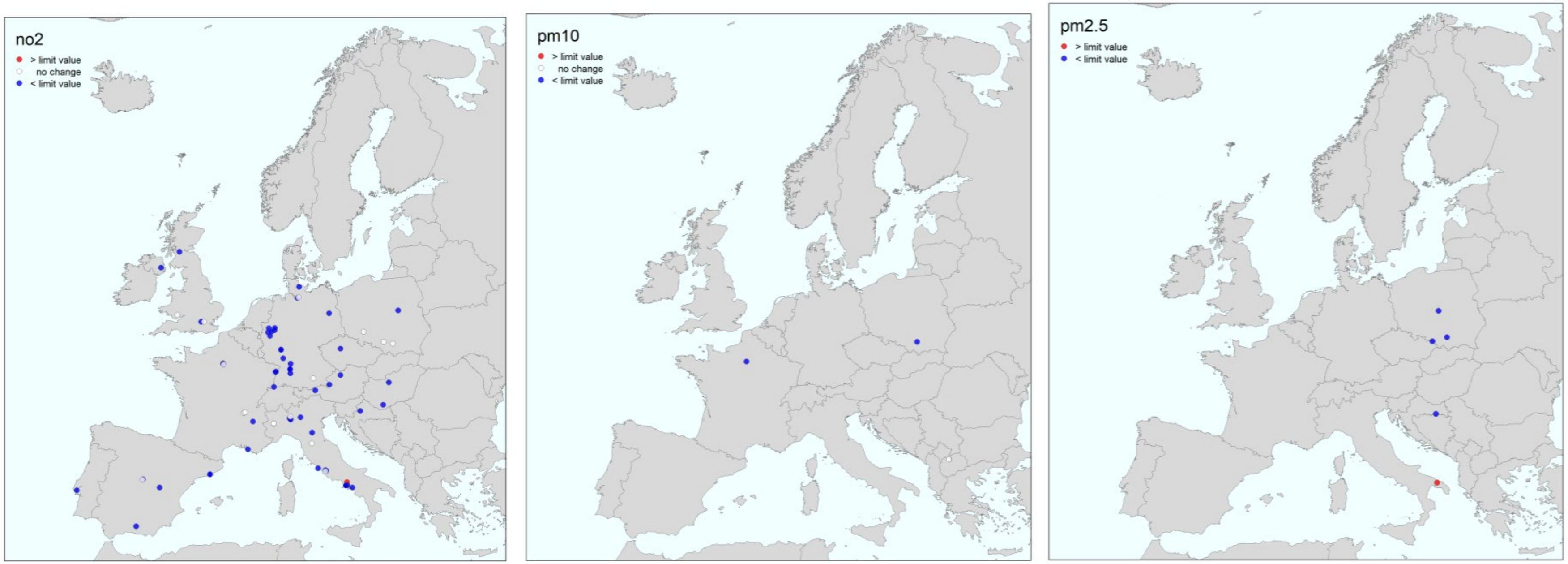
| Country | $NO_2$ | $PM_{10}$ | $PM_{25}$ | MDA8 | SOMO10 | SOMO35 |
|---|---|---|---|---|---|---|
| **AT** | -14 | -7 | -15 | -5 | -6 | -14 |
| **BE** | -13 | -1 | -4 | -1 | -1 | -1 |
| **BG** | | | | 0 | 0 | 5 |
| **CH** | -13 | | | -3 | -4 | -8 |
| **CZ** | -10 | -8 | -8 | -4 | -5 | -8 |
| **DE** | -11 | -2 | -6 | -2 | -3 | -5 |
| **DK** | -9 | | | -1 | -1 | 4 |
| **EE** | | | | -4 | -5 | 1 |
| **ES** | -18 | 1 | -4 | -5 | -7 | -18 |
| **FI** | -13 | 1 | | -4 | -6 | -16 |
| **FR** | -15 | -4 | -2 | -4 | -5 | -10 |
| **HR** | | -13 | | -6 | -7 | -8 |
| **HU** | -13 | | | -7 | -9 | -17 |
| **IE** | -34 | | | | | |
| **IT** | -14 | 0 | 0 | -3 | -3 | -8 |
| **LT** | -5 | -4 | | -1 | -1 | 24 |
| **LU** | -14 | | | 0 | 1 | 3 |
| **MK** | | | | -2 | -2 | 14 |
| **NL** | -12 | -2 | | 1 | 2 | 13 |
| **NO** | -11 | 2 | -8 | -7 | -9 | -23 |
| **PL** | -10 | -6 | -5 | -5 | -6 | -11 |
| **PT** | -14 | -18 | | -2 | -2 | 2 |
| **SE** | -16 | -11 | | -7 | -10 | -20 |
| **SI** | -19 | | | -9 | -11 | -22 |
| **SK** | -19 | | | -7 | -9 | -17 |

We have also estimated the possible changes in the exceedances of the annual limit values in 2020 as shown in Figure 2.8. These limit values are 40 ug/m$^3$ for $NO_2$ and $PM_{10}$, and 25 ug/m$^3$ for $PM_{2.5}$. Stations predicted to be below the limit value while the measured value exceeded it are marked in red, stations predicted to be above the limit value while the measured value was below, are given in blue, and stations for which both the modelled and measured values were above the limit value are given in white.

Although the change in annual mean concentrations for $NO_2$ are fairly small, a significant number of sites are found to drop below the limit value in 2020. In total, 54 stations are estimated to drop below the limit value, corresponding to 11 % of the traffic stations. This reflects that many sites are close to the limit value and just a minor reduction leads to the sites falling below these values. Also, for $PM_{10}$ and $PM_{2.5}$ very few sites are found to fall below the annual limit values, but substantially fewer than for $NO_2$.

It is important to evaluate these findings with care since there is a certain degree of uncertainty in these calculations and in some cases this uncertainty alone will lead to sites passing the limit value in either direction. That nearly all the estimated changes in exceedance show reductions is, however, a strong argument for the fact that many sites actually reduced their concentrations below the limit value due to the effect of restriction measures in 2020.

*Figure 2.8 Monitoring stations for which the AirGAM model estimates that the annual mean levels in 2020 passed above (red) or dropped below (blue) the limit values for $NO_2$, $PM_{10}$ and $PM_{2.5}$, respectively. Stations exceeding the limit value and for which the model estimates no change relative to the limit value are marked in white*



### *2.1.2 Results by country and station type*

The time series of observed and predicted daily data from the AirGAM modelling have been merged into country- and station-type based average plots as well as difference plots for all years, species, countries, and station types. This section presents some examples of these results while the reader is referred to Annex 8 for all details.

#### *2.1.1.1 $NO_2$*

All time-series plots in Annex 8 are of the type shown in Figure 2.9 that gives the mean daily $NO_2$ levels for all traffic sites in Spain in 2020 as observed and as predicted by the AirGAM model as well as the difference between the observed and modelled levels. The confidence interval and restriction periods are also marked in the figures. For details on how the confidence interval is calculated, please refer to Walker et al., forthcoming.

As discussed above, for $NO_2$ a clear signal of the restrictions is seen in many countries, and particularly for Spain and other countries that introduced the toughest restriction measures from mid-March 2020. As seen from , at traffic stations in Spain a sudden drop in the observed $NO_2$ levels relative to the expected levels occurred exactly as the restrictions were introduced. When the measures were lifted in May, a gradual recovery back to normal conditions started, and in the last part of July the observed levels were close to the expected. Later in the year (by October-November) the measured levels are again lower than the predictions, but the difference is much smaller than in spring.

As an example of a country that shows a less clear signal of the restriction period, Figure 2.10 gives the mean results for $NO_2$ at traffic sites in the Czech Republic. In contrast to the results for Spain, the reduction in NO2 during the first restriction period (which also was considerably shorter than in Spain) is very minor and within the uncertainty of the AirGAM calculations. On the other hand, when a second restriction period was introduced in late October in the Czech Republic, the measured NO2 data are seen to lie well below the expected levels for the rest of the year for most of the days.

For more details on each individual country and station category, the reader is referred to the plots in Annex 8.

*Figure 2.9 The upper panel shows the average observed (blue) and predicted (red) daily mean $NO_2$ concentrations based on all traffic sites in Spain in 2020. The lower panel shows the mean difference between the observations and predictions. The shaded grey area marks the estimated 95 % confidence interval. The start and the end of the first restriction period is marked with dotted lines*

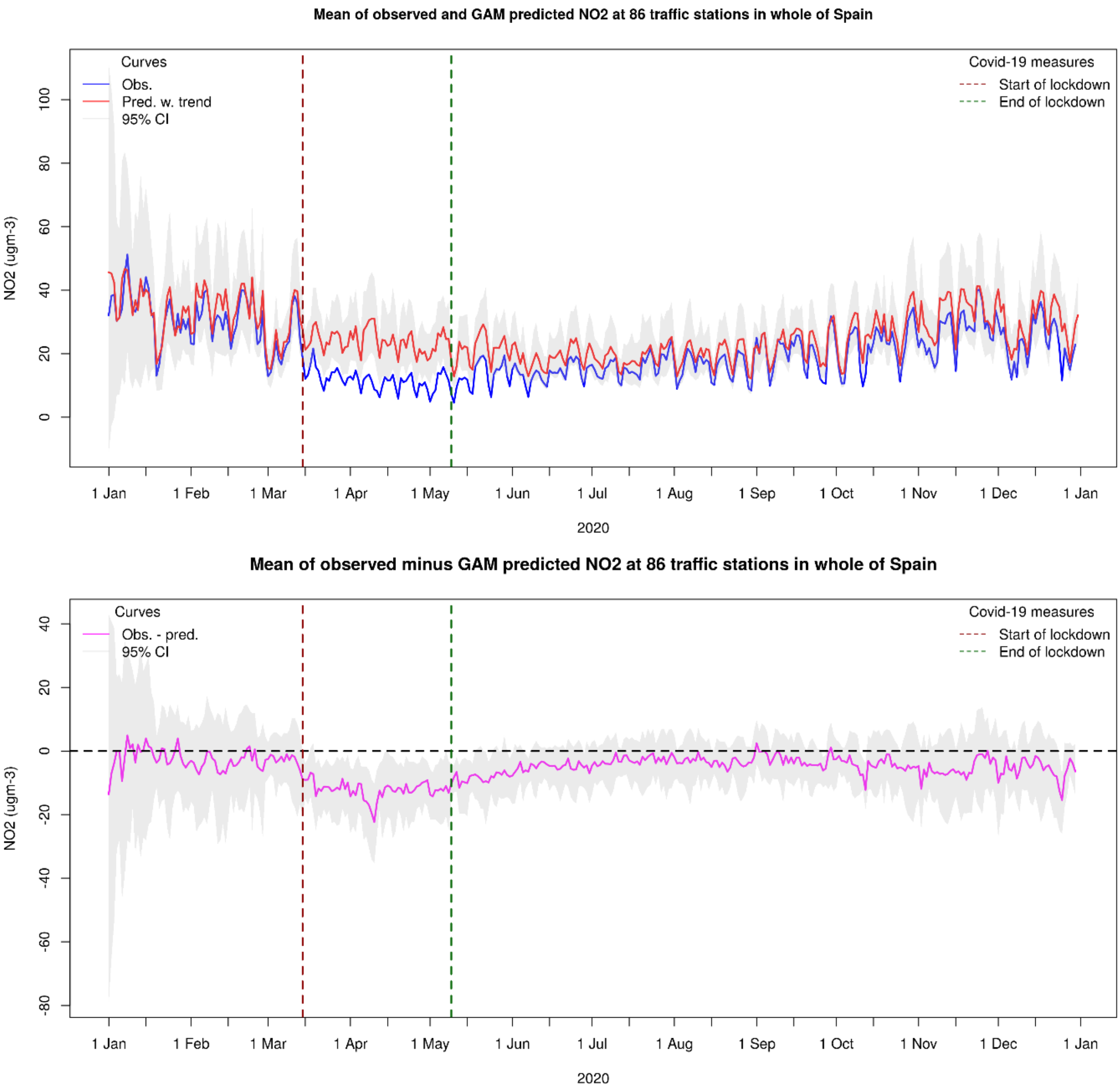
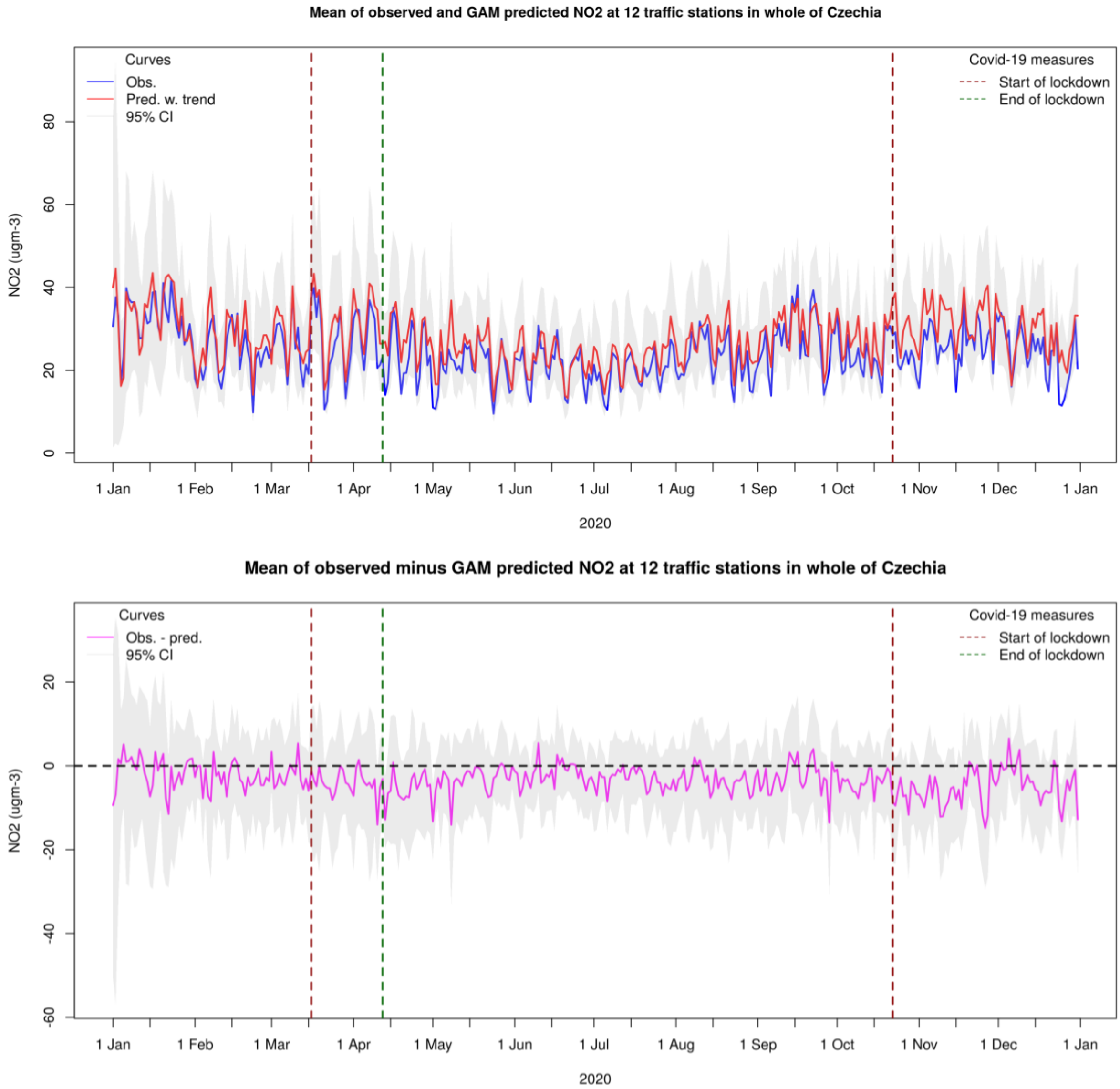
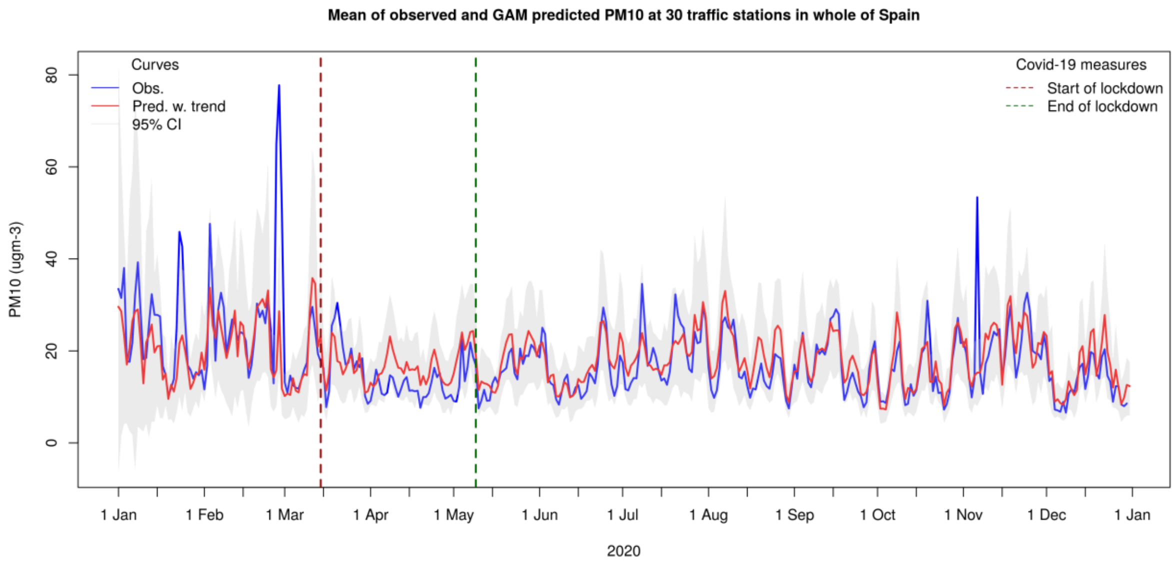


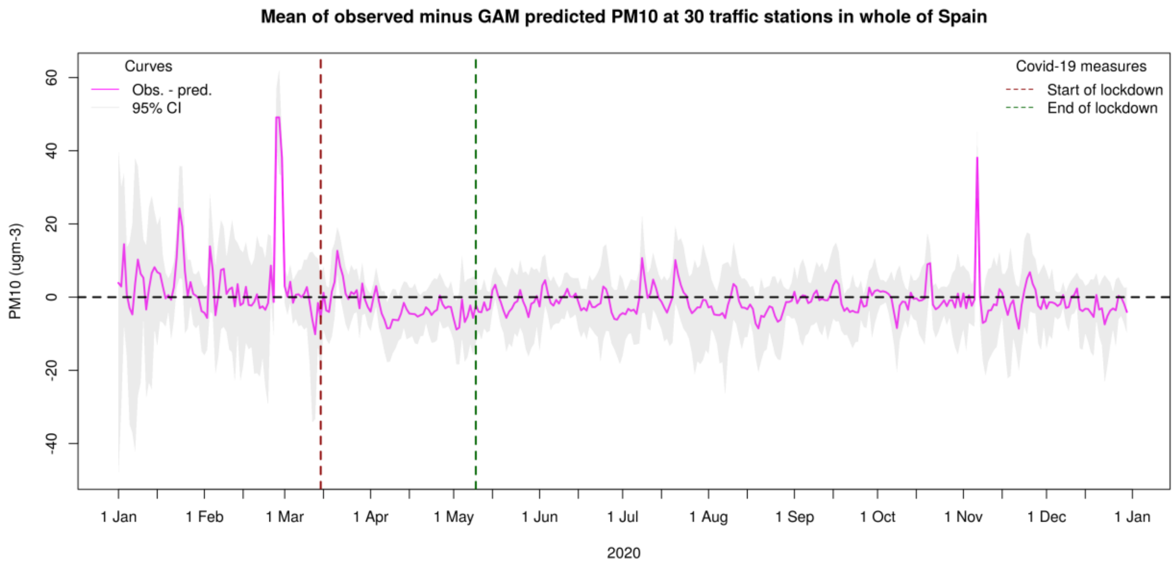
*Figure 2.10 Same as Figure 3.9 for the Czech Republic, including an autumn restriction periods*




### *2.1.1.2 $PM_{10}$*

In contrast to the clear signal in $NO_2$ levels at traffic sites in Spain, the levels of $PM_{10}$ during the first restriction period were not significantly different in a strict statistical way from the expected levels as seen at Figure 2.11

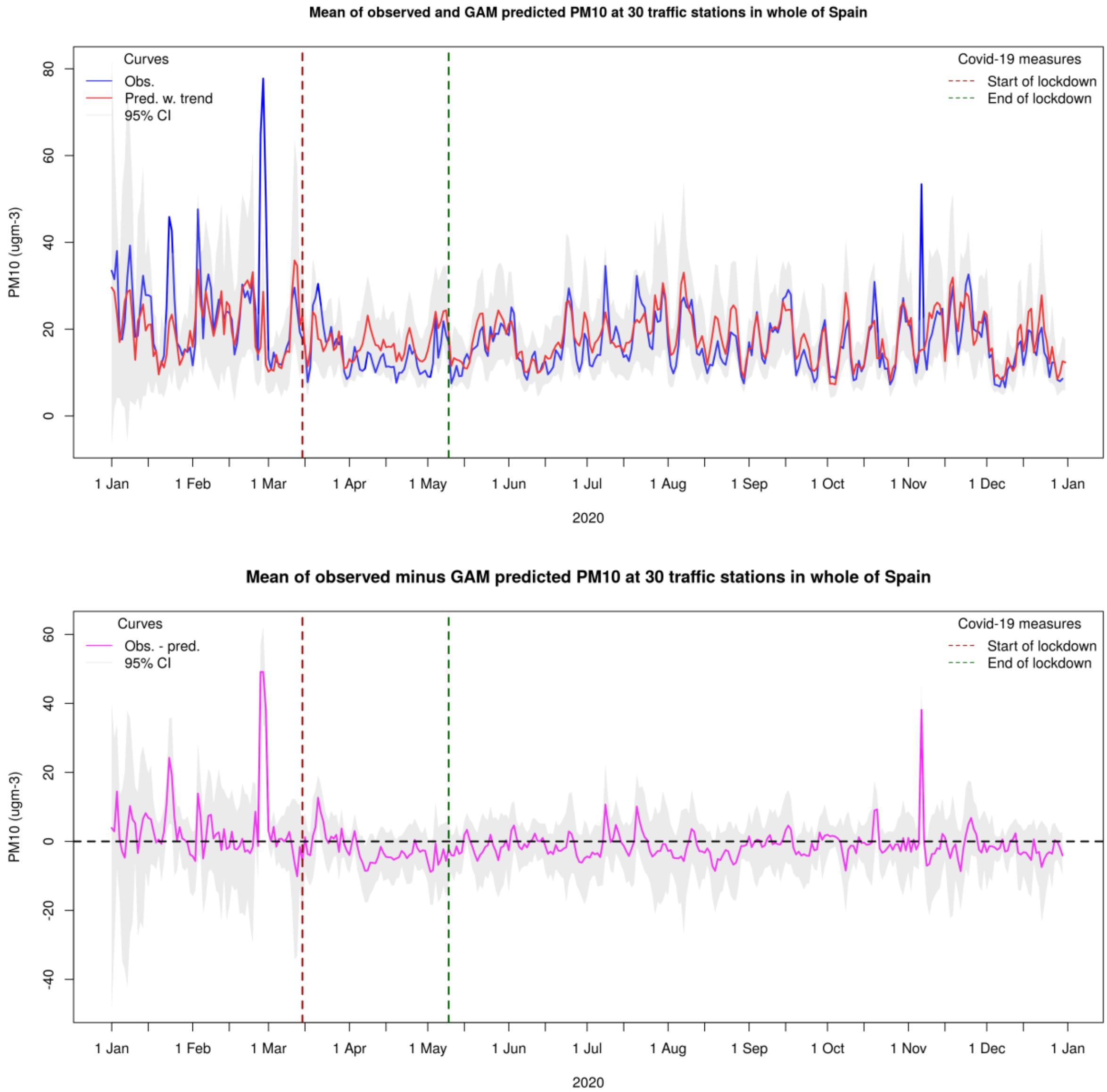



when considering the confidence levels. For the year as a whole, the predicted and observed average levels are seen to agree very well except for some cases with high peaks in the observations that could reflect episodes of wind-blown dust or other long-range transport events. In the restriction period, a small peak in $PM_{10}$ is first seen, followed by levels that lie somewhat below the predicted levels, but the reduction is much smaller than for $NO_2$, and the levels apparently went back to normal already by the start of May, before the restriction period ended. During most of April, the observed levels were lower than the predicted levels, but within the uncertainty range, so we can’t conclude that this was an effect of the restriction measures.

The sporadic $PM_{10}$ increases (typical from desert dust inflows in Spain and elsewhere in Europe) are not captured by the AirGAM. AirGAM is a local model, where observed air pollutant concentrations at a given stations are correlated with meteorological conditions at the same location, therefore not accounting for long range advection. Such a limitation is the motivation for the correlation threshold applied to $PM_{10}$ (0.55), lower than for $NO_2$ (0.65) as mentionned in 0. The time series of Figure 2.11 is also illustrative of the potentially large effect of missing such long range events on the estimation of restriction/reference difference.

*Figure 2.11 Same as Figure 2.9 for $PM_{10}$*




One question is if the restrictions on activity led to increased emissions from e.g. residential sources, and Figure 2.12 shows the mean $PM_{10}$ levels at rural background stations in Spain. The number of such sites is too low to draw firm conclusions (only three), but at least for these sites there is no indications of increased $PM_{10}$ emissions from residential areas. The measured levels are seen to follow closely the predicted levels during the restrictions. As for the traffic sites, the observed and predicted time series follows each other closely except for a number of peak episodes, partly coinciding with the peaks seen at traffic stations, giving further indications that these episodes are linked to long-range transport events.

*Figure 2.12 Same as Figure 2.9 for $PM_{10}$ at rural background stations in Spain*

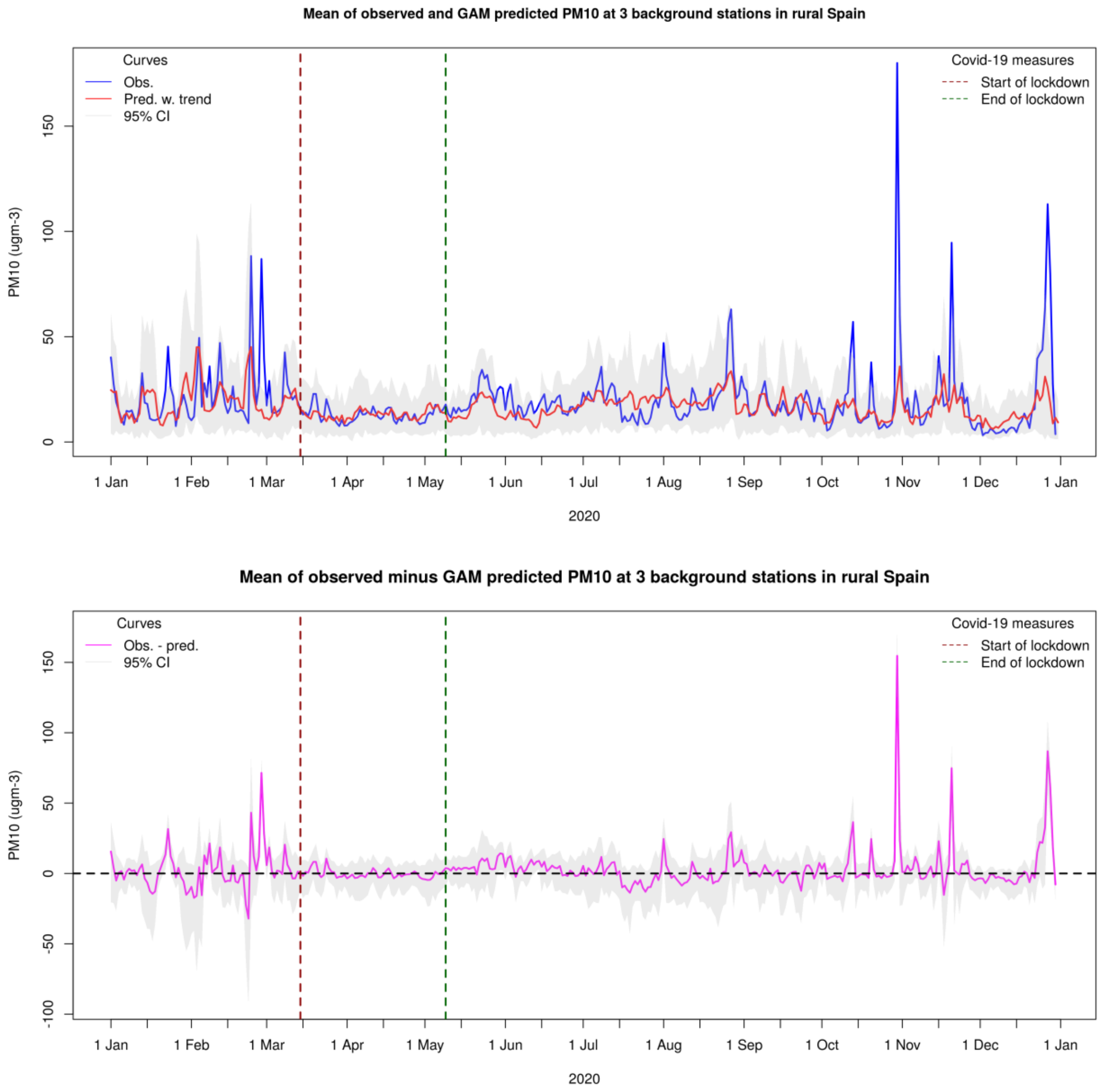
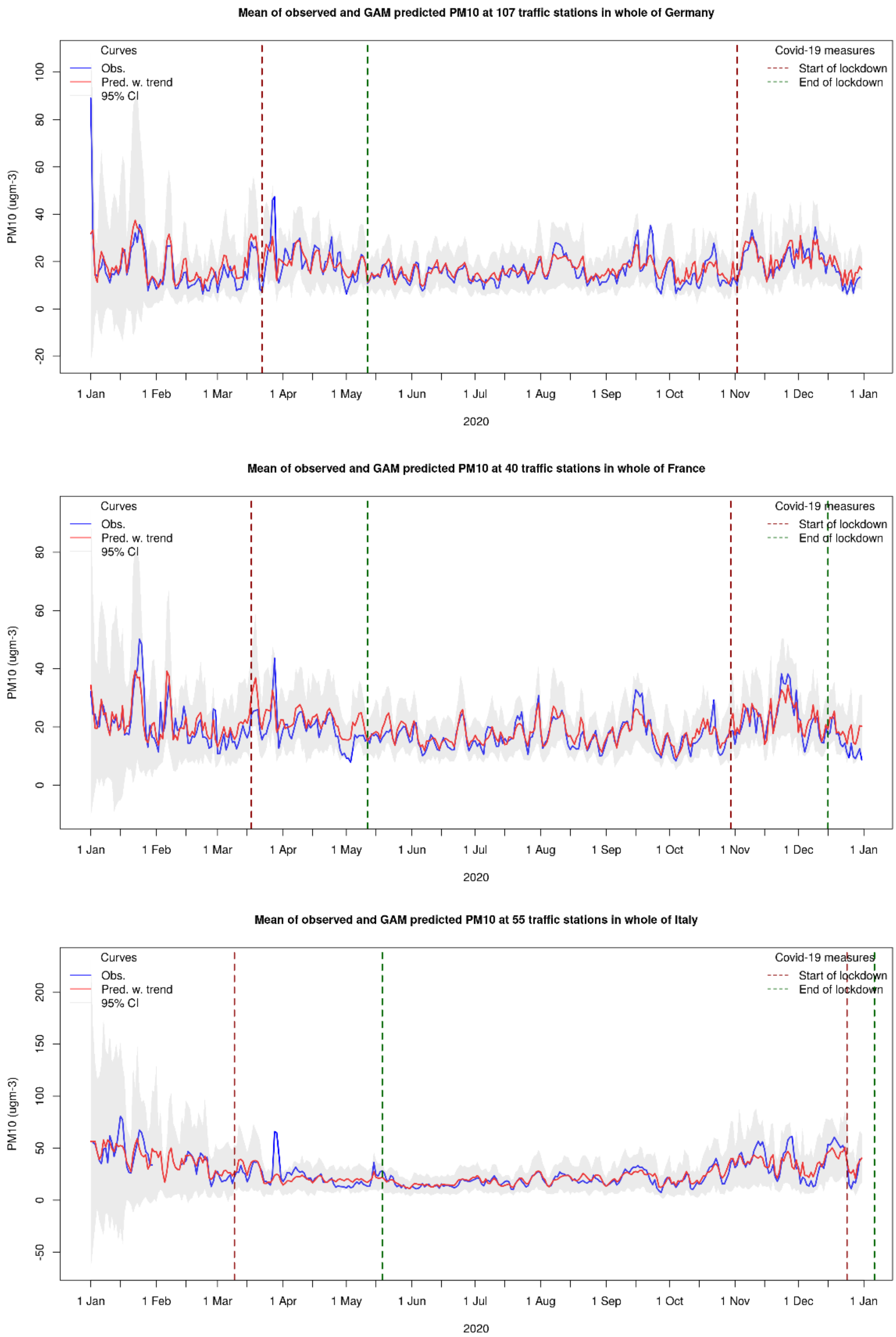



Figure 2.13 shows the mean $PM_{10}$ levels at traffic sites in Germany, France, and Italy which also show a very good agreement between observed and predicted daily mean levels through the year. The high peaks seen at sites in Spain are not apparent in these time series, and – as for Spain – it is hard to see any signal due to the restriction measures on the observed levels of $PM_{10}$ at these sites in contrast to the reductions in $NO_2$ as discussed above. In France, the measurements were particularly low in the last part of April coinciding with a drop in the predicted levels, but the observed levels dropped more, reaching down to the bottom of the confidence limits. As for Spain, this short period could be an effect of the strongly reduced traffic, but the range of uncertainty makes it difficult to conclude firmly.

We note that in many countries a spike in the $PM_{10}$ levels is seen by the end of March, also evident in Figure 2.13 for Germany, France, and Italy. This short episode was studied further by the CAMS Policy Service (https://policy.atmosphere.copernicus.eu/reports/CAMS71_IAR_2020.pdf) showing evidence that it would be due mainly to wind-blown dust.

*Figure 2.13 Mean daily values of $PM_{10}$ as observed and predicted by AirGAM at traffic sites in Germany, France, and Italy*



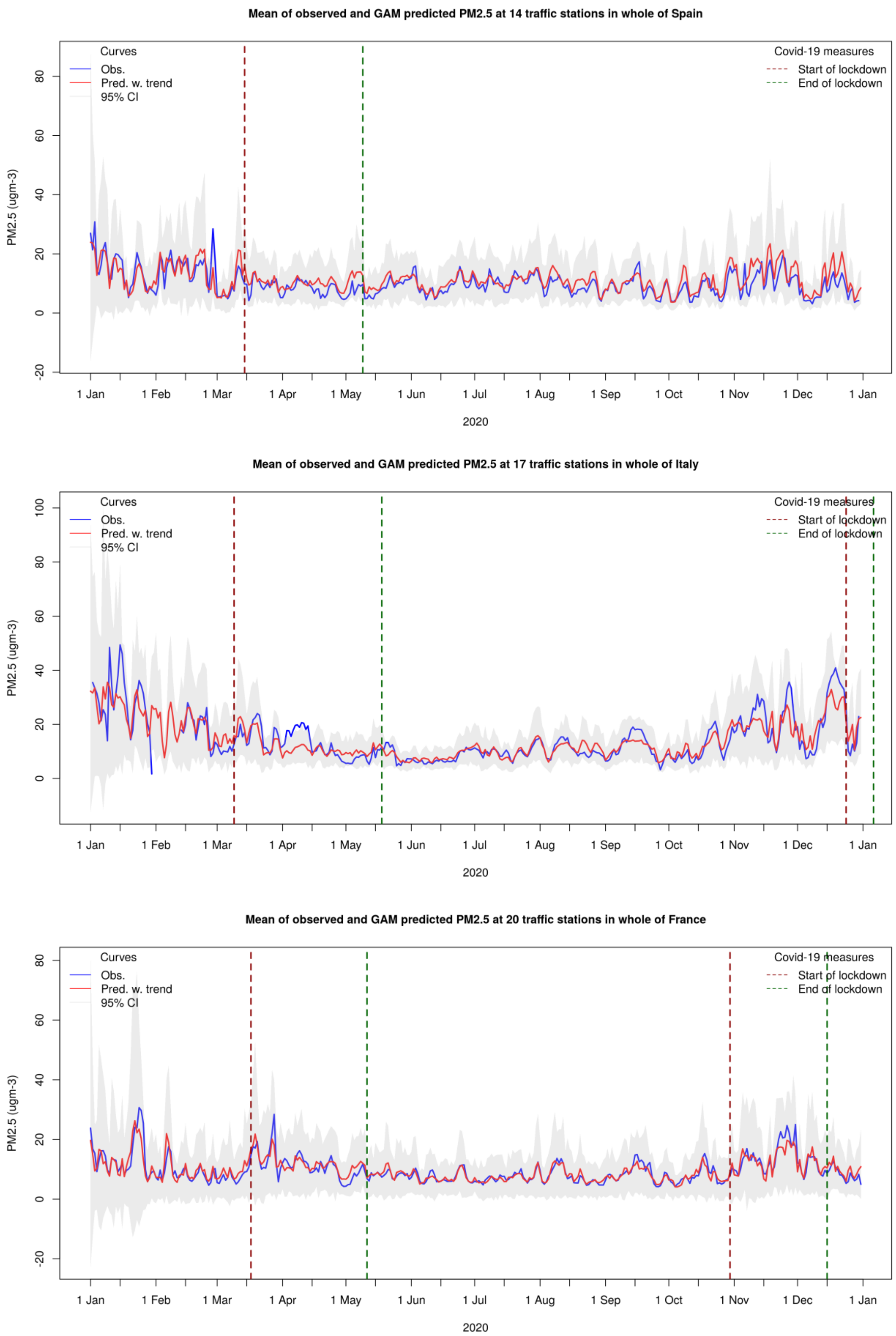

## 2.1.1.3 $PM_{2.5}$

Time series of observed and predicted $PM_{2.5}$ at traffic sites in three countries (Spain, Italy, and France) in 2020 are shown as examples in Figure 2.14. As for $PM_{10}$, very little impact of the 2020 restrictions is visible in these results, although a slight reduction during the first restrictions is indicated at the

Spanish stations whereas at the Italian sites, a shorter period of increased levels is seen. These deviations are, however, within the uncertainties and it is difficult to tell whether they could be ascribed to the restriction measures or whether they reflect random variations.

These results for the PM data reveal that concentration of these species is determined by other processes than the sources emitting $NO_x$ and $NO_2$. The European-wide reductions in $NO_2$ is certainly due to reduced road traffic during and partly after the restriction periods. The minor impact on the levels of PM in the air (both $PM_{10}$ and $PM_{2.5}$) at all types of monitoring stations shows that these species are substantially less influenced by the road traffic emissions (see Annex 8).

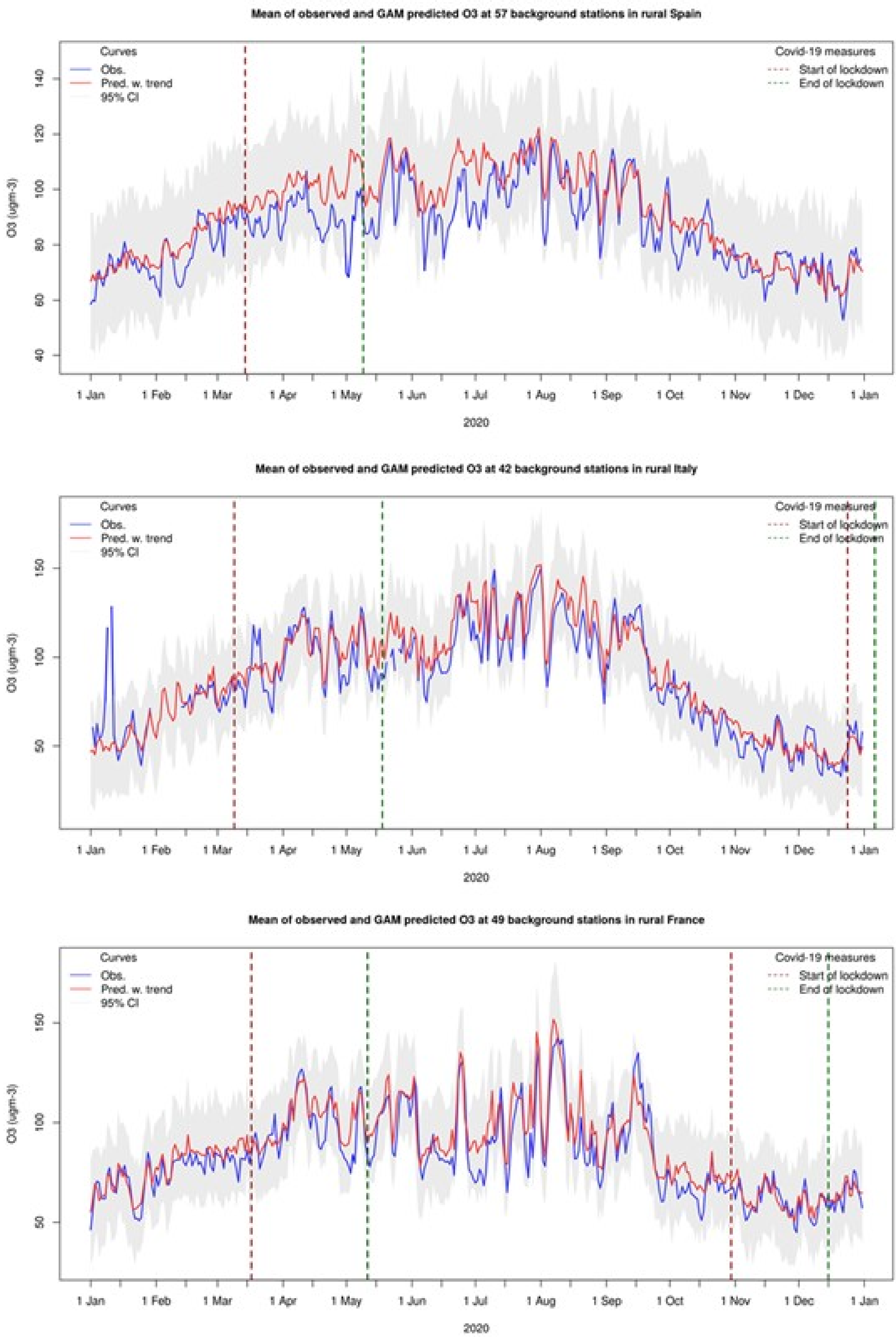
*Figure 2.14 Mean daily values of $PM_{2.5}$ in 2020 as observed and predicted by AirGAM at traffic sites in Spain, Italy, and France*



#### *2.1.1.4 $O_3$*

Observed and predicted levels of mean MDA8 $O_3$ at rural background sites in Spain, Italy and France are shown in Figure 2.15. A good agreement between these levels is seen also in these time series. For Italy and France there is no clear evidence of the activity-related measures, neither in the first or second restriction period or in mid-summer which is the main “ozone season”. For the Spanish sites the observed levels do lie below the predicted levels for extended periods of time, starting in the beginning of April. This difference is particularly marked in April and to somewhat less extent from mid-June to mid-July. The observations are seen to be within the confidence limits of the predictions, but the length of these periods makes it more likely that this represents a true anomaly induced by restriction measures, i.e. an effect of the activity-related measures that have reduced the $NO_2$ levels substantially. Given the fact that Spain was among the countries with the strongest drop in $NO_2$ levels and also a country with a fast and efficient “internal” ozone formation, it is not unexpected that this is the country in Europe showing the largest impact on the surface ozone levels.

*Figure 2.15 Mean daily values of MDA8 of $O_3$ in 2020 as observed and predicted by AirGAM at rural background sites in Spain, Italy, and France*



### *2.1.3 Conclusions*

Of the four pollutants studied, the signal of the 2020 pandemic is by far most evident in the $NO_2$ data showing clear reductions in most areas of Europe, even when looking at annual mean values. For the countries with the strongest reductions, a drop of 13-19 % in the annual mean is found while the median over all countries with at least 5 monitoring sites included in the analyses is 13.5 %. The first restriction period (from mid-March to April/May) was clearly the most severe, leading to major reductions in the $NO_2$ levels in many countries. The lifting of the measures led to a gradual normalisation by mid-July. Later in 2020 (from mid-October) reduced $NO_2$ levels are again evident in the data, but at a lower scale than in April.

For the annual mean of $PM_{10}$, $PM_{2.5}$ and MDA8 $O_3$ a reduction is also found, but only of the order of 4-5 %. A reduction in SOMO10 is also estimated while for SOMO35, the uncertainty is too high to draw firm conclusions, mainly because the level of 35 ppb is close to the mean ozone level in Europe[1]. For both $NO_2$ and PM, a larger reduction is seen at traffic sites compared to rural and suburban/urban background sites, but the differences among the station types are not very large. For $PM_{10}$ and $PM_{2.5}$, we estimate that 2 and 4 sites, respectively, dropped below the limit value in 2020 due the effects of the pandemic, whereas for $NO_2$ 11 % of the stations considered in the study fell below the limit value. Compared to the clear signal in $NO_2$ levels, very small changes are seen in PM data indicating that the air concentration of PM is dominated by other sources than road traffic. When averaged over individual countries, very good agreement between predicted and observed daily PM levels through 2020 are found both at rural, suburban/urban and traffic sites. This is a strong argument that restriction measures in Europe in 2020 had a very small impact on the atmospheric levels of $PM_{10}$ and $PM_{2.5}$.

## 2.2 Modelling the impact of restriction measures on air quality with the CHIMERE Chemistry-Transport model

### *2.2.1 Method*

The aim of this section is to assess the impact on air quality model based on the CHIMERE (v2020) model (Menut et al., 2021). In order to quantify the change in pollution levels due to emissions changes because of the restriction measures, two different simulations have been realized. The first simulation corresponds to a 'business as usual' (BAU) scenario which reproduces 2020 as if no restrictions had happened. The second simulation is a ‘lockdown’ scenario using 2020 emission data coherent with the restrictions implemented by the countries.

#### *2.2.1.1 Presentation of the CHIMERE model*

The air quality model CHIMERE (Menut et al. 2021) is co-developed by the CNRS (the French National Council for Scientific Research) and INERIS (French National Institute for Industrial Environment and Risks). This model gathers a set of equations representing the transport and transformation of chemical species to simulate the temporal evolution of atmospheric pollutants over a range of spatial scales, from the regional scale (several thousand kilometers) to the urban scale (spatial resolution of a few kilometers).

Using meteorological and emission data, CHIMERE simulates tridimensional concentrations for various pollutants (including $O_3$, $NO_2$ or PM) with hourly outputs. The model integrates a chemical mechanism containing more than one hundred chemical reactions. It simulates the formation and evolution of airborne particles with diameters ranging from a few nanometers to 10 µm. Particles in CHIMERE

[1] This is the reason why the SOMO35 analysis is not shown before.

consist of primary PM (anthropic or natural) emitted directly into the air and of secondary PM that are formed by chemical reactions in the atmosphere (nitrate, ammonium, sulfate and secondary organic aerosols).

#### *2.2.1.2 Emissions*

The emission inventory used for the reference (Business-as-Usual: BAU) scenario was provided by TNO who projected the emissions used in the CAMS regional inventory (inventory developed under CAMS_81 Service, (Super et al., 2021; Guevara et al., forthcoming) to the year 2020 accounting for the current legislation but excluding the impact of the restriction measures (Super et al., 2021). It is therefore an estimate of what 2020 emissions would have been if the restrictions had not occurred, by extrapolation of the previous years. Specific policies introduced in 2020 were also included, in particular for the new sulfur caps[2] in international shipping emissions (on top of emission control areas which were already introduced in the North, English and Baltic Seas).

This inventory has a resolution of 0.1° x 0.05°, equivalent to ~ 6x6km over central Europe. The CAMS regional inventory is based on official emissions reported by the countries to the EU (under the NEC Directive) and UNECE (under the Air Convention and the EMEP program). It is referred to as CAMS-REG-AP and is used every day in the European CAMS forecasts (Kuenen et al., 2022).

The 'lockdown' emissions were estimated by applying to the BAU scenario the restriction induced adjustment factors computed by the Barcelona Computing Center (CAMS-REG_EAF-Covid19[3] version 2 dataset, (Kuenen et al., forthcoming)). This dataset includes specific daily, sector, pollutant and country emission adjustment factors for Europe. These factors are calculated by gathering data from a wide range of information sources such as open access, measured activity data, proxy indicators and other available reports. Adjustment factors were calculated as a ratio between the activity data for a given time (day/week/month) and the value of this activity over a pre-restriction period. The dataset is provided for a period that goes from 21 February to 31 December 2020, and for six emission sectors: energy industry, manufacturing industry, road transport, other stationary combustion activities (such as residential), shipping and aviation (landing and take-off cycles). The sources of information considered to construct the factors were as follows:

- Energy industry: Electricity demand data reported by (ENTSO-E, 2021), which was combined with meteorological information from ECMWF Reanalysis v5 (ERA5, CS3, 2017) and gradient boosting machine models (Petetin et al., 2020) to deriver BAU country-dependent electricity load values
- Manufacturing industry: Industrial production indexes and energy balances reported by Eurostat (Eurostat, 2021a; Eurostat, 2021b)
- Road transport: Use of the Google movement trend reports (LLC, 2021), which were adjusted by using measured traffic counts reported by multiple European national road administrations
- Other stationary combustion activities: Use of the Google movement trend reports (LLC, 2021), which were adjusted considering information on residential and commercial energy consumption statistics
- Shipping: Port call trends reported by (EMSA, 2021)

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[2] ("IMO 2020" rule that limits the sulphur content in the fuel oil used on board ships operating outside designated emission control areas to 0.50 % m/m (mass by mass). https://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx

[3] As explained in the report D1.2-M4: Documentation describing the emission adjustment factors (CAMS_COP_079_2021SC1_D1.2-M4_202107_v1.pdf)

- Aviation: Airport movement statistics reported by (EUROCONTROL, 2021)

Table 2.2 summarises the overall emission changes obtained for each individual country per species when combining the BAU emissions with the Covid-19 adjustment factors. The most pronounced declines occur in those countries where the strictest restrictions were implemented, such as Italy, Spain or France. Despite only implementing national recommendations, Sweden presents one of the largest reductions in $PM_{10}$ emissions (4.7 %). This is due to the large contribution of the road transport sector to total $PM_{10}$ emissions in this country when compared to average levels (45 % versus 12.5 %). In the aggregate, the largest change was seen for $NO_x$ (-10.5 %), followed by -4.7 % in CO, -4.6 % in $SO_2$, -3.0 % in $PM_{10}$, -2.5 % in NMVOC and -2.1 % in $PM_{2.5}$. $NH_3$ emissions, which are mainly linked to agricultural activities, were practically unaffected by Covid-19 restrictions.

*Table 2.2 Relative change in emissions of criteria pollutants [%] per pollutants and country between January 1st and December 31st 2020*

| ISO3 | NOx | $SO_2$ | CO | $NH_3$ | NMVOC | $PM_{10}$ | $PM_{2.5}$ |
|---|---|---|---|---|---|---|---|
| AUT | -14.9 | -7.9 | -4.8 | -0.4 | -1.1 | -5.1 | -4.0 |
| BEL | -12.7 | -3.1 | -5.6 | -0.4 | -1.8 | -2.9 | -1.9 |
| BGR | -6.2 | -3.1 | -8.2 | -0.3 | -3.3 | -1.1 | 0.0 |
| CYP | -9.0 | -3.0 | -12.3 | -0.4 | -4.7 | -5.7 | -6.2 |
| CZE | -5.2 | -2.1 | 0.0 | -0.1 | -0.2 | -0.4 | 0.6 |
| DEU | -8.6 | -4.7 | -7.9 | -0.3 | -2.4 | -4.6 | -4.1 |
| DNK | -7.3 | -2.2 | -2.9 | -0.1 | -0.5 | -0.8 | -0.2 |
| ESP | -13.5 | -6.8 | -5.7 | -0.1 | -2.1 | -2.7 | -2.5 |
| EST | -2.9 | -3.1 | -1.9 | -0.5 | -1.0 | -2.6 | -2.1 |
| FIN | -3.9 | -2.7 | -0.5 | -0.2 | -0.7 | -2.3 | -0.5 |
| FRA | -13.5 | -9.0 | -4.4 | -0.1 | -2.6 | -4.4 | -4.0 |
| GRC | -5.8 | -2.8 | -6.6 | -0.4 | -5.9 | -1.3 | 0.0 |
| HRV | -7.2 | -2.4 | -0.5 | -0.1 | -1.2 | 0.0 | 0.5 |
| HUN | -6.7 | -1.8 | -0.8 | -0.1 | -1.5 | -1.2 | 0.4 |
| IRL | -13.2 | 0.2 | -7.8 | -0.1 | -1.4 | -2.5 | -1.9 |
| ITA | -15.1 | -10.8 | -3.3 | -0.3 | -3.5 | -2.4 | -1.5 |
| LTU | -5.0 | -1.1 | -2.0 | -0.1 | -0.3 | -1.1 | -2.2 |
| LUX | -12.4 | -10.3 | -7.9 | -0.2 | -1.5 | -3.4 | -2.6 |
| LVA | -4.0 | -2.4 | -0.7 | -0.3 | -1.1 | -1.9 | -1.0 |
| MLT | -12.9 | -17.3 | -12.8 | -0.5 | -6.8 | -4.4 | -5.4 |
| NLD | -8.6 | -7.3 | -8.5 | -0.4 | -2.1 | -3.3 | -3.1 |
| POL | -7.3 | -1.4 | -4.2 | -0.2 | -3.0 | -2.2 | -2.4 |
| PRT | -12.8 | -4.7 | -7.6 | -0.6 | -4.1 | -5.1 | -5.3 |
| ROU | -7.4 | -5.1 | -1.9 | 0.0 | -1.8 | -0.7 | 0.1 |
| SVK | -8.9 | -6.7 | -5.0 | -0.2 | -2.0 | -1.6 | -0.8 |
| SVN | -8.7 | -4.5 | -1.3 | 0.0 | -1.3 | -1.0 | 0.0 |
| SWE | -4.9 | -3.1 | -1.8 | -0.4 | -1.0 | -4.7 | -2.5 |
| EU27 | -10.0 | -4.3 | -4.6 | -0.2 | -2.4 | -2.7 | -1.9 |

Table 2.3 summarises the relative change in emissions by sector and pollutant. The aviation sector presents the largest drop in emissions (between 51 and 56 %), followed by road transport (between 15.5 % and -8.8 %). For the other stationary combustion activities, the species that are mainly related to residential wood combustion processes (e.g., $PM_{10}$, $PM_{2.5}$) experienced a slight increase (between 1.1 % and 1.7 %).

*Table 2.3 Relative change in emissions of criteria pollutants [%] by sector and species between January 1st and December 31st 2020 for EU-27. For the shipping sector, all the European sea regions are included*

| Sector | NOx | SO2 | CO | NH3 | NMVOC | PM10 | PM2.5 |
|---|---|---|---|---|---|---|---|
| Energy industry | -3.0 | -2.8 | -2.9 | -3.4 | -3.2 | -2.8 | -2.8 |
| Manufacturing industry | -5.8 | -5.6 | -6.9 | -3.2 | -3.5 | -6.0 | -5.7 |
| Other stationary combustion activities | -2.7 | -1.0 | 1.7 | 1.6 | 1.1 | 1.6 | 1.7 |
| Road transport | -16.1 | -16.3 | -17.8 | -17.6 | -18.8 | -15.3 | -16.1 |
| Shipping | -11.0 | -11.0 | -11.0 | - | -11.0 | -11.0 | -11.0 |
| Aviation | -55.2 | -55.2 | -49.9 | -55.9 | -54.1 | -54.1 | -54.2 |

#### 2.2.1.3 Stringency index

To compare the efficiency of restriction measures on air quality, the effect of restrictions on air quality is compared to the importance of restriction measures based on the Oxford stringency index. The stringency index is an indicator on how the response of governments varied over several indicators related to containment and closure policies, such as school or non-essential workplaces closures and restrictions in movement. These stringency index trends are computed by the Oxford Covid-19 Government Response Tracker (OxCGRT)[4].

Closure policies effect is likely to be highly contingent on local political and social contexts. These issues create substantial methodological difficulties when seeking to compare national responses. The stringency index is a composite measure which combine different indicators into a general index. However, composite measures leave out information, and make assumptions about what kinds of information is important.

In our study the stringency index trends are plotted next to the time series of relative concentration difference between the two scenarios in order to illustrate the chronology of the restrictions implemented. This is done for four pollutants: $NO_2$, $PM_{10}$, $PM_{2.5}$ and $O_3$ and including all EU-27 countries but also providing a closer focus on six European countries with different restriction patterns (Italy, Spain, France, Germany, Poland and Sweden).

#### 2.2.1.4 Configuration of simulations

Simulations are performed over Europe at a resolution of 0.2°x0.2° from January 1st to December 31st, 2020. Simulations for the two scenarios ('lockdown' and BAU scenarios) use the same meteorology and boundary conditions: the Integrated Forecasting System (IFS) meteorological data from the European Centre for Medium-range Weather Forecasts (ECMWF) and the boundary conditions data for gases and particles from the results CIFS forecasts. The model setup is therefore very close to the operational configuration in the Copernicus Atmosphere Monitoring Service.

[4] https://www.bsg.ox.ac.uk/research/research-projects/covid-19-government-response-tracker.

### 2.2.2 Results

This section presents the effect of restrictions on the annual concentrations and temporal evolution of $NO_2$, particles and ozone as well as the effect on several ozone metrics (SOMO10, SOMO35, 4DMA8, AOT40). Comparisons of the impact of restriction measures on concentrations to the Oxford stringency index are shown in the Annexes.

Definition of the metrics used:

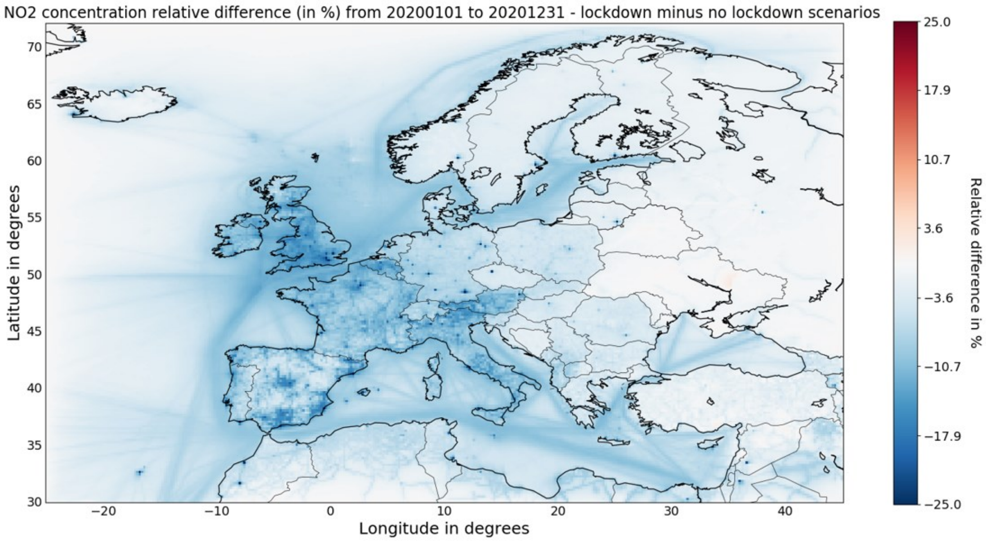
- SOMO10: Accumulated $O_3$ concentrations (8-hour daily maximum) above 10 ppb
- SOMO35: Accumulated $O_3$ concentrations (8-hour daily maximum) above 35 ppb
- AOT40: accumulated $O_3$ concentrations over the threshold value of 40 ppb during the growing period of crops (May-July)
- 4DMA8: the 4th highest 8-hour daily maximum $O_3$ concentration over the year, a metric representative of peak concentrations.

#### 2.2.1.5 $NO_2$

**Annual relative difference**

Figure 2.16 shows $NO_2$ relative differences; widespread decrease is found in Europe. Concentration changes are more important for countries with strong implemented restriction measures than for countries with less strong restrictions. Moreover, areas with large anthropogenic emissions (like large cities and main roads) are generally more affected than rural areas. For countries with strong restrictions implemented such as France, Italy, Spain, there is up to 25 % reduction in $NO_2$ annual means in large cities and around 17 % in rural areas. For countries with less strong restrictoins (for example Germany and Poland) the impact is generally lower (less than 10%) except in large cities (decrease reaching 25 % in some cities of Germany). For Sweden where no restrictions were obligatory (only recommended), the impact is very low in rural areas (between 0 and 5 %) but the capital Stockholm is strongly impacted with a reduction reaching 25 %. Additionally, the overall maritime traffic in Europe has been strongly affected with a reduction in $NO_2$ along maritime routes around 10 %.

*Figure 2.16 Impact of restrictions (lockdown - BaU scenario) on annual concentrations of $NO_2$ (change in %) in Europe for 2020*




## Day-to-day evolution

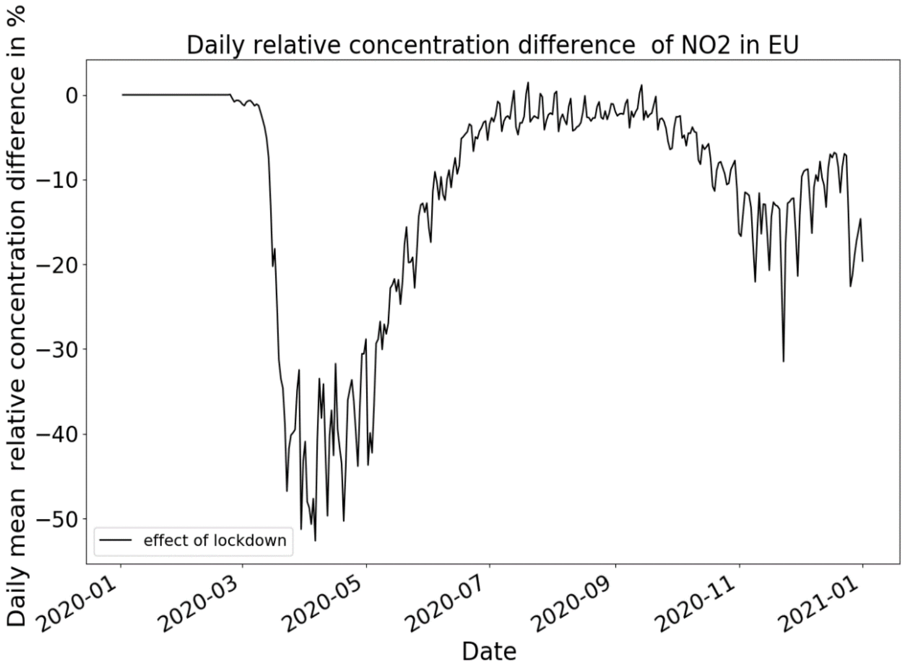
The time series in Figure 2.17 and in Annex 1 show the impact of restriction measures on $NO_2$ concentrations (relative differences between the 'lockdown' and BAU scenarios) averaged over the European Union (EU-27) and different countries plotted next to the stringency index of these countries. Over the whole year after March a weekly cycle can be seen with stronger reductions during weekdays compared to weekends. As shown in these figures, the maximum impact occurs between March and June. This corresponds to the first restriction period in Europe which is consistent with the sudden increase in relative concentration difference. During this period, the decrease of concentrations reaches a maximum of 50 % over EU. The most impacted countries are France, Spain and Italy where the restrictions were stricter with a decrease in the concentrations in relation to the expected ones of around 60 %, that reaches a maximum of 80 % in the three cases. For Germany and Poland where restriction measures were less strict, the decrease is weaker (between 30 and 40 % for Germany and between 20 % to 35 % for Poland). Finally, for Sweden where no restrictions were obligatory, the decrease is even weaker, between 10 % and 20 %.

After this period, lower decrease of concentration were simulated, as the restrictions are loosened during late spring and summer. Over the European Union, the lockdown scenario reaches similar levels to the business-as-usual scenario from end of June until end of September (close to 0 % difference). For Italy and France, the impact of restriction measures decreases rapidly at the end of the restriction period in May and concentrations of the lockdown scenario gradually reaches similar levels to the business-as-usual scenario. For Spain the impact of measures gradually decreases from May, without never reaching the BaU levels. For Germany, Poland and Sweden the return to baseline levels is faster as the previous restrictions (and difference in concentration) was weaker. Small increase of concentrations were found in Germany and Poland, which is consistent with the BSC adjustment factor that can lead to an increase of emissions during summer.

The final period from end of September to the end of the year corresponds to the general 2nd Covid-19 wave and the subsequent implementation of restrictions. For this period, Figure 2.17Figure 2.16 shows that a new phase of concentration decrease was simulated. The behavior is similar to that of the the first wave but with a lower reduction (reaching 30 % for the average over EU-27). France, Italy and

Spain are once again more impacted with a relative difference up to 40 %. Germany, Poland, and Sweden are less impacted with relative difference concentration spikes that reaches up to 30 %,20 % and 10 % respectively.

*Figure 2.17 Impact of restriction measures on $NO_2$ daily concentrations (in %) averaged over the European Union for year 2020*



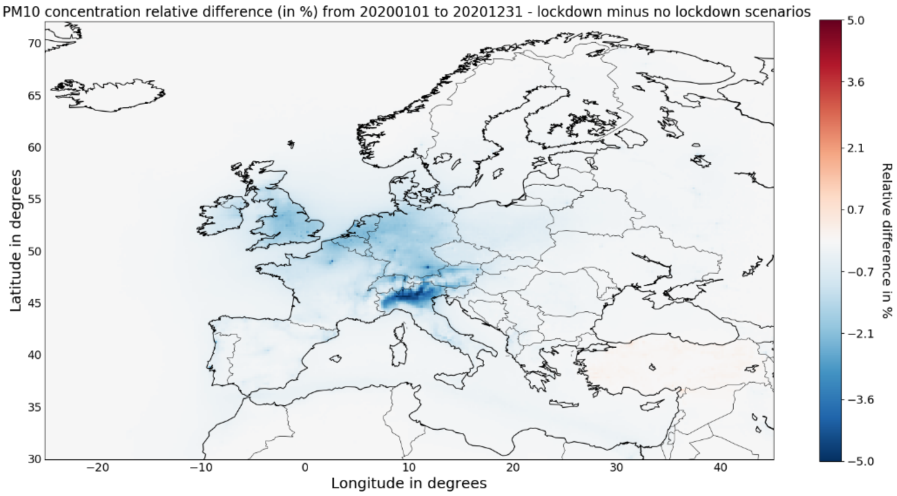

### 2.2.1.6 $PM_{10}$ and $PM_{2.5}$

The simulated impact of restriction measures on $PM_{2.5}$ and $PM_{10}$ concentrations are very similar between the two pollutants. Only the impact on $PM_{10}$ concentrations is therefore analyzed as $PM_{2.5}$ follow the same conclusions. Results for $PM_{2.5}$ are shown in Annexes 3 to 5.

**Annual relative difference**

Figure 2.18 shows that the strongest impact of restriction measures on $PM_{10}$ concentrations is concentrated in most of Western Europe (Austria, Germany, France, Switzerland, Belgium and Netherlands) with a maximum reduction that reaches 5 % over northern Italy. The decrease of concentrations is much lower than for $NO_2$ both in cities and rural areas. This is because $NO_2$ is mainly related to traffic emissions, while PM are also influenced by emissions of other activities sectors (some sectors were less affected by restriction measures, residential PM emissions even increased according to the adjustment factors), natural sources and several nonlinear processes (like ammonium nitrate formation, since, depending on ammonia concentrations, reducing $NO_2$ emissions may not lead to reduction of ammonium nitrate).

*Figure 2.18 Impact of restrictions (lockdown - BaU scenario) on annual concentrations of $PM_{10}$ (change in %) in Europe for 2020*




## Day-to-day evolution

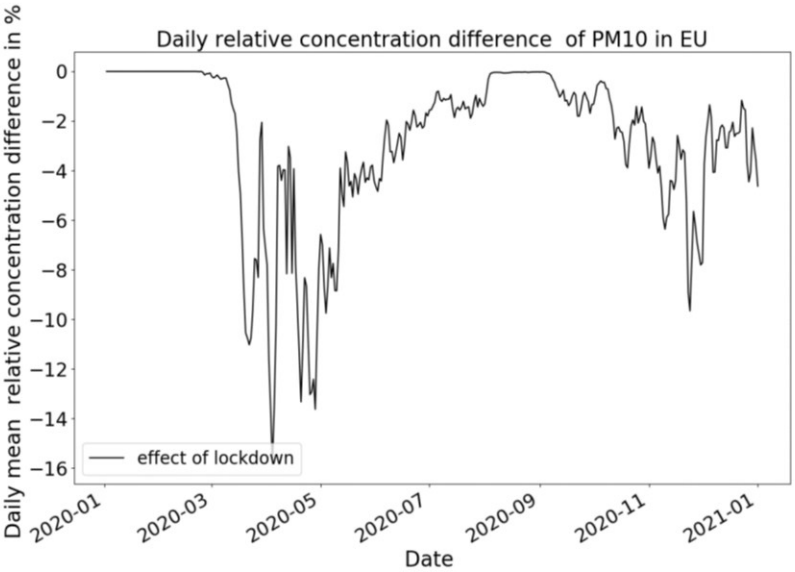
The time series in Figure 2.19 show the impact of restriction measures on daily concentrations of $PM_{10}$ averaged over EU. The same figure is shown for different countries in Annex 2 and along with the evolution of the stringency index for these countries.

As for $NO_2$, there is a strong impact of restriction measures during the first wave of Covid-19 (between March and June), corresponding to the first restrictions period in Europe, with a decrease of daily mean concentrations due to restrictions between 7 % and 14 %. The impact for $PM_{10}$ is however weaker than for $NO_2$.

A maximum impact around 20 %-25 % is simulated for Spain, Italy and France. Although restriction measures on Germany were not as intense as in these countries (which leads to a moderate impact of restriction measures on $NO_2$ concentrations), decreases of $PM_{10}$ concentrations over Germany are close to these countries with also a maximum around 20 %. For Poland and Sweden, lower relative differences for $PM_{10}$ were simulated: maximum decreases between 6 %-10 % for Poland and 4 %-6 % for Sweden.

After the first wave, the temporal evolution of concentration differences for $PM_{10}$ are similar to those of $NO_2$ concentrations.

*Figure 2.19 Impact (change in %) of restriction measures on $PM_{10}$ daily concentrations averaged over the European Union for year 2020*



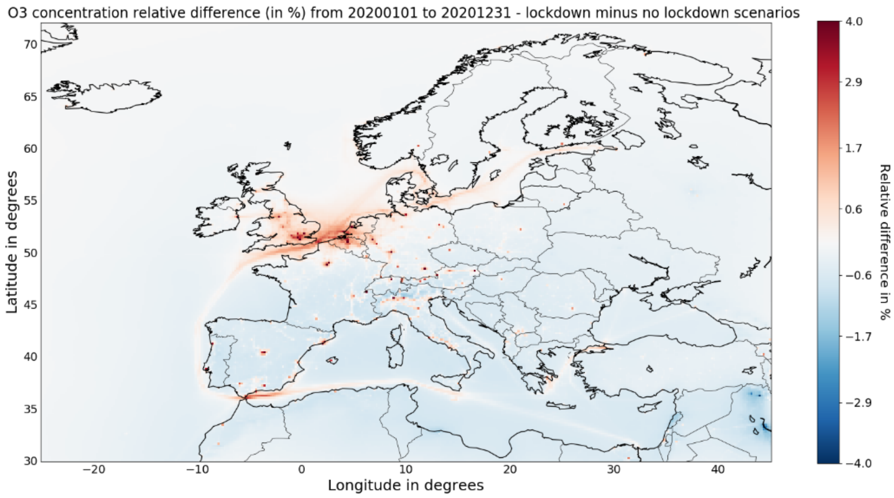

### *2.2.1.7 $O_3$*

The impact of restriction measures is relatively similar for $O_3$ daily concentrations and for $O_3$ 8-hour daily maximum concentrations with slightly lower response for the later. The results for 8-hour daily maximums are shown in Annex 7.

**Annual relative difference**

Figure 2.20 shows that the restriction measures mainly lead to an increase of $O_3$ annual mean of daily concentrations especially in areas with high anthropogenic emissions (such as cities and some maritime routes). An increase above 5 % was simulated for some cities. Except for these areas, the differences between the scenarios are generally quite low (<1 %).

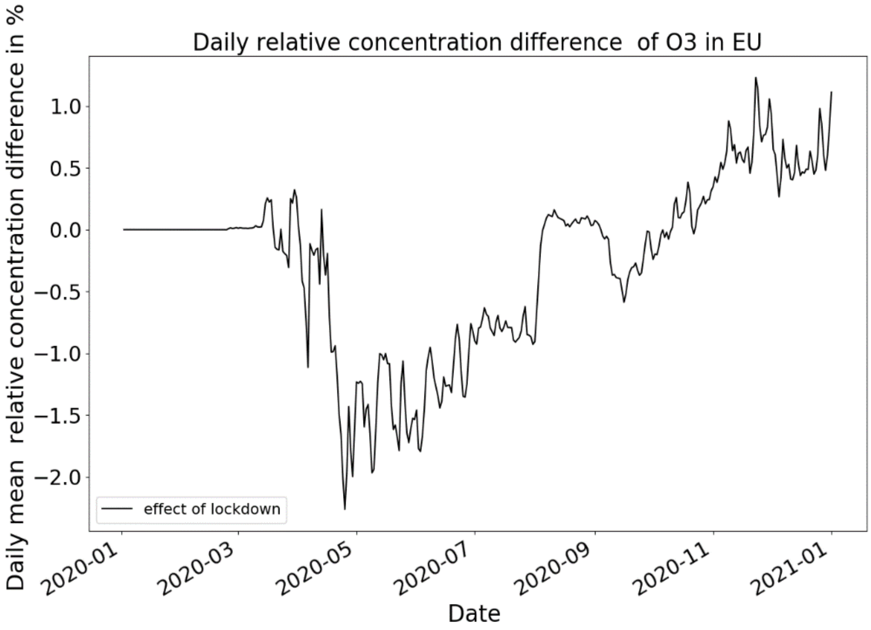
*Figure 2.20 Impact of restrictions (lockdown - BaU scenario) on annual concentrations of $O_3$ (change in %) in Europe for 2020*




## Day-to-day evolution

The time series in Figure 2.21 shows the impact of restriction measures on daily mean concentrations of $O_3$ averaged over EU. The same figure is shown for different countries in Annex 6 along with the evolution of the stringency index for these countries. The overall impact of the restrictions on the relative concentration is overall quite low (less than 2.5 % for the EU mean and less than 5 % for individual countries). All the time series have the same behavior: a weak decrease of concentrations due to restrictions during the spring and summer and a low increase in concentrations during fall. This feature is likely due to differences in NOx regimes between the seasons. Under very high NOx conditions, a decrease of NOx emissions can lead to an increase of $O_3$ concentrations. These conditions are likely to be obtained during fall and winter (due to low biogenic emissionsof volatile organic compounds during these periods).

*Figure 2.21 Time series of European Union daily relative concentration difference (in %) of daily mean $O_3$ for year 2020*




### *2.2.1.8 SOMO10 and SOMO35 annual relative difference*

For SOMO10 (FigureFigure 2.22) and SOMO35 (Figure 2.23), unlike annual mean $O_3$, an overall reduction was simulated over a large part of Europe with nevertheless substantial areas where increases are found. Those areas with increases are mainly coastal zones around the English Channel, the North and the Baltic seas and the Gibraltar Strait. Figure 2.23 shows a "mosaic pattern" due to the large number of O3 hourly concentrations close to 35 ppb, resulting in a threshold effect on the computation of differences between the two scenarios. This same thresholding effect was already reported to induce larger uncertainties for the AirGAM estimated of SOMO35.

*Figure 2.22 Impact of restrictions (lockdown - BaU scenario) on annual SOMO10 (change in %) in Europe for 2020*

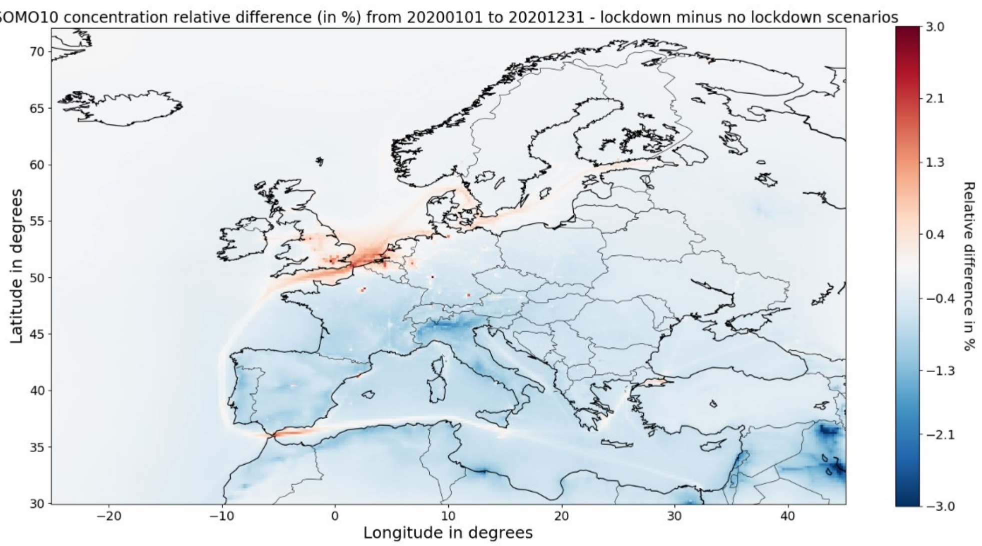
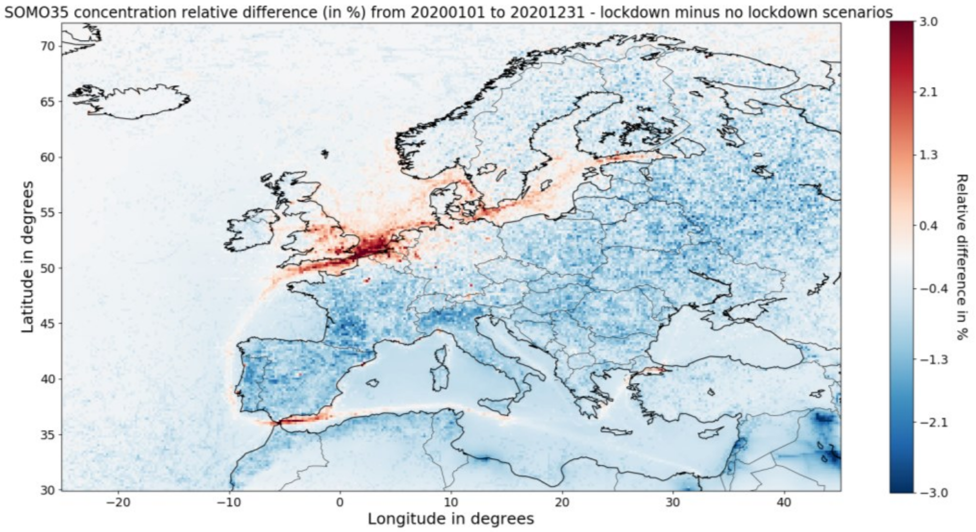


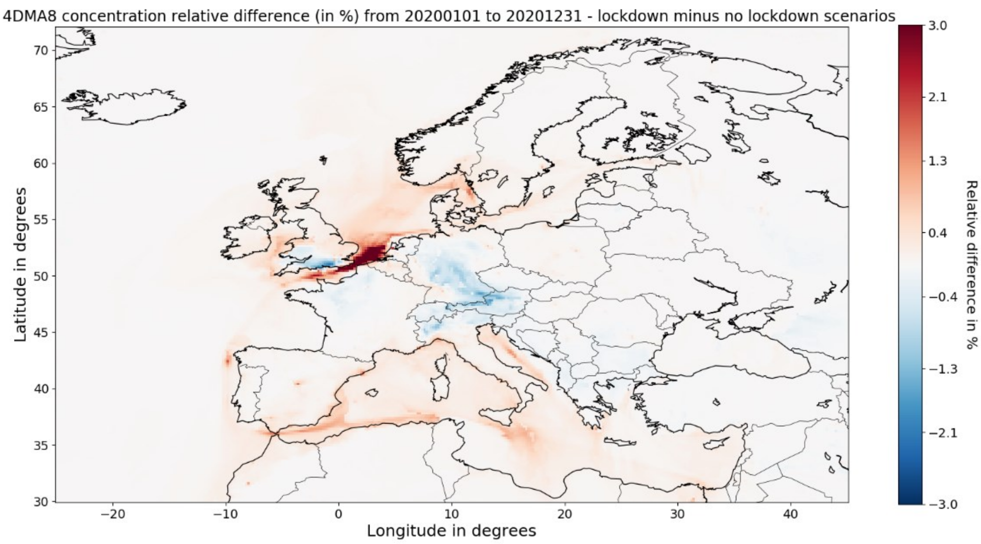
*Figure 2.23 Impact of restrictions (lockdown - BaU scenario) on annual SOMO35 (change in %) in Europe for 2020*




### *2.2.1.9 4MDA8 annual relative difference*

Figure 2.24 shows that 4MDA8 relative difference were less strongly affected by the restriction measures (differences between -1 % and 1 %) for most land areas. A local increase of a few percent was however simulated by the model over sea areas and the city of Madrid. A possible explanation can be that NOx emissions increase with the BSC adjustment factor which could increase for some cities during some days but not for others. For the seas, it is very likely that the strong reduction of shipping activities led to a strong decrease of NOx emissions over seas and therefore an increase of $O_3$ concentrations (less titration due to high NOx concentrations and low VOC concentrations over seas).

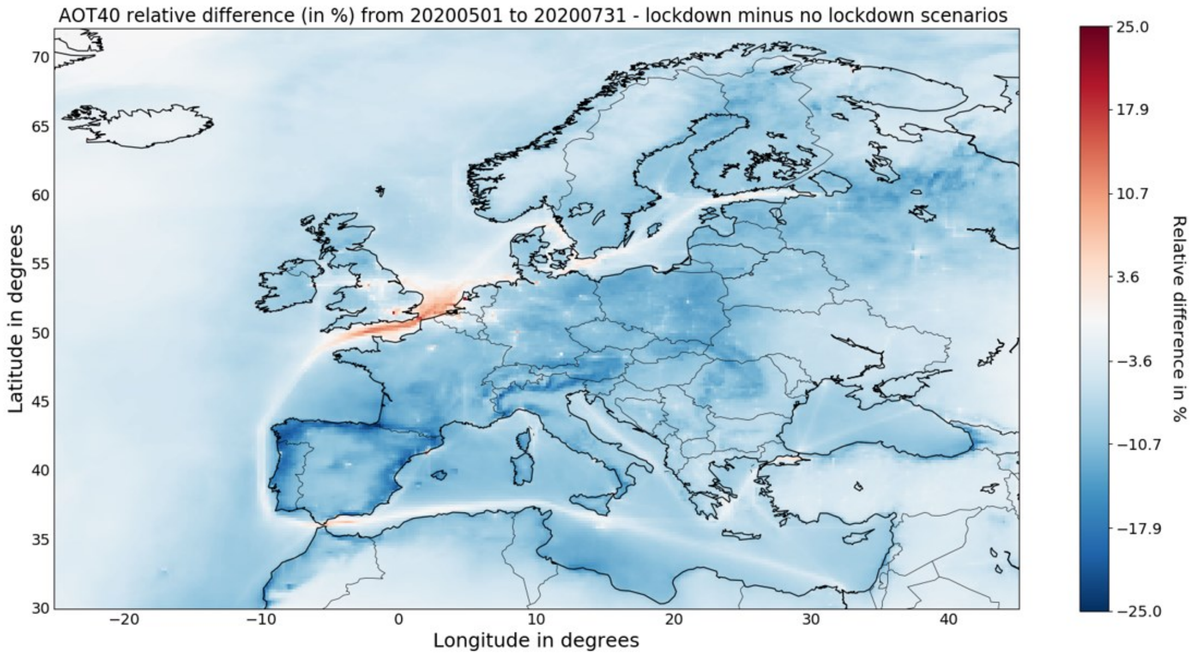
*Figure 2.24 Impact of restrictions (lockdown - BaU scenario) on annual 4MDA8 of $O_3$ (change in %) in Europe for 2020*



### 2.2.1.10 AOT40 annual relative difference

A stronger impact of restriction measures was simulated for AOT40 with strong decrease over most Europe that can reach 20 % over some areas (especially on the coasts of Spain). A few local increases of AOT40 were however simulated over some of the largest cities and the English Channel, where no or little impact is to be expected since there is no much vegetation.

*Figure 2.25 Impact of restrictions (lockdown - BAU scenario) on annual AOT40 (in %) in Europe for 2020*




## 2.3 Comparison of AirGAM and CHIMERE results

The impact of restrictions estimated with the CHIMERE model for the annual concentrations of $NO_2$, and PM and several ozone metrics are summarized in Table 2.4. It is important to keep in mind that the results from AirGAM and CHIMERE could not be compared directly. The main reason being that the latter is based on a comparison between gridded model data covering all countries whereas the former is based on individual station data and thus strongly dependent on the station coverage in the individual countries. Thus, these two very different approaches have their separate pros and cons. A chemical transport model such as CHIMERE is designed to reproduce physio-chemical processes in the atmosphere but may have imperfections in predicting the actual conditions e.g. at measurement sites located in urban areas. AirGAM is a statistical model only based on observed systematic relationships between explanatory and predicted variables at a given location without consideration of long range impacts or parameterization of the physiochemical processes ruling the relationship between emission and concentrations. This could, however, also be an advantage in situations that are difficult to be described properly in grid models, such as urban stations where the CHIMERE simulation resolution is not sufficient to capture local features.

Both models estimate that the strongest impact of the restrictions were on $NO_2$ concentrations with decrease of concentrations between 13 % and 19 % according to AirGAM and between 10 % and 13.5 % with CHIMERE for the countries with the strongest response to the first wave of Covid-19 (Belgium, France, Italy, Portugal, , and Spain). In comparison, both models estimate lower decreases (less than 10 %) due to the restrictions for particulate matter but with higher estimated impact by AirGAM (median decrease over all countries of 5 %) than by CHIMERE (decrease of 0.7 % for all countries). Important differences in the impact on $NO_2$ concentrations can however be found between the two methods for specific countries, especially for Ireland (-34 % for AirGAM and -13.5 % for CHIMERE, but the value for AirGAM was regarded as an artifact), Sweden (-16 % for AirGAM and -5 % for CHIMERE), Slovenia (-19 % for AirGAM and -7.5 % for CHIMERE) and Slovakia (-19 % for AirGAM and -6 % for CHIMERE). As mentioned above these differences could reflect the station network in the individual countries since AirGAM is based only on the monitoring stations whereas CHIMERE calculates the average over the whole country.

In the case of $O_3$, AirGAM estimated effects on MDA8 annual concentrations (changes between -7 % and +1 %), SOMO35 (between -23 % and +24 %) and SOMO10 (between -11 % and +1 %) yet indicating that those difference were not statistically significant. These values are generally higher than those estimated by CHIMERE (change between -1.1 % and +1 % for all these metrics). CHIMERE estimates however a strong effect of restrictions on AOT40 (decrease of 10 % over EU), which was not computed with AirGAM.

*Table 2.4 Estimated effect by CHIMERE (in % change) of restrictions on annual concentrations of $NO_2$, $O_3$, $PM_{10}$, $PM_{2.5}$ and several ozone metrics for the countries of the European Union*

| Country | $NO_2$ | $O_3$ | $PM_{10}$ | $PM_{2.5}$ | MDA8 | SOMO10 | SOMO35 | 4DMA8 | AOT40 |
|---|---|---|---|---|---|---|---|---|---|
| AT | -12,8 | -0,2 | -1,6 | -2,3 | -0,7 | -0,7 | -0,6 | -0,5 | -3,8 |
| BE | -13,6 | 0,9 | -1,9 | -2,5 | 0,2 | 0,2 | 0,5 | 0,3 | -8,0 |
| BG | -4,3 | -0,4 | -0,1 | -0,2 | -0,5 | -0,5 | -0,8 | -0,1 | -9,3 |
| CY | -8,2 | -0,5 | -0,1 | -0,1 | -0,7 | -0,7 | -0,7 | 0,1 | -12,0 |
| CZ | -4,4 | -0,4 | -0,7 | -1,0 | -0,5 | -0,5 | -0,6 | 0,0 | -10,0 |
| DE | -8,3 | 0,1 | -1,5 | -2,0 | -0,3 | -0,3 | -0,2 | -0,1 | -5,5 |
| DK | -9,9 | 0,2 | -0,6 | -0,9 | 0,0 | 0,0 | 0,2 | 0,3 | -10,8 |
| EE | -4,1 | -0,1 | -0,1 | -0,2 | -0,2 | -0,2 | -0,4 | 0,1 | -14,1 |
| ES | -13,5 | -0,4 | -0,3 | -0,5 | -0,7 | -0,7 | -0,9 | 0,2 | -9,1 |
| FI | -3,8 | -0,1 | -0,1 | -0,1 | -0,1 | -0,1 | -0,4 | 0,0 | -10,9 |
| FR | -11,8 | -0,3 | -0,7 | -1,2 | -0,6 | -0,6 | -0,7 | 0,1 | -7,6 |
| GR | -6,9 | -0,5 | -0,1 | -0,2 | -0,6 | -0,6 | -0,7 | 0,0 | -9,0 |
| HR | -4,9 | -0,6 | -0,3 | -0,4 | -0,7 | -0,7 | -0,8 | 0,0 | -10,6 |
| HU | -4,4 | -0,5 | -0,3 | -0,4 | -0,6 | -0,6 | -1,1 | 0,0 | -8,8 |
| IE | -13,5 | -0,1 | -0,7 | -1,2 | -0,2 | -0,2 | -0,3 | 0,1 | -10,9 |
| IT | -13,1 | -0,4 | -0,8 | -1,3 | -0,9 | -0,9 | -0,9 | 0,1 | -10,9 |
| LT | -3,0 | -0,2 | -0,3 | -0,4 | -0,2 | -0,2 | -0,7 | 0,0 | -10,4 |
| LU | -11,0 | 0,1 | -1,5 | -2,0 | -0,4 | -0,4 | -0,3 | 0,1 | -11,3 |
| LV | -2,6 | -0,2 | -0,2 | -0,2 | -0,2 | -0,2 | -0,7 | 0,0 | -4,4 |
| MT | -13,0 | 0,0 | -0,2 | -0,4 | -0,2 | -0,2 | -0,2 | 0,4 | -1,9 |
| NL | -9,3 | 1,0 | -1,8 | -2,5 | 0,4 | 0,4 | 1,0 | 0,4 | -13,0 |
| PL | -4,9 | -0,2 | -0,5 | -0,7 | -0,4 | -0,4 | -0,7 | 0,1 | -13,5 |
| PT | -10,6 | -0,4 | -0,2 | -0,3 | -0,6 | -0,6 | -0,9 | 0,1 | -9,4 |
| RO | -4,1 | -0,4 | -0,2 | -0,2 | -0,5 | -0,5 | -1,0 | 0,0 | -8,0 |
| SE | -5,2 | -0,1 | -0,1 | -0,2 | -0,1 | -0,1 | -0,3 | 0,1 | -12,2 |
| SI | -7,5 | -0,5 | -0,9 | -1,3 | -0,7 | -0,7 | -0,8 | -0,1 | -12,6 |
| SK | -5,8 | -0,4 | -0,5 | -0,7 | -0,6 | -0,6 | -1,0 | 0,0 | -10,7 |
| EU-27 | -7.5 | -0,2 | -0,34 | -0,5 | -0,5 | -0,5 | -0,7 | 0,1 | -10,4 |

## 2.4 Conclusions on AirGAM and CHIMERE modelling

The effect of restriction measures on air quality was analyzed with the statistical AirGAM model and the deterministic geophysical CHIMERE model. Both models estimate that the strongest impact of the restrictions were on $NO_2$ concentrations with decrease of concentrations between 13 % and 19 % according to AirGAM and between 10 % and 13.5 % with CHIMERE for the countries of the European Union, with the largest reductions over the countries with the strongest response to the first wave of Covid-19 (Belgium, France, Italy, Portugal and Spain). Both models indicate that the first restriction period (from mid-March to April/May) was clearly the most severe, leading to major reductions in the $NO_2$ levels in many countries. The lifting of the measures led to a gradual normalisation by mid-July. Later in 2020 (from mid-October), significant reduction of $NO_2$ concentrations were estimated, but at a lower scale than during the first wave.

In comparison, the impact of restrictions on PM and $O_3$ concentrations is quite low (with an impact of the restrictions on concentrations close to zero according to CHIMERE and at most a decrease of few percents according to AirGAM). However, a significant impact on AOT40 over Europe (-10.4 %) was found with CHIMERE.

For both $NO_2$ and PM, a larger reduction is estimated with AirGAM at traffic sites compared to rural and suburban/urban background sites, but the differences among the station types are not very large. For $PM_{10}$ and $PM_{2.5}$, AirGAM estimated that 2 and 4 sites, respectively, dropped their concentrations below the annual limit values in 2020 due the effects of the pandemic, whereas for $NO_2$ 11 % of all the considered stations saw their concentrations fall below the annual limit value.

While the main conclusions are similar with the two approaches, some differences were obtained with the two models. In the case of $O_3$ MDA8, the AirGAM model estimates an increase of concentrations over some countries of a few percent (up to 7 % for Malta) whereas an increase of annual concentrations was simulated with CHIMERE only over large European cities. A change of annual concentrations over countries between -1 % and +1 % was estimated with CHIMERE (a decrease of -0.2 % is estimated for EU).

# 3 Case study: Effect of measures associated with Covid-19 pandemic on NOx concentrations in major cities in the Czech Republic

Oftentimes, cities or regions are faced with the need to provide an analysis of such interventions without the benefit or access to the complex modeling systems. There are various statistical methods that aim to compensate for the effect of the meteorological conditions. Carslaw and Taylor (2009) developed a method that uses boosted regression trees. Other authors, such as for example Munir (Munir et al., 2021; Solberg et al., 2021, or Chapter 2 of this report) used Generalized Additive Model (GAM) to try to estimate the contribution of meteorological factors towards observer air pollutant concentrations. To apply the above methods, accurate and complete long-term data representing the actual meteorological parameters are needed, and is not always available.

In this case study, a different approach was used to try to “de-weather” the pollutant concentration data. This method requires data from two nearby stations of different classification (background and traffic). If these stations are geographically close enough, one can make the assumption that in the long-term, the meteorological parameters will be very similar, but the local emission intensities will vary. During the restriction period, traffic and mobility of the population in general was limited, and the emissions from traffic are thus assumed to be reduced.

In order to investigate this hypothesis, we define pairs of nearby background and traffic stations, with assumed similar meteorological conditions in the long-term. Then, instead of comparing the actual measured values during the restriction period and a reference period, we calculate the ratio between the concentrations measured at the two types of stations and compare those. The contribution of traffic towards the overall observed concentrations is much more significant at traffic stations than at background stations. The hypothesis therefore is that if there is a decrease in traffic emissions, assuming same meteorological parameters, there should be a change in this ratio.

In the Czech Republic, traffic contributes the most towards the concentrations of nitrogen oxides ($NO_x$) (nitrogen dioxide, $NO_2$ + nitrogen monoxide, NO). Therefore, concentrations of $NO_x$ tend to be much higher at traffic stations compared to background stations. Reduced traffic leading to lowered emissions from traffic, should result in a decreased ratio between $NO_x$ traffic / $NO_x$ background (i.e. the difference between $NO_x$ concentrations at the traffic and nearby background station should be smaller).

## 3.1 Stations analyzed

The following case study analysis uses data from pairs of traffic-background station from the three largest cities in the Czech Republic – Prague, Brno and Ostrava. For each pair, a ratio between $NO_x$ concentrations at the traffic and background station is calculated and grouped by year, month and week of the year. These ratios are then compared for the year 2020 and the 5-year average 2015-2019[5] (reference period).

Table 3.1 shows summary information for the analyzed stations. In each case, the horizontal distance between the two stations is within 20 km, in the case of Ostrava even less than 5 km. For the two largest cities (Prague and Brno), a station at the main airport was used. However, in the case of Prague, this station is categorized as traffic, while in the case of Brno as background. This is due to the major different between how busy the airports are. Prague Airport is the main Czech airport. In contrast, the airport in Brno-Tuřany is very small and not very busy.

[5] in one pair, data is only available since 2017, so in this case a 3-year average 2017-2019 was used instead.

*Table 3.1 Characterization of the studied station pairs*

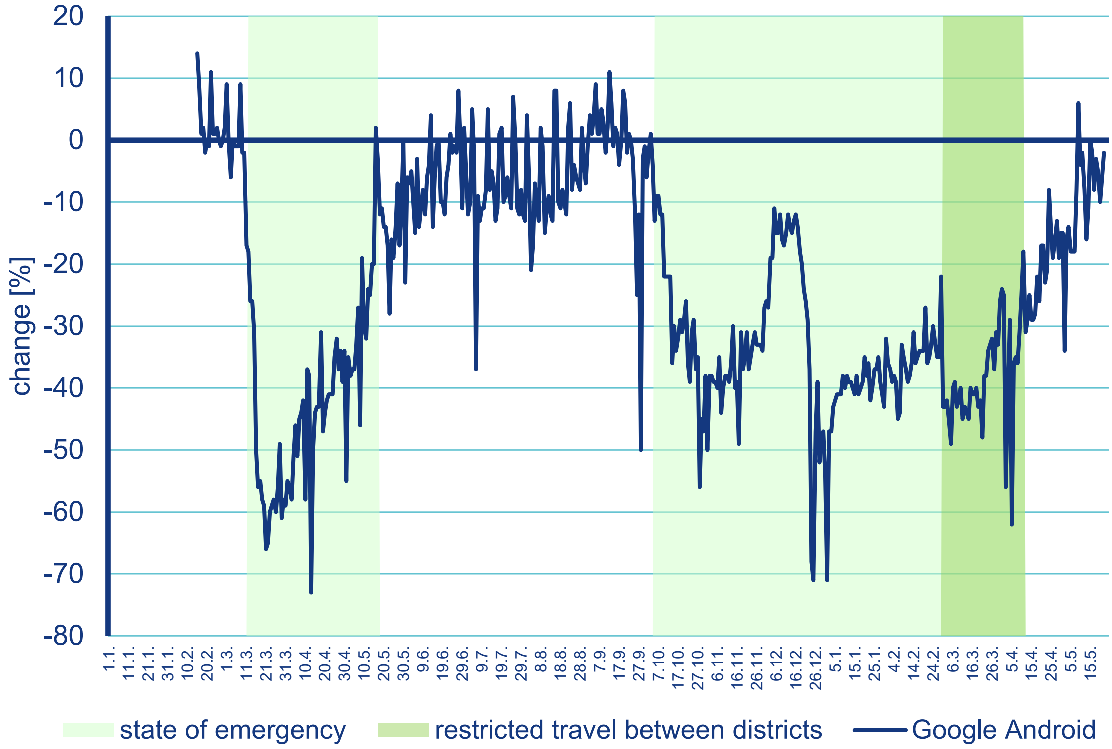
| Name | Type | Zone | Lat/lon | Distance |
|---|---|---|---|---|
| **Prague (Praha)** | | | | |
| **Praha Letiště (Prague airport)** | Traffic | Suburban | 50°06'25.5"N 14°15'26.0"E | 17.4 km |
| **Praha-Libuš** | Background | Suburban | 50°00'26.3"N 14°26'45.4"E | |
| **Brno** | | | | |
| **Brno-Úvoz (hot spot)** | Traffic | Urban | 49°11'53.1"N 16°35'37.1"E | 8.7 km |
| **Brno-Tuřany (Brno airport)** | Background | Suburban | 49°08'56.3"N 16°41'46.4"E | |
| **Ostrava** | | | | |
| **Ostrava-Poruba DD** | Traffic | Urban | 49°50'07.7"N 18°09'54.8"E | 1.2 km |
| **Ostrava-Poruba ČHMÚ** | Background | Suburban | 49°49'31.1"N 18°09'33.4"E | |

## 3.2 Measures to prevent the spread of coronavirus

First cases of Covid-19 in the Czech Republic were reported on March 1, 2020. The disease was spreading relatively quickly. Already 12 days later, on March 12, schools were closed and on March 16, a state of emergency declared in the entire country. Many people were scared, the government highly recommended employers to utilize working from home as much as possible. This led to a significant decrease in traffic intensity.

Figure 3.1 represents mobility given as percentage from reference period. This data comes from anonymous data from Google Android operating system users in the Czech Republic (LLC, 2021). This chart shows the period between mid of February 2020 to May 20, 2021. State of emergency is highlighted by light green color. Period, during which travel between districts was restricted is shown in dark green.

*Figure 3.1 Anonymous mobility data for the studied period, as per cent change from the reference period (the 5-year average 2015-2019).*




It can be seen that after the first state of emergency was declared in mid-March 2020, there was a major decrease in mobility. As time passed, the difference from reference value became smaller. This can be explained by several factors – after the initial shock and fear, and in some cases panic, people calmed down and thus slowly started moving around again. Also, the third and fourth week in March 2020 was characterized by very below-average temperatures and bad weather in general, which changed in April. This could also be a reason why people started leaving their homes more frequently.

During the summer, the number of Covid-19 patients was very low and it seemed like the pandemic was over. This is reflected in the graph above, where the mobility during the summer months of 2020 was close to the long-term normal (change of 0 %). Then in the fall a second wave of the pandemic occurred, leading to another state of emergency and another major decrease in mobility.

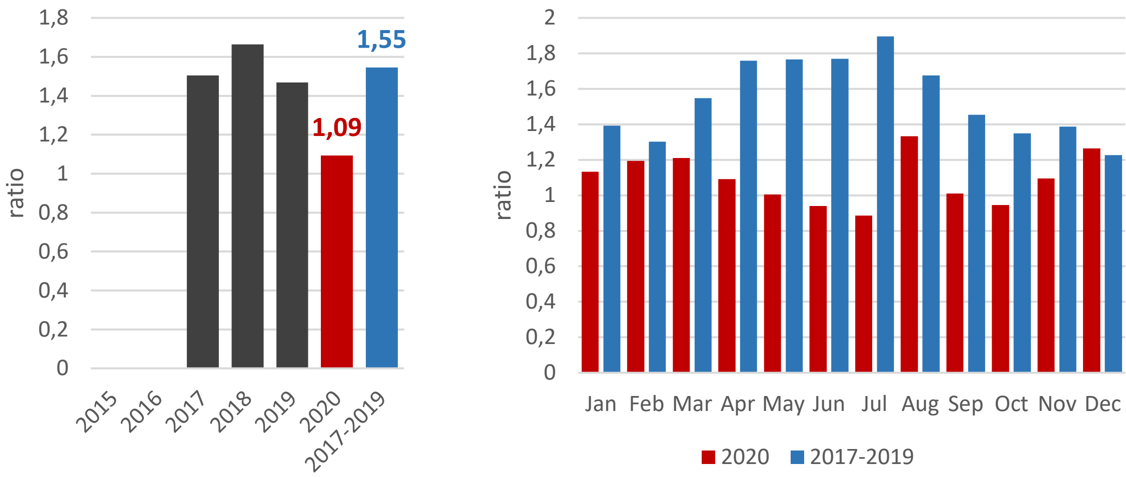
## 3.3 Results

### *3.3.1 Prague*

Two stations were compared in Prague. A traffic suburban station Praha-Letiště (Prague Airport) and a background suburban station Praha-Libuš (Czech Hydrometeorological Institute observatory). The main international airport was one of the places where traffic decreased the most. The number of flights was drastically reduced and this meant lower emissions from both cars and buses taking passengers to and from the airport, as well as the planes themselves. For this pair of stations, data from both stations is only available since 2017.

Figure 3.2 shows the average annual and monthly ratios between the concentrations of $NO_x$ Praha-Letiště and $NO_x$ Praha-Libuš. Values for the year 2020 are shown in dark read, values of 2017-2019 average are shown in dark blue color.

*Figure 3.2 Annual (left) and monthly (right) mean ratio between $NO_x$ concentrations at Praha Letiště (traffic station) and Praha-Libuš (background station) for the years 2017 to 2020 and 2017-2019 overall average*

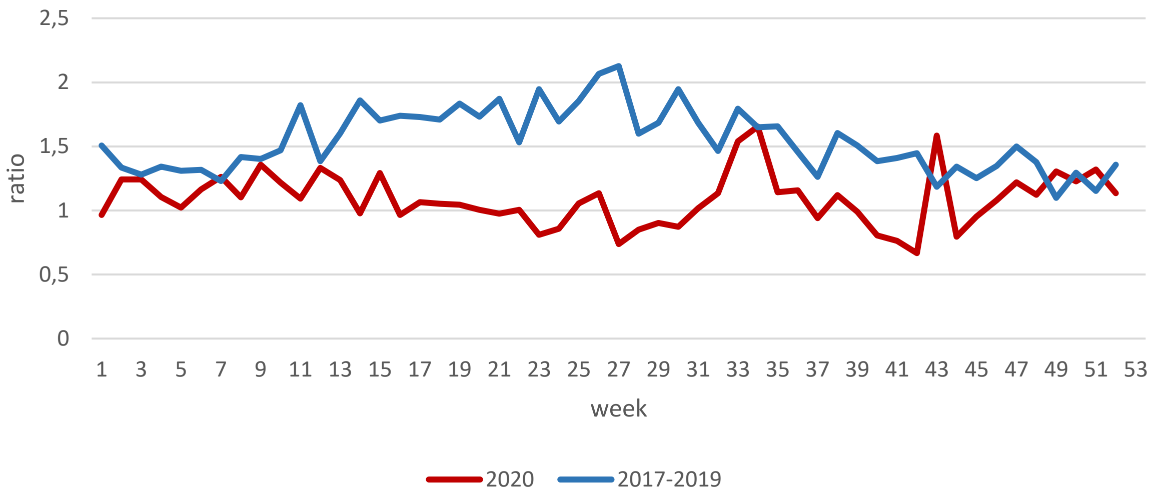



In the case of the first annual chart, the ratio is by far the lowest in the year 2020. This corresponds to the hypothesis and expectation that the contribution of traffic is much lower, thus $NO_X$ concentrations are lower at the traffic station. In the long-term annual average 2017-2019, the $NO_x$ concentrations were approximately 55 % higher at the traffic station compared to the background station. In 2020, the overall difference was only less than 10 %.

The second monthly bar chart shows a major decrease in the ratio especially after March, although the ratio was also lower in the first two months of 2020 (primarily because of exceptionally favorable meteorological conditions in those two months).

Figure 3.3 shows the average ratio between the $NO_x$ concentrations at the traffic and background station grouped by the week of the year. Just like the previous two charts, one can see that the red line (year 2020) closely follows the 2017-2019 average until approximately the week 12. The first state of emergency was declared on March 16$^{th}$ 2020, which corresponds to the 12$^{th}$ week of the year. The weekly ratio chart therefore again shows that the contribution of traffic decreased as a result of the measures associated with the pandemic.

*Figure 3.3 Average ratio between $NO_x$ hourly concentrations at Praha Letiště (traffic station) and Praha-Libuš (background station) for the years 2017 through 2020 and 2017-2019 overall average for the individual weeks of the year*

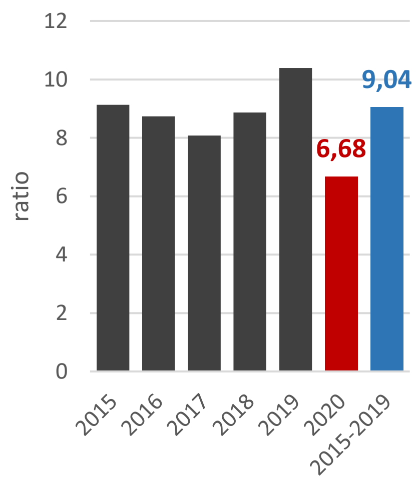


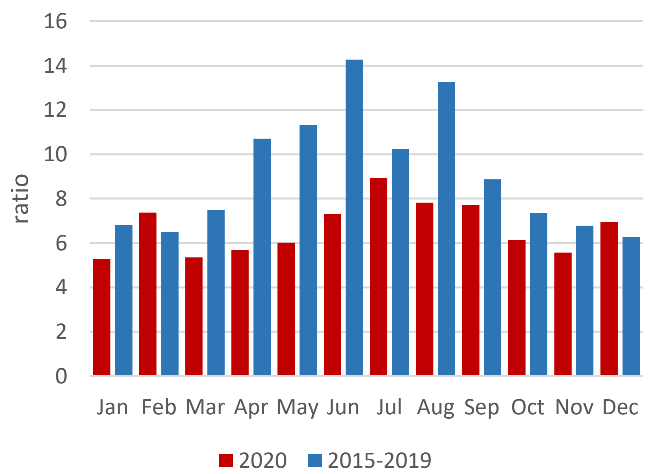

### 3.3.2 Brno

In Brno, the second largest city in the Czech Republic, urban traffic (hot-spot) station Brno-Úvoz was compared with a suburban background station Brno-Tuřany. The two stations are less than 10 km apart from each other.

Figure 3.4 show the average annual and monthly ratios between the concentrations of $NO_x$ Brno-Úvoz and $NO_x$ Brno-Tuřany. Values for the year 2020 are shown in dark read, values of 2015-2019 average are shown in dark blue color.

*Figure 3.4 Annual (left) and monthly (right) mean ratio between $NO_x$ hourly concentrations at Brno-Úvoz (traffic station) and Brno-Tuřany (background station) for the years 2015 through 2020 and 2015-2019 overall average*

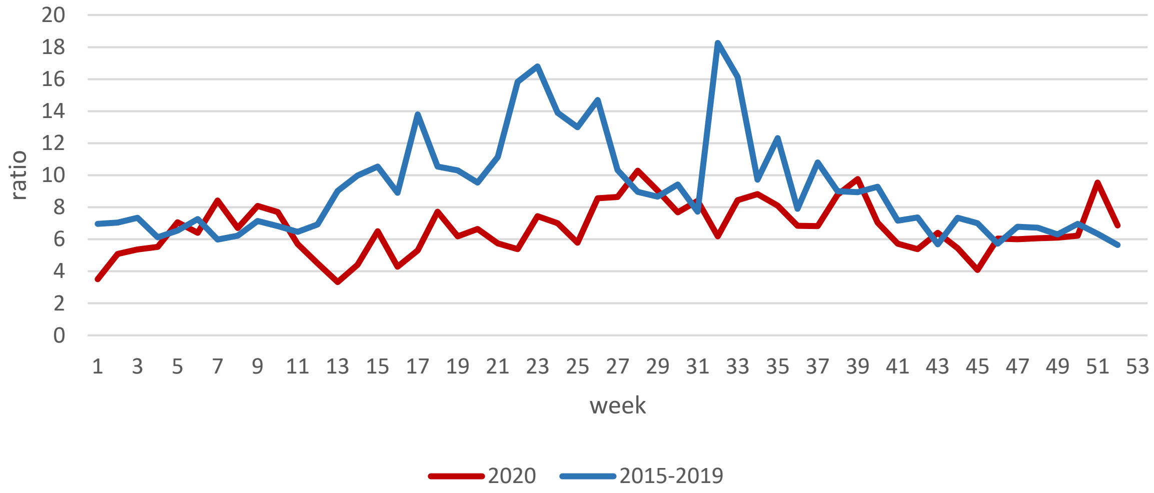



The station Brno-Úvoz is situated at a crossroad between two major roads close to the city center. It is further classified as a "hot-spot" station, meaning it is one of the most traffic-intense stations in the country. This is also proven by the very high overall ratio between this traffic station and the nearby background station. In some months the $NO_x$ concentration at Brno-Úvoz station is more than 10 times the value in Brno-Tuřany.

The annual bar chart shows that in 2020, the $NO_x$ ratio was the lowest of all six years analyzed. Compared to a long-term 5-year average, the difference is approximately 33 %. Also, the monthly means show that from March 2020, there has been a change and the ratio decreased with the declaration of the first state of emergency. This can also very well be seen in Figure 3.5, which shows weekly progress of the $NO_x$ ratio at these two stations.

*Figure 3.5 Average ratio between $NO_x$ hourly concentrations at Brno-Úvoz (traffic station) and Brno-Tuřany (background station) for the years 2015 through 2020 and 2015-2019 overall average for individual weeks of the year*



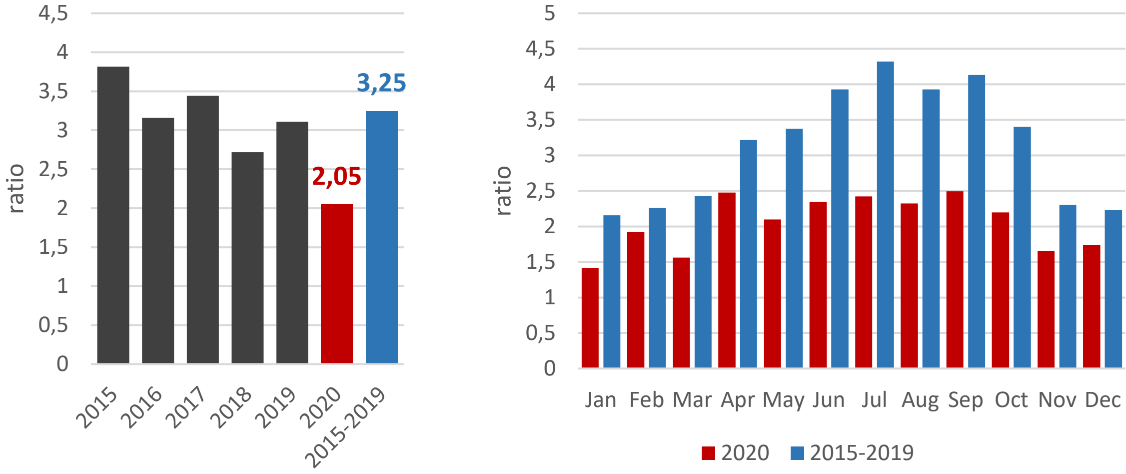

Just like in the case of Prague (Figure 3.3), starting in the 12th week, the ratio, which until then was in 2020 close to the 2015-2019 average, started to significantly decrease.

### *3.3.3 Ostrava*

In Ostrava, two stations just a little over 1 km apart from each other were compared. Both are located in the Poruba suburb of Ostrava, one being a traffic station (Ostrava-Poruba DD) and the other one being a background station (Ostrava-Poruba ČHMÚ).

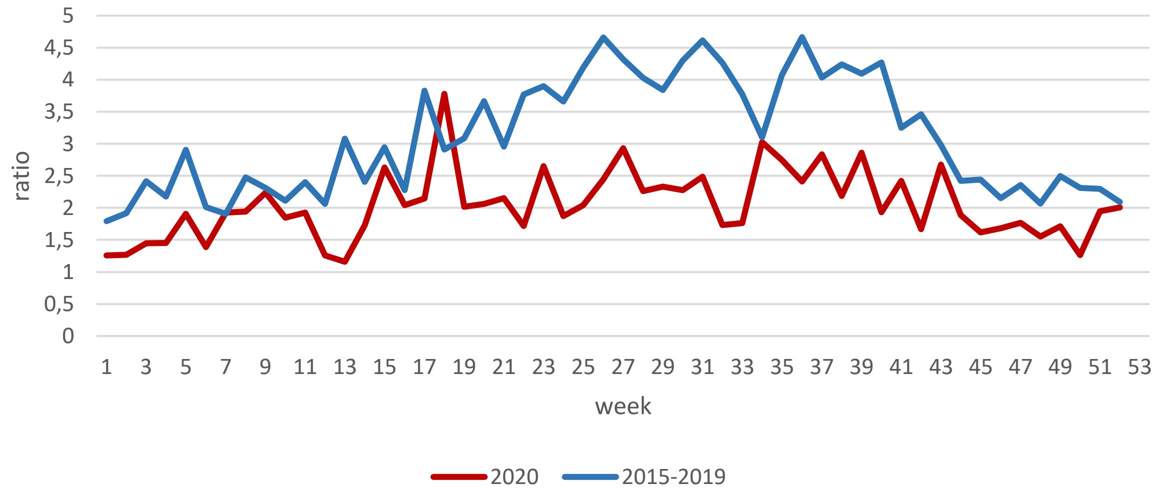
Figure 3.6 shows the average annual and monthly ratios between the concentrations of $NO_x$ Ostrava-Poruba DD and $NO_x$ Ostrava-Poruba ČHMÚ. Values for the year 2020 are shown in dark read, values of 2015-2019 average are shown in dark blue color.

*Figure 3.6 Annual (left) and monthly (right) mean ratio between $NO_x$ hourly concentrations at Ostrava-Poruba DD (traffic station) and Ostrava-Poruba ČHMÚ (background station) for the years 2015 through 2020 and 2015-2019 overall average*




In the year 2020, the average annual ratio was the lowest from all the six years analyzed. While the long-term 5-year average shows that the concentration of $NO_x$ is on average 3,25 times higher than that at the background station, in 2020 it was only slightly above 2 times higher. In addition, the monthly bar chart shows that the difference was observed mostly after the onset of the pandemic measures. Figure 3.7 shows the same ratio, this time averaged by week number of the year. The ratio decreased after week 12, increased back to long-term average and decreased again after week 19.

*Figure 3.7 Average ratio between $NO_x$ concentrations at Ostrava-Poruba DD (traffic station) and Ostrava-Poruba ČHMÚ (background station) for the years 2015 through 2020 and 2015-2019 overall average for the individual weeks of the year*



## 3.4 Conclusion

In each of the three station pairs, there was a clear evidence of the effect of the reduced traffic associated with the measures taken to prevent the spread of the Covid-19 disease. The study focused on the comparison between $NO_x$ concentrations at a traffic station and a nearby background station, looking at the concentration ratios.

In all three cases, the year 2020 had by far the lowest ratio of the years analyzed (2015-2020 in the case of Brno and Ostrava and 2017-2020 in the case of Prague). Average ratios calculated for the individual weeks of the year showed a major divergence from the long-term average usually during the 12$^{th}$ week of the year 2020, which exactly matches the week when the first state of emergency was declared.

Absolute values of concentrations are not directly proportional to the actual emissions. Other factors come into play, primarily meteorological conditions which have a very significant effect on air quality and are mostly responsible for interannual variability.

Comparing the ratio of concentrations at two nearby stations, where it can be assumed that in lthe ong-term the meteorological conditions are comparable, tries to subtract the effect of meteorological factors.

Although it cannot be said that as a result of the measures the concentrations of $NO_x$ were lower (they could have been, but not necessarily in all cases), it can be said that if there was no pandemic and no measures taken, under the same meteorological conditions, the $NO_x$ concentrations would have been higher.

In 2020, the first two months there were no restrictions and no significant reduction in traffic. This is also proven by the monthly bar charts where the major decrease occurred only in March. The difference between the annual average ratio 2015-2019 and the 2020 average ratio can be slightly biased by this fact. Table 3.2 compares the long-term averages and the differences between mean ratios only for the period Mar-Dec for the three cities analyzed. The table also shows percentage decrease in ratio in 2020.

*Table 3.2 Average ratio of $NO_x$ concentrations for three city station pairs, period March to December, reference period and intervention period*

| City | Mean 2015-2019* Mar-Dec | Mean 2020 Mar-Dec | Difference between mean ratios (%) |
|---|---|---|---|
| **Prague** | 1.58 | 1.08 | 31.7 |
| **Brno** | 9.65 | 6.75 | 30.1 |
| **Ostrava** | 3.37 | 2.13 | 36.8 |

* in the case of Prague 2017-2019.

Based on the results, the approximate decrease in $NO_x$ emissions at the stations analyzed ranges between 30 and 37 %. This approximation is very close to the estimates of reduction in traffic based on direct traffic counting. In Prague it was estimated to be approximately 35 % (TSK, 2020). This is broadly in line with the results presented in Chaper 2 (e.g., see Figure 2.10).

In addition to estimating the effects of the restrictions on $NO_x$ concentrations in Prague, Brno and Ostrava, this approach is an alternative to CTM or GAM modeling when only limited input data are available. For the studied stations, this simplified approach has yielded reasonably consistent result with the more complex modeling. CTM and GAM modeling results are to be expected to provide a more comprehensive picture of developments in larger geographic areas, but they require computational capacity and complex input data. The statistical approach shown here is undemanding on computational resources and input data. It can be used for areas where there are data from pairs of stations located within an area with similar meteorological characteristic but expected differences in emission strength development, but where computational capabilities or input data for CTM or GAM modeling are not available. While likely less transferable beyond each given pair of stations, the results give a first indication of the developments in ambient concentrations with emission changes.

# 4 Impacts on the restrictions on future NECD compliance

This chapter explores the potential impacts of Covid-19 related restrictions and subsequent recovery on the European Union (EU) Member States' compliance with 2030 commitments under the Directive (EU) 2016/2284 of the European Parliament and of the Council on the reduction of national emission of certain atmospheric pollutants (the 'NECD'). The impact is assessed with the aid of information submitted under Commission Implementing Decision (EU) 2018/1522 which requires Member States to submit data on additional policies and measures (PaMs) which are being considered (but not yet selected for adoption) and those which have been selected for adoption (but not yet adopted) to meet national emission reduction commitments. It should be noted that if a Member State considers that they will continue to meet their emission reduction commitments with existing PaMs then information is not required to be reported under the NECD.

In 2021, Member States submitted projected emissions (using a base year of 2019) under the NECD, these projections have been compared against the 2030 emissions targets. Member States are defined as being at risk of non-compliance in this report when their projected 2030 emissions are either above their 2030 emission target or below by less than 5 %. These at-risk Member States may be reliant on the additional PaMs reported for implementation between 2020 and 2030 to reach their 2030 emissions target. This report examines the potential impacts of the Covid-19 restrictions and recovery on the effective implementation of the types of additional PaMs reported by Member States that are at risk of non-compliance with their 2030 targets.

## 4.1 Member States' NECD compliance status

In 2021, Member States reported air pollution emissions projections for 2030 for without measures (WM) and with additional measures (WAM) scenarios (Annex VI submissions under the NECD). The difference between the WM and WAM scenarios is that the WAM scenarios account for measures already in the pipeline that will affect emissions between the baseline and the future year. The planned policies in WAM scenarios may be affected by Covid-19 recovery. However, as these policies are already prepared, it is expected that the effect on implementation will be limited. Therefore, this analysis focuses on the additional PaMs beyond the WAM scenario that are not yet in the pipeline, which Member States may be relying on to achieve compliance. The additional PaMs reported by Member States that are deemed to be at risk of non-compliance have been evaluated. Some Member States have not reported WAM scenarios for 2030, and so the WM values have been used.

Member States that have reported projections of air pollutant emissions that exceed the 2030 threshold emissions target (red) or are below the 2030 target by less than 5 % (amber) have been listed in Table 4.1.

*Table 4.1 Member States that have reported projected emissions above their 2030 compliance target or below their 2030 target by less than 5 %*

| Pollutant | Member State | Projection for 2030 (kt)[a] | Compliance target 2030 (kt) | Amount above or below target (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019, the latest available inventory year |
|---|---|---|---|---|---|---|
| $NH_3$ | Austria | 59.75 | 52.87 | 6.88 | 11.5 % | Agriculture (livestock) |
| $NH_3$ | Croatia | 30.71 | 32.17 | -1.46 | -4.7 % | Agriculture (crops and livestock) |
| $NH_3$ | Czechia | 76.02 | 77.48 | -1.47 | -1.9 % | Agriculture (crops and livestock) |
| $NH_3$ | Denmark | 74.41 | 68.50 | 5.91 | 7.9 % | Agriculture (crops and livestock) |
| $NH_3$ | Estonia | 9.62 | 9.99 | -0.37 | -3.9 % | Agriculture (livestock) |
| $NH_3$ | Germany | 454.20 | 455.43 | -1.22 | -0.3 % | Agriculture (livestock) |
| $NH_3$ | Greece | 66.94 | 67.27 | -0.33 | -0.5 % | Agriculture (crops and livestock) |
| $NH_3$ | Hungary | 77.49 | 54.42 | 23.07 | 29.8 % | Agriculture (crops and livestock) |
| $NH_3$ | Ireland | 112.74 | 113.72 | -0.99 | -0.9 % | Agriculture (livestock) |
| $NH_3$ | Italy | 341.53 | 357.61 | -16.08 | -4.7 % | Agriculture (livestock) |
| $NH_3$ | Latvia | 14.28 | 14.34 | -0.06 | -0.4 % | Agriculture (crops and livestock) |
| $NH_3$ | Lithuania | 32.87 | 33.67 | -0.80 | -2.4 % | Agriculture (crops and livestock) |
| $NH_3$ | Luxembourg | 4.83 | 4.35 | 0.48 | 10.0 % | Agriculture (livestock) |
| $NH_3$ | Malta | 1.38 | 1.42 | -0.04 | -3.1 % | Agriculture (livestock) |
| $NH_3$ | Slovakia | 27.40 | 25.38 | 2.02 | 7.4 % | Agriculture (crops and livestock) |
| $NH_3$ | Sweden | 48.36 | 48.00 | 0.36 | 0.7 % | Agriculture (livestock) |

| Pollutant | Member State | Projection for 2030 (kt)[a] | Compliance target 2030 (kt) | Amount above or below target (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019, the latest available inventory year |
|---|---|---|---|---|---|---|
| *NMVOC* | *Bulgaria* | *43.76* | *43.97* | *-0.21* | *-0.5 %* | *Manufacturing industry and residential, commercial & institutional* |
| *NMVOC* | *Czechia* | *116.63* | *117.52* | *-0.90* | *-0.8 %* | *Manufacturing industry and residential, commercial & institutional* |
| *NMVOC* | *Hungary* | *80.38* | *60.06* | *20.33* | *25.3 %* | *Manufacturing industry and agriculture (livestock)* |
| *NMVOC* | *Ireland* | *69.23* | *52.34* | *16.89* | *24.4 %* | *Manufacturing industry and agriculture (livestock)* |
| *NMVOC* | *Lithuania* | *31.80* | *25.20* | *6.59* | *20.7 %* | *Manufacturing industry and agriculture (livestock)* |
| *NMVOC* | *Spain* | *398.19* | *382.55* | *15.64* | *3.9 %* | *Manufacturing industry and agriculture (livestock)* |
| $NO_X$ | Austria | 74.44 | 73.55 | 0.89 | 1.2 % | Transport |
| $NO_X$ | Croatia | 37.27 | 33.37 | 3.91 | 10.5 % | Transport |
| $NO_X$ | Czechia | 96.90 | 98.04 | -1.14 | -1.2 % | Transport and energy production |
| $NO_X$ | Germany | 576.91 | 532.77 | 44.14 | 7.7 % | Transport and energy production |
| $NO_X$ | Hungary | 66.08 | 55.22 | 10.86 | 16.4 % | Transport |
| $NO_X$ | Lithuania | 31.23 | 27.30 | 3.93 | 12.6 % | Transport and agriculture (crops) |
| $NO_X$ | Malta | 4.66 | 2.01 | 2.65 | 56.8 % | Transport |
| $NO_X$ | Sweden | 75.86 | 60.31 | 15.55 | 20.5 % | Transport and manufacturing industry |
| *$PM_{2.5}$* | *Austria* | *11.72* | *12.18* | *-0.46* | *-3.9 %* | *Residential, commercial & institutional and transport* |

| Pollutant | Member State | Projection for 2030 (kt)[a] | Compliance target 2030 (kt) | Amount above or below target (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019, the latest available inventory year |
|---|---|---|---|---|---|---|
| *$PM_{2.5}$* | *Croatia* | *18.62* | *18.83* | *-0.21* | *-1.1 %* | *Residential, commercial & institutional* |
| *$PM_{2.5}$* | *Cyprus* | *0.65* | *0.66* | *0.00* | *-0.7 %* | *Transport and manufacturing industry* |
| *$PM_{2.5}$* | *Czechia* | *16.93* | *17.30* | *-0.37* | *-2.2 %* | *Residential, commercial & institutional* |
| *$PM_{2.5}$* | *Denmark* | *12.55* | *9.87* | *2.68* | *21.4 %* | *Residential, commercial & institutional* |
| *$PM_{2.5}$* | *Germany* | *80.78* | *80.45* | *0.33* | *0.4 %* | *Manufacturing industry and transport* |
| *$PM_{2.5}$* | *Hungary* | *30.86* | *18.84* | *12.02* | *38.9 %* | *Residential, commercial & institutional* |
| *$PM_{2.5}$* | *Spain* | *71.01* | *73.50* | *-2.49* | *-3.5 %* | *Residential, commercial & institutional and waste* |

If the WAM projection is not available, the WM projection is used.

**Source:** Adapted from EEA, 2021b.

## 4.2 Policies impacted by Covid-19 recovery

Across Member States, there are common sectors that consistently act as the largest contributor of emissions for each pollutant. These can be identified using the latest emissions inventories reported by each Member State (EEA, 2021b), as highlighted in Table 4-2. The Covid-19 pandemic has had a different distinct impact on each of these sectors.

*Table 4.2 The typical largest contributors to emissions of each pollutant across Member States*

| | Agriculture (crops) | Agriculture (livestock) | Manufacturing industry | Residential, commercial & institutional sectors | Transport | Energy production |
|---|---|---|---|---|---|---|
| $NH_3$ | ✓ | ✓ | | | | |
| NMVOC | | ✓ | ✓ | ✓ | | |
| $NO_X$ | | | | | ✓ | ✓ |
| $PM_{2.5}$ | | | ✓ | ✓ | ✓ | |

To attempt to reduce emissions, Member States may implement PaMs in each of these sectors through various instrument types[f]:

- **Regulatory**: PaMs that set binding standards and regulations or permitting system. This includes, for instance, building regulations, eco-design standards, establishment of permit and inspection procedures. These PaMs are expected to be the most robust to Covid-19 impacts but may face delays in implementation.
- **Fiscal:** a PaM that provides a financial incentives and disincentives via taxes. These include both increases and decreases in taxes. Similar to regulatory PaMs, they are expected to be robust but may be delayed.
- **Economic:** a PaM that provides an economic incentive or disincentive to reduce air pollutant emissions. These include measures such as subsidies, investment programmes, loans and grants, charges, and fees for non-beneficial actions, such as waste fees or congestion charges. During Covid-19 recovery, funding for economic PaMs may be prioritised elsewhere, but fiscal and economic policy incentives can be more valued in times of economic hardship.
- **Planning:** PaMs such as waste management plans, transport plans, and urban planning. Planning has the potential to be enhanced due to new priorities of citizens such as active travel but can have long lead times.
- **Information:** measures such as labelling and awareness-raising campaigns. The objective is to disseminate information to the general public or specific target groups. These measures are generally weak in isolation and need support through another type of instrument to maximise effectiveness e.g. an awareness campaign on the harms of burning wet wood alongside a ban/tax on burning wet wood.
- **Voluntary:** a voluntary standard/regulation such as regulatory and information measures but agreed between regulators and the sector targeted. These are considered the weakest type of instrument, as they rely on goodwill and capacity of actors.

[f] These instrument types are specified in the NEC Directive for the reporting of additional policies and measures.

- **Source-based:** measures to control pollution directly at the source, such as on exhausts of vehicles or stacks of an industrial plant. These technology-dependent measures have various mechanisms for enforcement, some of which may rely on supply chains rebalancing after the impacts of Covid-19.
- **Other**: measures that do not fit in any of the above categories, such as public procurement.

The potential impact of Covid-19 on potential PaMs in each sector is explored in more detail below.

### *4.2.1 Transport*

The COVID-19 pandemic resulted in a modal shift towards active travel, such as cycling, due to fears of contagion of the virus on public transport and more than EUR 1 billion was invested by Member States into cycling infrastructure across ninety-four European cities between the outbreak of COVID-19 and late 2020. However, also as a result of contagion fears, interest in private car purcharses also increased. (Griffiths, et al., 2021). Fueled by this trend, the electric vehicle market grew, and while it remains a small proportion of the total car market, the pandemic had accelerated this growth (de Vet et al., 2021) - electric car sales increased 135 % across the whole of Europe between 2019-2020 compared to a decline of 24 % for other car sales across the same period. This was driven in part by affluent households being less affected by the pandemic (IEA, 2020) and recovery measures linked to the green transition incentivising investments into greener transport (de Vet et al., 2021). However, aviation and automakers, after suffering heavy economic impacts, received more financial support than railways and urban public transport during the pandemic, going against the EU's objectives to encourage carbon neutral transport use (Finger et al., 2020).

Additional PaMs reported by Member States in this sector include increasing alternative fuel use and deploying pollution abatement technologies on vehicles. It is unclear how COVID-19 may impact these PaMs. Still, even with economic backing, changes in household income and the change in public perception of public transport over the pandemic may mean that these policies are not as effective as anticipated.

### *4.2.2 Agriculture (crops and livestock)*

The Covid-19 pandemic put pressures all along food supply chains from agricultural processes to food production, processing distribution and consumer demands (Aday & Aday, 2020). The agricultural sector, like many other sectors, experienced a lack of workers due to sickness, mandated isolation and travel restrictions. This had an impact on labour-intensive processes such as livestock production, horticulture, planting and harvesting (Stephens, et al., 2020). However, this disruption was not equal across all Member States – the agriculture sector is more developed in certain Member States and is not as labour intensive due to widespread technology use (Liu, 2020). Ammonia emissions from fertiliser spreading is a dominant source of emissions in western Europe in late winter and early spring (Menut, et al., 2020), but levels were not affected by the pandemic. This is due to the fertiliser market being volatile for over a decade, and as such, fertiliser companies ensured the supply chain remained resilient (Ilinova, et al., 2021). However, labour shortages delayed practices such as fertiliser application (Seleiman, et al., 2020).

Half of the additional PaMs to be implemented in the agricultural sector across Member States are economic policies instated by government and may have stronger uptake than otherwise by those experiencing economic hardship post-Covid-19. However, some of the reported additional PaMs are source-based, require technological investment, and are susceptible to not being implemented if there is not a swift economic recovery from the pandemic.

### 4.2.3 Manufacturing industry

Covid-19 restrictions negatively impacted the global supply of raw materials and spare parts, which had knock on effects for many manufacturers. Paired with subsequent fluctuations in demand from consumers, many manufacturers have faced great uncertainty (Cai, 2020). Food manufacturing was disrupted during the pandemic due to labour shortages. The sharp decrease in the manufacture of motor vehicles, trailers, and semi-trailers due to industry shutdown prevented food from being transported to supermarkets (Liu, 2020). No information on additional PaMs was identified.

### 4.2.4 Residential, commercial and institutional sectors

The pandemic restrictions resulted in an increase in people spending more time indoors, where ambient air pollutant levels can be worse than that outdoors. A study in Madrid by Dominguez-Amarillo et al. (2020) found that an increase in domestic cleaning and disinfectant use and cooking resulted in higher indoor $PM_{2.5}$ and VOC emissions compared to pre-pandemic levels. While these increases will make little impact on national totals, the increased exposure of residents is significant. This was exacerbated in households with at least one keyworker, where more rigorous cleaning was conducted to reduce transmission of the virus (Domínguez-Amarillo , et al., 2020). PM concentrations may also have increased due to an increase in emissions from domestic combustion of coal or wood for heating, due to more time spent in homes (EEA, 2020). Pollutants were not effectively dispersed due to limited voluntary use of ventilation systems such as opening windows due to residents desiring to minimise heating costs. Heating systems of city buildings, particularly residential and service buildings, including legacy buildings with poor energy efficiency, remained a significant source of urban pollution in the city throughout the start of the pandemic, contributing one-third of $NO_X$ and PM levels between February and April 2020. Whilst the study published by Domínguez-Amarillo (2020) is limited to Madrid, similar trends are expected across Europe.

Residential heating energy use in parts of Europe contributed to 40 % higher electricity consumption year-on-year in March and early April 2020 (IEA, 2020). Whilst energy consumption in commercial buildings has declined, most unoccupied buildings still use energy to maintain heating, ventilation, and air conditioning (HVAC) systems, or to power servers. Overall, emissions from the residential, commercial and institutional sectors are expected to have increased as a result of restrictions (IEA, 2020).

Additional PaMs reported related to energy consumption are predominantly regulatory, fiscal, or economic. These include prohibition of the combustion of solid fuels in specific regions, financial incentives for households to connect to a district heating network, and increasing the rate of excise duty on coal, coke, and lignite for heat production. Covid-19 may potentially impact PaMs targeting the residential sector. Regulatory PaMs will likely be unaffected, but those involving financial incentives may be negatively impacted if Member States cannot financially recover from the pandemic due to prioritisation of recovery efforts.

### 4.2.5 Energy production

The instigation of restrictions across nations resulted in an energy demand shock, accompanied by a temporary drop in fossil fuel prices. The uncertainty in demand caused by the pandemic temporarily increased the value of assets based on fossil fuels, and in some cases, disincentivised technology use based on alternate fuels (Heffron, et al., 2021). After the initial restrictions, the price of oil rebounded; in 2021 prices have been restored to 2018 levels (Sönnichsen, 2021). If this uncertainty were to continue for an extended time, this could have a potential impact on the types and effectiveness of policies that need to be implemented to meet compliance targets.

Covid-19 restrictions reduced energy demand across Europe, primarily because of a reduction in industrial and commercial activities. The impact on energy production varied from country to country, depending on the existing energy mix. Reductions in demand increased the share of renewables in the electricity supply of most European countries as their output is largely unaffected by demand. Other factors including the number of wind and solar parks in operation and weather conditions affect renewable generation. Many Member States, in particular Italy, Spain and Germany, set new records in the share of electricity produced by intermittent renewable sources (IEA, 2021). Conversely, generation from nuclear, coal and gas were reduced (Werth, et al., 2021). It is unclear whether this trend will be long-lasting, or a temporary response to unstable demand.

The supply chain of the wind power industry was disrupted in February 2020 as components could not be imported from China. However, wind manufacturing sites were able to remain open during the onset of the pandemic (Hosseini, 2020). Additionally, the European Grid effectively aided in the distribution of required energy. In response to the pandemic, the EU established the 'Next Generation EU' recovery stimulus package. This includes EUR 10 billion to reduce reliance on fossil fuels by investing money into renewable energy and storage, clean hydrogen, batteries and carbon capture and storage (Beyer & Vandermosten, 2021). No information on additional PaMs was identified.

## 4.3 Expected impact on Member States

Analysis shows that the COVID-19 pandemic may negatively impact Member States with a low proportion of robust additional PaMs, such as regulatory or financial, such as Hungary which is relying on potentially vulnerable source-based policies to target $NH_3$ emissions in the agriculture sector. COVID-19 may also negatively impact Estonia, Luxembourg and Slovakia's paths towards $NH_3$ compliance. Further action by these Member States might be needed to ensure 2030 compliance, including reviewing or redesigning planned policies to better suit the changed economic and political landscape of each Member State. On the other hand, the pandemic may aid in $NO_X$ compliance for some Member States such as Lithuania due to an increased demand in electric vehicles and active travel such as cycling.

Of the nineteen Member States listed in Table 4.3 as being at risk of non-compliance with their 2030 target, seven Member States did not report any additional PaMs that are being considered for adoption between 2019 and 2030, as highlighted in grey in Table 4.3. These seven Member States are not necessarily predicted to achieve their compliance targets.

*Table 4.3 Member States at risk of non-compliance with their 2030 target*

| Member State | Pollutants at risk of non-compliance in 2030 | Reported additional PaMs |
|---|---|---|
| Austria | $NH_3$, $NO_X$, $PM_{2.5}$ | No additional PaMs reported |
| Bulgaria | NMVOC | No additional PaMs reported |
| Croatia | $NH_3$, $NO_X$, $PM_{2.5}$ | No additional PaMs reported |
| Cyprus | $PM_{2.5}$ | No additional PaMs reported |
| Czechia | $NH_3$, NMVOC, $NO_X$, $PM_{2.5}$ | 2 |
| Denmark | $NH_3$, $PM_{2.5}$ | 2 |
| Estonia | $NH_3$ | 14 |
| Germany | $NH_3$, $NO_X$, $PM_{2.5}$ | No additional PaMs reported |

| Member State | Pollutants at risk of non-compliance in 2030 | Reported additional PaMs |
|---|---|---|
| Greece | $NH_3$ | No additional PaMs reported |
| Hungary | $NH_3$, NMVOC, $NO_X$, $PM_{2.5}$ | 12 |
| Ireland | $NH_3$, NMVOC | 2 |
| Italy | $NH_3$ | No additional PaMs reported |
| Latvia | $NH_3$ | 24 |
| Lithuania | $NH_3$, NMVOC, $NO_X$ | 22 |
| Luxembourg | $NH_3$ | 1 |
| Malta | $NH_3$, $NO_X$ | 10 |
| Slovakia | $NH_3$ | 5 |
| Spain | NMVOC, $PM_{2.5}$ | 2 |
| Sweden | $NH_3$, $NO_X$ | 8 |

Member States do not report information on the measures that are already planned and included in the WAM scenarios, therefore the only information available on the PaMs of each Member State is through the additional PaMs (additional to the WAM scenario) reported under the NEC Directive to the EEA. Member States that have not submitted information on additional PaMs are not examined further in this analysis.

The twelve Member States that did report information on additional PaMs are examined in further detail. The projected air pollutant emissions reported by these Member States are presented in tables below:

projections that exceed the 2030 target are highlighted in red
projections that fall below the 2030 target by less than 5 % are highlighted in amber
projections that fall below the 2030 target by more than 5 % are highlighted in green.

Information regarding the sector that contributed most to emission in 2019 is sourced from EEA (2021).

### *4.3.1 Czechia*

The status of Czechia's projected compliance with 2030 targets is recapped in Table 4.4, along with the number of additional PaMs reported.

*Table 4.4 The status of Czechia's NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019 | No. of additional PaMs reported for the pollutant[a] |
|---|---|---|---|---|---|
| $NH_3$ | 77.48 | -1.47 | -1.9 % | Agriculture | 2 |
| NMVOC | 117.52 | -0.90 | -0.8 % | Manufacturing industry and residential commercial institutional | 1 |
| $NO_X$ | 98.04 | -1.14 | -1.2 % | Transport and energy production | 1 |
| $PM_{2.5}$ | 17.30 | -0.37 | -2.2 % | Residential commercial institutional | 1 |

(a) One policy is cross-cutting and therefore applies to all pollutants.

Two additional PaMs were reported by Czechia, one that is cross-cutting and one that targets the agricultural sector. The former is an amendment to national legislation regarding air protection and targets all sectors and pollutants. This regulatory measure is unlikely to be impacted by Covid-19 recovery.

The second additional reported PaM targets $NH_3$ reductions in the agricultural sector; it aims to gather sufficient information to refine emission projections and introduce an obligation under the air protection legislation to report annual average bred livestock, applied emission abatement technologies, and average manure application times. It is uncertain how the increased detail captured in the new reporting obligation may increase or decrease the emission projections.

For all pollutants, Czechia is very close to its compliance target, the meeting of these targets is sensitive to all impacts. Therefore, Czechia's ability to reach compliance with its 2030 NECD targets for all pollutants may be affected by Covid-19 recovery.

### 4.3.2 Denmark

The status of Denmark's projected compliance with 2030 targets is recapped in Table 4.5, along with the number of additional PaMs reported.

*Table 4.5 The status of Denmark's NECD compliance. A policy that focuses on $SO_2$ reduction is not shown in this table*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019 | No. of additional PaMs reported for the pollutant |
|---|---|---|---|---|---|
| $NH_3$ | 68.50 | 5.91 | 7.9 % | Agriculture | 0 |
| NMVOC | 67.17 | -10.09 | -17.7 % | Agriculture (livestock) | 0 |
| $NO_X$ | 60.01 | -8.92 | -17.5 % | Transport | 1 |
| $PM_{2.5}$ | 9.87 | 2.68 | 21.4 % | Residential commercial institutional | 0 |

Denmark is predicted to exceed its 2030 compliance targets for $NH_3$ and $PM_{2.5}$. However, it only reported two additional PaMs that target $SO_X$ and $NO_X$ emissions reductions in the industrial and energy supply sectors, respectively. As Denmark is projected to be well below the $NO_X$ compliance target, and there is no target set for $SO_X$ emissions, the impact of Covid-19 on these additional PaMs is not discussed here.

As Denmark has not reported any additional PaMs related to $NH_3$ or $PM_{2.5}$, Covid-19 recovery is unlikely to impact Denmark's predicted non-compliance with NECD 2030 targets for these pollutants.

### *4.3.3 Estonia*

The status of Estonia's projected compliance with 2030 targets is recapped in Table 4.6, along with the number of additional PaMs reported.

*Table 4.6 The status of Estonia's NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below complian ce target | Sector that contributed most to emissions in 2019 | No. of additional PaMs reported for the pollutant |
|---|---|---|---|---|---|
| $NH_3$ | 9.99 | -0.37 | -3.9 % | Agriculture (livestock) | 3 |
| NMVOC | 19.95 | -3.21 | -19.2 % | Manufacturing industry | 0 |
| $NO_X$ | 28.49 | -7.80 | -37.7 % | Transport and energy supply | 11 |
| $PM_{2.5}$ | 7.66 | -1.98 | -34.8 % | Residential, commercial & institutional | 0 |

Estonia reported eleven PaMs affecting the transport sector. These PaMs target $NH_3$, NMVOC, $NO_X$, $PM_{2.5}$ and $SO_2$ emissions but as all emissions from pollutants other than $NH_3$ are more than 5 % below the 2030 compliance target, they are not discussed here.

Estonia is currently projected to be under its compliance target for $NH_3$, by only around 4 %, but the reported additional PaMs in the agriculture sector may reduce these emissions even further. These measures include increasing the usage of low-emission manure techniques (especially slurry injection), increasing covering liquid manure tanks, and rapidly incorporating mineral fertilisers to limit ammonia emissions. The implementation start date is also 2021. These PaMs are characterised as economic and information and could be negatively impacted by Covid-19 if there is not widespread information and monetary incentives to implement these PaMs.

### *4.3.4*

The status of Hungary's projected compliance with 2030 targets is recapped in Table 4.7, along with the number of additional PaMs reported.

*Table 4.7 The status of Hungary's NECD compliance. A policy to build $CO_2$ net zero flats that is not listed in this table*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019 | No. of additional PaMs reported for the pollutant |
|---|---|---|---|---|---|
| $NH_3$ | 54.42 | 23.07 | 29.8 % | Agriculture | 6 |
| NMVOC | 60.06 | 20.33 | 25.3 % | Manufacturing industry and Agriculture (livestock) | 3 |
| $NO_X$ | 55.22 | 10.86 | 16.4 % | Transport | 3 |
| $PM_{2.5}$ | 18.84 | 12.02 | 38.9 % | Residential, commercial & institutional | 3 |

Hungary is at risk of non-compliance for $NH_3$, NMVOC, $NO_X$, and $PM_{2.5}$, by a significant margin for all pollutants. It is expected that Hungary will be heavily reliant on its additional PaMs in order achieve compliance in 2030.

Six PaMs focus on reducing $NH_3$ emissions through the agriculture sector and include the following regulatory measures:

- extending the obligation to prepare nutrient management plans
- reducing the protein content of feeds

These measures are unlikely to be impacted by Covid-19 as they have implementation start date of 2025, which could provide enough time to recover from labour shortages and supply chain issues post-pandemic. The remaining agricultural measures are source-based:

- increasing requirements such as air purification in barns and reducing manure-covered areas
- introducing feeding strategies such as using enzymes to increase feed digestibility
- tracking the nutrient content in animal feed
- replacing urea-based fertilisers with ammonium nitrate-based fertilisers

The robustness of these source-based PaMs is difficult to comment on as no information is available on the method of enforcement. The implementation start date for three out of four of these measures is 2021 or 2022, when labour shortages due to Covid-19 may still be an issue and the technology development required may not be prioritised. This may result in a delay in the implementation of the policies.

Finally, one policy extends a ban on open-field burning of agricultural plant residues to reduce $PM_{2.5}$ emissions. This is a regulatory policy to be implemented in 2025 and consequently is unlikely to be impacted by Covid-19.

Hungary has reported three PaMs to reduce NMVOC and $NO_X$ emissions. The first will introduce requirements for the installation of abatement technologies and the control of fugitive emissions from industrial processes. The second will introduce regulations for the operation of combustion plants with rated thermal inputs of less than 140 kW. These regulatory policies are unlikely to be impacted by Covid-19. The final PaM is the creation of a sustainable urban mobility plan which will provide sustainable and high-quality transport and mobility. This is a planning PaM and could negatively be impacted by Covid-19 due to prioritisation of other projects, lack of funding, or expertise availability. The increase in active travel during Covid-19 might make urban mobility plans more favourable, or they might need re-evaluating and strengthening if the focus is on public transport, given the public's slow return due to Covid-19 transmission fears.

Finally, a policy to amend the Social Fuel Support Scheme from 2021 which ensures that only dry firewood is provided to the population aims to reduce $PM_{2.5}$ emissions.

Hungary has reported additional PaMs which cover several sectors and pollutants in an interlinked way. For example, many policies targeting $NH_3$ emissions in agriculture cover animal feed and manure management, which can be expected to also impact NMVOC emissions, as livestock is the largest NMVOC emitter in Hungary. Some of these PaMs are potentially vulnerable to Covid-19 impacts as they rely on introducing technology updates and potentially labour-intensive practices.

The diverse range of measures reported to reduce NMVOC and $NO_X$ emissions, covers the industrial, energy consumption and transport sectors. Similarly, $PM_{2.5}$ is targeted by a range of policies in the agricultural and energy consumption sectors, so there is inherent robustness in that these policies span a range of sectors.

Hungary may be at risk of non-compliance with their 2030 $NH_3$ target due to the vulnerabilities of the additional PaMs in the agricultural sector. Covid-19 is expected to have a less significant impact on the achievement of the NMVOC, $NO_X$, and $PM_{2.5}$ targets due to the diverse range of sectors that the additional measures cover.

### *4.3.5 Ireland*

The status of Ireland's projected compliance with 2030 targets is recapped in Table 4.8 , along with the number of additional PaMs reported.

*Table 4.8 The status of Ireland's NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019[a] | No. of additional PaMs reported for the pollutant |
|---|---|---|---|---|---|
| $NH_3$ | 113.72 | -0.99 | -0.9 % | Agriculture (livestock) | 0 |
| NMVOC | 52.34 | 16.89 | 24.4 % | Manufacturing industry and Agriculture (livestock) | 2 |
| $NO_X$ | 44.70 | -11.23 | -33.6 % | | 2 |
| $PM_{2.5}$ | 11.41 | -1.53 | -15.5 % | | 2 |

The two energy sector policies reported by Ireland cover multiple pollutants.

Ireland is projected to be non-compliant with its NMVOC target in 2030. While the two additional PaMs were reported to reduce multiple pollutants, including NMVOC, they are both in the energy sector, accounting for 3 % of NMVOC emissions in 2019.

Ireland's compliance with its 2030 targets is not expected to be impacted by Covid-19 recovery.

### *4.3.6 Latvia*

The status of Latvia's projected compliance with 2030 targets is recapped in Table 4.9, along with the number of additional PaMs reported.

*Table 4.9 The status of Latvia's NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019 | No. of additional PaMs reported for the pollutant |
|---|---|---|---|---|---|
| $NH_3$ | 14.34 | -0.06 | -0.4 % | Agriculture | 9 |
| NMVOC | 28.82 | -2.32 | -8.8 % | | 8 |
| $NO_X$ | 27.18 | -6.09 | -28.9 % | | 11 |
| $PM_{2.5}$ | 16.09 | -3.76 | -30.4 % | | 14 |

Latvia reported 24 additional PaMs, nine of which target the agriculture sector. All the additional agricultural PaMs have an implementation start date of 2021, and most are economic measures that provide financial support within the Rural Development Programme to promote practices such as direct incorporation of liquid manure into soil, the optimisation of application of nitrogen fertilisers, and to promote the development of biological dairy farming.

Even if these economic measures are impacted by COVID-19 recovery, considering how close Latvia is to the $NH_3$ target, any slight impact may change the compliance status. Therefore, Latvia's compliance with its $NH_3$ target is likely to be affected.

### *4.3.7 Lithuania*

The status of Lithuania's projected compliance with 2030 targets is recapped in Table 4.10 , along with the number of additional PaMs reported.

*Table 4.10 The status of Lithuania's NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019 | No. of additional PaMs reported for the sector[a] |
|---|---|---|---|---|---|
| $NH_3$ | 33.67 | -0.80 | -2.4 % | Agriculture | 2 |
| NMVOC | 25.20 | 6.59 | 20.7 % | Manufacturing industry, agriculture (livestock) and energy supply | 12 (4 manufacturing industry, 1 livestock, 7 energy supply) |
| $NO_X$ | 27.30 | 3.93 | 12.6 % | Transport and agriculture (crops) | 10 (including 1 crop PaM) |
| $PM_{2.5}$ | 5.42 | -1.18 | -27.8 % | | NA |

(a) Lithuania has reported many PaMs that cover multiple pollutants, therefore the number of PaMs has been split by sector.

Most of the additional PaMs reported by Lithuania target the transport and energy consumption sectors. Seven of the transport sector policies target all four main pollutants, and the remaining target NMVOC, $NO_X$ and $PM_{2.5}$. The transport policies include financial incentives for:

- electric or hybrid car purchases
- installing $NO_X$ catalytic reduction technology in heavy commercial vehicles
- key municipalities in Lithuania to establish diesel vehicle traffic restriction systems,
- municipalities to purchase public low-emissions vehicles.

These financial measures are unlikely to be impacted negatively by Covid-19 recovery, in fact, increased purchases of electric vehicles at the beginning of the pandemic suggests that the impact of some of these measures may be accelerated.

Of the three PaMs that target the industrial sector, two aim to reduce $SO_2$ emissions (so will not be discussed here) and one aims to reduce NNVOC emissions using financial incentives to apply detection and decomposition measures.

Two PaMs target agriculture - a financial incentive to reduce inorganic fertiliser consumption and a regulatory measure to control the emissions from livestock housing. Little detail is given on the latter measure and therefore it is unclear whether it is vulnerable to impacts of Covid-19 recovery.

Overall, Lithuania's compliance with 2030 targets is unlikely to be strongly impacted by Covid-19 recovery as most of its additional measures comprise of financial incentives that are likely to remain robust. The increased uptake of electric vehicles since the pandemic may increase the effectiveness of Lithuania's transport policies. Therefore, compliance with the $NO_X$ target may be more likely.

### 4.3.8 Luxembourg

The status of Luxembourg's projected compliance with 2030 targets is recapped in Table 4.11, along with the number of additional PaMs reported.

*Table 4.11 The status of Luxembourg's NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019 | No. of additional PaMs reported for the pollutant |
|---|---|---|---|---|---|
| $NH_3$ | 4.35 | 0.48 | 10.0 % | Agriculture (livestock) | 1 |
| NMVOC | 7.06 | -0.56 | -8.7 % | | 0 |
| $NO_X$ | 9.43 | -1.94 | -25.9 % | | 0 |
| $PM_{2.5}$ | 1.51 | -0.13 | -9.7 % | | 0 |

Luxembourg reported one additional PaM with the aim of reducing $NH_3$ emissions in the agriculture sector to reduce emissions during the application of fertiliser/manure on cropland and grassland by incorporating manure within four hours after spreading. This policy may be negatively impacted if continued travel restrictions due to Covid-19 result in labour shortages; Luxembourg may be less likely to achieve its 2030 compliance.

### 4.3.9 Malta

The status of Malta's projected compliance with 2030 targets is recapped in Table 4.12, along with the number of additional PaMs reported.

*Table 4.12 The status of Malta's NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019[a] | No. of additional PaMs reported for the sector |
|---|---|---|---|---|---|
| $NH_3$ | 1.42 | -0.04 | -3.1 % | Agriculture (livestock) | 0 |
| NMVOC | 1.67 | -0.25 | -17.5 % | | 0 |
| $NO_X$ | 2.01 | 2.65 | 56.8 % | Transport | 3 |
| $PM_{2.5}$ | 1.51 | -0.13 | -9.7 % | | 0 |

(a) Seven energy sector PaMs are not listed in this table as this sector contributes to 0 % of $NH_3$ emissions and 7 % of $NO_X$ emissions in 2019.

Malta reported ten additional PaMs; seven applied to the energy sector, which is a minor contributor to $NH_3$ and $NO_X$ emissions (the pollutants for which Malta is at risk of non-compliance with the 2030 target), representing 0.04 % and 7 % respectively. Energy sector PaMs will not be discussed further here as even a dramatic decrease in emissions in this sector will have little effect on $NH_3$ and $NO_X$ emissions.

Three additional transport PaMs were reported by Malta. One economic measure incentivises individuals to avoid traveling at peak times and opt for cleaner travel methods. This may be bolstered by the public's reaction to the pandemic, where people try to avoid busy areas such as peak travel times. Another measure aims to improve public transport infrastructure, and the third involves delivering goods for stores in the Valletta region to a single centralised location using electric vehicles, with the aim to reduce congestion due to freight transport. Uptake of public transport may be decreased due to the pandemic, however, this effect is unlikely to critical in Malta's compliance with it's $NO_X$ target as a reduction of more than 50 % is required to achieve compliance.

Therefore, Malta's compliance with its 2030 targets is unlikely to be affected by Covid-19 recovery.

### *4.3.10 Slovakia*

The status of Slovakia's projected compliance with 2030 targets is recapped in Table 4.13, along with the number of additional PaMs reported.

*Table 4.13 The status of Slovakia NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below compliance target | Sector that contri-buted most to emissions in 2019 | No. of additional PaMs reported for the pollutant[a] |
|---|---|---|---|---|---|
| b$NH_3$ | 25.38 | 2.02 | 7.4 % | Agriculture | 1 |
| NMVOC | 102.43 | -26.87 | -35.6 % | | 4 |
| $NO_X$ | 49.39 | -11.18 | -29.3 % | | 3 |
| $PM_{2.5}$ | 17.52 | -5.03 | -40.2 % | | 4 |

(a) Three cross-cutting PaMs apply to NMVOC, $NO_X$ and $PM_{2.5}$; one transport PaM applies to NMVOC and $PM_{2.5}$.

Slovakia reported five additional PaMs, only one of which targets $NH_3$ emissions in the agricultural sector, extending measures which currently require large farms to comply with legislation relating to $NH_3$ emission reductions to include farms of medium size. The measure will focus on manure storage and application to soil potentially reducing ammonia emissions by over 40 % and 30 %, respectively. Implementation of the relevant regulations, planned for 2021, may be affected by labour shortages caused by the Covid-19 pandemic.

### 4.3.11 Spain

The status of Spain's projected compliance with 2030 targets is recapped in Table 4.14, along with the number of additional PaMs reported.

*Table 4.14 The status of Spain NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WAM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019 | No. of additional PaMs reported for the pollutant[a] |
|---|---|---|---|---|---|
| $NH_3$ | 405.80 | -45.24 | -12.5 % | | 0 |
| NMVOC | 382.55 | 15.64 | 3.9 % | Manufacturing industry and agriculture (livestock) | 2 |
| $NO_X$ | 483.24 | -151.65 | -45.7 % | | 2 |
| $PM_{2.5}$ | 73.50 | -2.49 | -3.5 % | Residential, commercial & institutional and waste | 2 |

(a) Two cross-cutting measures apply to multiple pollutants.

Spain reported two additional cross-cutting PaMs which both target the agricultural crop and waste management sector, the latter being a significant emitter of $PM_{2.5}$ in 2019. The PaMs aim to reduce the amount of biomass collected in vineyards and in olive groves that is burnt in the open air, and instead encourage producers to reincorporate it into soils or send the waste to cogeneration companies to produce thermal and electrical energy, respectively. Both measures would be established within the framework of the Common Agriculture Policy strategic plan. These measures may be vulnerable to shortages in labour, however biomass burning does not make up a large proportion of Spain's NMVOC and $PM_{2.5}$ emission; crop agriculture making up 2 % and 5 % of total emissions in 2019 respectively. Therefore Spain's compliance with its 2030 target is unlikely to be impacted by the Covid-19 pandemic.

### *4.3.12 Sweden*

The status of Sweden's projected compliance with 2030 targets is recapped in Table 4.15, along with the number of additional PaMs reported.

*Table 4.15 The status of Sweden's NECD compliance*

| Pollutant | 2030 Compliance target (kt) | Amount above or below target (WM) (kt) | % above or below compliance target | Sector that contributed most to emissions in 2019 | No. of additional PaMs reported for the pollutant[a] |
|---|---|---|---|---|---|
| $NH_3$ | 48.00 | 0.36 | 0.7 % | Agriculture (livestock) | 0 |
| NMVOC | 110.73 | -18.50 | -20.1 % | | 0 |
| $NO_X$ | 60.31 | 15.55 | 20.5 % | Transport and manufacturing industry | 8 |
| $PM_{2.5}$ | 25.21 | -10.53 | -71.7 % | | 0 |

(a) Two cross-cutting measures apply to multiple pollutants.

Sweden reported eight additional PaMs, all targeting $NO_X$ emissions. Six PaMs target the industrial processes sector, enforcing the stricter application of Best Available Technique – associated emission levels (BAT-AEL) techniques via plant-specific treatment technical measures. These PaMs are source-based and technology-dependent and are unlikely to be affected unless supply chain issues continue.

The transport sector was the largest emitter of $NO_X$ for Sweden in 2019. Two additional PaMs were reported to ensure the reduction of this pollutant, aiming to phase out light diesel trucks and passenger cars from 2025 and cease sales of new diesel vehicles after 2030. These regulatory PaMs are unlikely to be affected by Covid-19 recovery.

## 4.4 Conclusions

This chapter explored the potential impact of Covid-19 restrictions and subsequent recovery on EU Member States' progress toward meeting their 2030 NECD compliance targets. The 2019 reported projected emissions for each Member State under the NECD were compared against the 2030 emissions targets for $NH_3$, NMVOC, $NO_X$ and $PM_{2.5}$.

Member States were defined as being at risk of non-compliance in this report when their projected 2030 emissions were either above their 2030 emission target or below by less than 5 %. These at-risk Member States may be reliant on the additional PaMs reported for implementation between 2020 and 2030 to reach their 2030 emissions target. Of the nineteen Member States at risk of non-compliance, twelve reported additional PaMs which were analysed for vulnerabilities to Covid-19 impacts. Member States which consider that they will meet their emission reduction commitments with existing PaMs have not been discussed.

Compliance targets for $NH_3$ are most commonly at risk, with six Member States projected to exceed their targets and ten projected to narrowly meet their 2030 target by a margin of <5 %. Member States which fall into the latter category are most at risk of moving from compliance to non-compliance. Across Member States, the largest contributor of $NH_3$ emissions is the agriculture sector which experienced a lack of workers due to sickness, required isolation, and travel restrictions. This had the most impact on labour-intensive processes such as livestock production, horticulture, planting, harvesting and fertiliser application. Estonia, Hungary, Luxembourg and Slovakia may be less likely to effectively implement their additional agriculture PaMs effectively due to Covid-19 impacts, and therefore may be at risk of non-compliance with their 2030 $NH_3$ targets.

Six Member States are at risk of non-compliance with their NMVOC targets and 5 reported additional PaMs. Across Member States, NMVOC emissions mostly arise from the manufacturing industry, agriculture (livestock) and residential, commercial and institutional sectors. Many of the additional PaMs that affected NMVOC emissions did so as part of a wide cross-cutting measure, and therefore were less vulnerable to the impacts of Covid-19.

Of the eight Member States at risk of non-compliance with their $NO_X$ targets, seven are projected to miss their targets, some by a significant amount. When the target is likely to be exceeded by >10 %, as is the case for five Member States, additional PaMs may not be expected to bring the Member State below the compliance threshold. For most Member States, the transport and energy sectors are the largest contributors of $NO_X$ emissions. While the energy sector has not been greatly affected by Covid-19, the transport sector has experienced significant upheaval which has resulted in investments to improving cycling and electric vehicle infrastructure, with concurrant increases in uptake of these modes of transport. Policies that aim to encourage further modal shift from vehicles to active travel may be bolstered by the public's reaction during Covid-19. The compliance status of Member States relating to their $NO_X$ target is not expected to be negatively impacted by Covid-19. Lithuania may be more likely to reach its compliance target as an increase in uptake may increase the effectiveness of its electric vehicle policies.

Eight Member States are at risk of non-complance with their $PM_{2.5}$ targets. Of these, four did not report any additional PaMs. Of the Member States that reported additional PaMs, only Hungary reported a PaM that specifically focused on $PM_{2.5}$.

Covid-19 is expected to impact $NH_3$ compliance to the greatest extent. $NH_3$ is the pollutant for which the most Member States are at risk of non-compliance with their 2030 target. The agriculture sector has also been impacted by labour shortages caused by Covid-19 illness and may remain impacted as travel restrictions for labourers continue. Agricultural PaMs that heavily rely on manual labour are expected to be vulnerable to impacts of Covid-19. Compliance with targets for the other pollutants may not be affected as much as the additional PaMs that are proposed to reduce emissions are not expected to be so heavily impacted by Covid-19.

# 5 Impacts on restriction measures on environmental noise

Covid-19 has been a disruptor of the overall system, given the measures taken that impacted all economy and daily life levels. Most governments' imposition of quarantine measures has caused people to stay more time at home. With this, the use of private and public transportation has decreased significantly. Also, commercial activities stopped almost entirely for a significant number of months over 2020 -2021. All these changes have caused the noise level to drop considerably in most cities in the world (Zambrano-Montserrate, 2020).

Therefore, there is an opportunity to compile the existing information to understand better the extent of noise reduction under such drastic mobility changes and related health impacts. Literature on the recovery period is more scarce but still valuable to hint at the evolution and potential mid-long term impact of the measures taken.

## 5.1 Literature review methodology

The literature review for the impact of the measures taken during the Covid-19 restrictions on noise is based on results of search in SCOPUS, obtained using the search string provided in Table 5.1.

*Table 5.1 Components of the search string used to extract the references for noise and Covid-19.*

| Component | Query |
|---|---|
| Covid | (covid OR coronavirus OR Covid OR SARS-CoV) AND |
| Noise | (noise OR acoustic OR sound) AND |
| Transport | (transport* OR mobility) AND |
| Subject area | ( LIMIT-TO ( SUBJAREA,"ENVI" ) OR LIMIT-TO ( SUBJAREA,"SOCI" ) OR LIMIT-TO ( SUBJAREA,"AGRI" ) OR LIMIT-TO ( SUBJAREA,"BUSI" ) OR LIMIT-TO ( SUBJAREA,"DECI" ) OR LIMIT-TO ( SUBJAREA,"ECON" ) OR LIMIT-TO ( SUBJAREA,"MULT" ) OR LIMIT-TO ( SUBJAREA,"NEUR" ) OR LIMIT-TO ( SUBJAREA,"ARTS" ) OR LIMIT-TO ( SUBJAREA,"PSYC" ) ) AND |
| Time frame | ( LIMIT-TO ( PUBYEAR,2021) OR LIMIT-TO ( PUBYEAR,2020) ) |

The search string was intentionally designed to provide good coverage of the diverse research on cities and their planning, design, and management. Information was extracted in February 2021, and a second check was done in June 2021 to publication only released during March-June 2021. Finally, about 479 references were compiled. They were further filtered by the following criteria :

- Excluded those out of the scope (e.g. focus on psychological effects)
- Geographic scope: Europe

Finally, 169 references were retained. From them, 11 references were analysed in depth since they provided sufficient information to understand the link between measures undertaken, the impact on environmental noise and, in few cases, impact on health.

## 5.2 Summary of literature

Most of the studies focus on the restriction period, and there is still a substantial gap in the recovery period (Table 5.2). Also, the details on the measures taken beyond traffic restrictions (e.g. reducing space for cars) and noise reduction are scarce.

Most of the study cases base their analysis on existing noise sensors. Therefore, the availability of noise monitoring stations and existing monitoring networks have been critical for the overview presented in Table 5.2. Moreover, noise observatories and strategic noise maps have also been valuable in several studies (Begocci, 2020 ; Munoz et al., 2020 ; Vogiatzis et al., 2020). Noise observatories provide an integrated approach to noise, from monitoring, assessment of people's perception, and finally converted to valuable information for noise management and asareness.

There is a general agreement on a decrease of road traffic noise between 3 and 10 dB, with a variable traffic reduction -not always provided, during the restriction periods (Table 5.2). In all cases, the measures restricted traffic to only essential services. Therefore, the impact of restrictoins on noise reduction can be directly attributed to traffic reduction. One consequence is that the noise reduction is higher on the less busy streets or green urban areas. This is explained because the essential services are using the main roads, usually one of the noisier areas in normal circumstances. It should be noted that in most cases the noise reduction is based on measures on sensors where other noise sources may be relevant. However, all the literature reviewed here has an explicit mention of the corresponding noise source (road in most of the cases) and, therefore, noise reduction could be mainly attributed to changes to traffic.

Weekly patterns have also been observed: noise reduction is higher during the weekend when the essential services have a lower activity than the weekdays. This pattern is similar to the situation before the restrictions.

Most of the studies focus on traffic inside the city. In the case of highways, some studies show that the traffic decrease is counteracted with an increased speed, resulting in smaller differences compared with the pre-restriction period (Vogiatzis, 2020).

Concerning other noise sources, Athens experienced a higher decrease of noise (6 to 8 dB) next to the airport (Vogiatzis, 2020). Although this information is coming from a single study, the conclusions could be generalised. Aircraft noise is more localised than road traffic, having a limited locally strong impact around the airports.

*Table 5.2 Overview of main findings related to traffic reduction, dB reduction during the restriction (March-May/June 2020) and the recovery period (June-August 2020).*

| z | Noise source(s) | Lock-down | | | | Recovery | | Reference |
|---|---|---|---|---|---|---|---|---|
| | | Traffic reduction | Difference from the Pre-lock | Weekly noise levels | Patterns by the time of the day | Traffic reduction | Difference from the Pre-lock | |
| France | | | | | | | | |
| Five metropolitan areas[g] | Road traffic | 55 % | 4-6 dB (Lden) | Higher noise reduction during the weekends. | Similar to pre-restrictions | na | na | Munoz et al., 2020 |
| Germany | | | | | | | | |
| Rhur region | Road traffic | 18-20 % | 5 dB | Lower noise levels on Sundays. | Similar to pre-restrictions | na | na | Hornberg, 2021 |
| Greece | | | | | | | | |
| Athens | Road traffic /major airports | 65 % | 3 to 6 dB for road / 6 to 8 dB adjacent to major airport | na | na | na | na | Vogiatzis, 2020 |
| Italy | | | | | | | | |
| Milan | Road traffic | na | 6 dB | na | na | na | na | Benocci et al, 2020 |

[g] Lyon, Metropolis of Aix-Marseille-Provence, Metropolis ofGrenoble-Alpes, Metropolis of Saint Etienne and Metropo-lis of Toulouse

| z | Noise source(s) | Lock-down | | | | Recovery | | Reference |
|---|---|---|---|---|---|---|---|---|
| | | Traffic reduction | Difference from the Pre-lock | Weekly noise levels | Patterns by the time of the day | Traffic reduction | Difference from the Pre-lock | |
| Monza | Road traffic | na | 6-10 dB | na | na | na | 4 dB | |
| Rome | Road traffic | 65 % | 5 dB only on urban roads (not freeway) | na | na | 35 % | 3 dB (only urban roads) | Aletta et al, 2020 |
| Turin | | 70 % | 5 dB | na | na | na | na | Benocci et al, 2020 |
| Spain | | | | | | | | |
| Barcelona (Spain) | Road traffic | na | 5 dB | na | na | na | 3 dB | Ajuntametn de Barcelona, 2021 |
| Madrid (Spain) | Road traffic | 85% | 4 dB | Greater reduction of noise during the weekend | Peak hours are not so clearly discerned during the restrictions. | na | na | Asensio et al., 2020 |
| Sweden | | | | | | | | |
| Stockholm | Road traffic | | 4 dB | | | | 2 dB | Rumpler et al., 2020 |
| Slovenia | | | | | | | | |
| Koper | Port (combined nosie sources : | 35 % (number of ships) | 3.5 dB | | | | | Čurović et al., 2021 |

| z | Noise source(s) | Lock-down | | | | Recovery | | Reference |
|---|---|---|---|---|---|---|---|---|
| | | Traffic reduction | Difference from the Pre-lock | Weekly noise levels | Patterns by the time of the day | Traffic reduction | Difference from the Pre-lock | |
| | industry, traffic) | | | | | | | |

The case of the port of Koper is relevant since this is the only case where the impact on industry and transport noise is analysed (Čurović et al., 2021). In that case noise reduction (3 dB) is in the lower range of the cases studied.

Reduced noise is also reflected in people's perception of reduced noise annoyance (Redel-Macías et al., 2021). However, socio-economic aspects (age, gender, type of property, education) significantly influence people's perceptions.

When data is available, the recovery period reflects an increase of noise from traffic, but still with significant differences compared to the pre-restriction period. Moreover, available information reflects more variability between cities than the restriction period, with higher noise levels for those with a more significant population and bigger peripheries (Redel-Macías, 2021). In the case of Barcelona (Bonet-Solà et al., 2021), considering noise background, found that the stages where shops, museums, and sports centers were allowed to open had similar noise patterns to the restrictions. On the contrary, the opening of bars and restaurants in the first place and of entertainment venues and traffic outside the city later on, led to similar noise patterns to the normal pre-restrictions situation.

A questionnaire sent to the EIONET (Fons and Blanes, 2021) reflected that only 28 % of the respondents, from 23 EEA countries, considered that the changes introduced during the restrictions would be extended and, consequently, the positive effect in noise reduction will continue in the future, to a certain extent. The major obstacles that may lead to a negative impact are the increase in use of private cars during the recovery period and changing priorities on the budget towards the recovery of the economy.

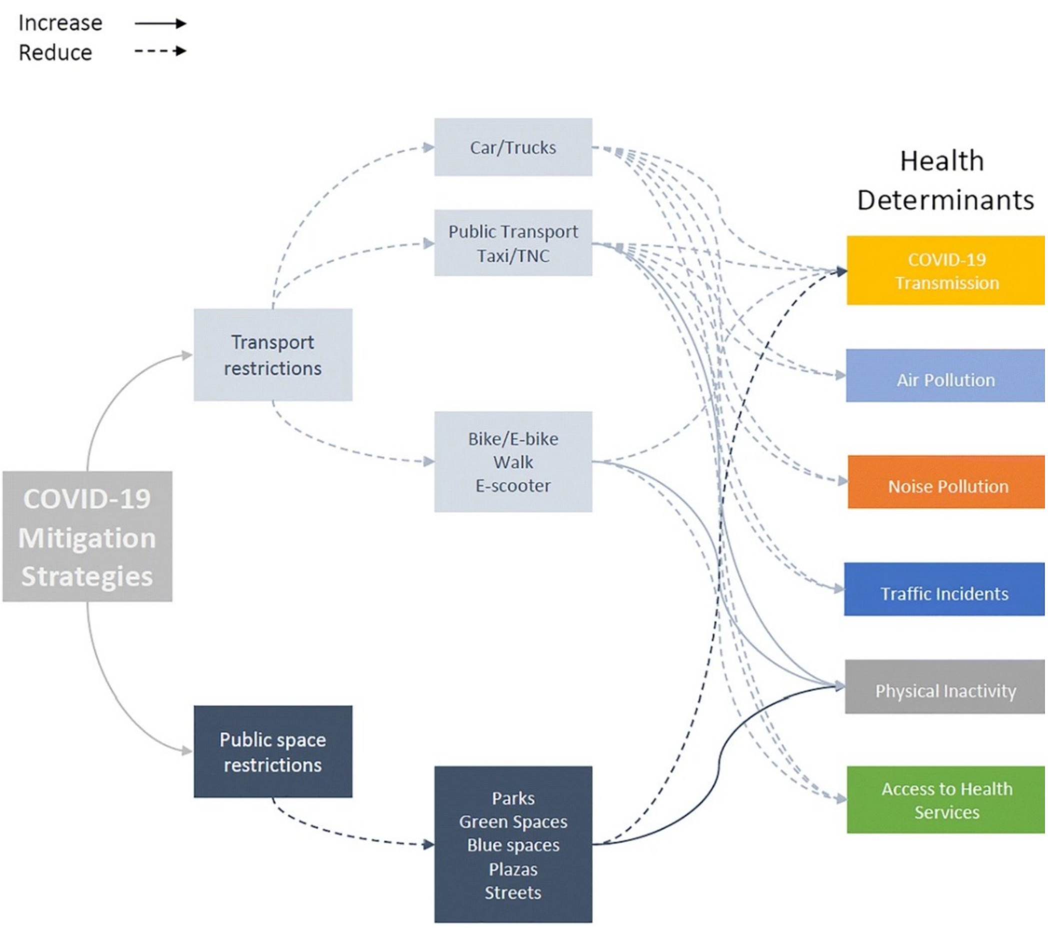
Figure 5-1 Framework of Covid-19 mitigation strategies, urban health determinants. TNC transport network companies (e.g., Uber/Lyft/Cabify), E-bike electric bikes, E-scooter electric scooters. Blue spaces refer to public beaches, lakes, and riversides, among othersprovides an overview of the link between measures taken and health determinants (Rojas-Rueda and Morales-Zamora, 2021). The framework describes how these mitigation strategies could reduce or increase related health determinants. Mitigation strategies aim to reduce Covid-19 transmission with a subsequent reduction in morbidity, mortality, and health economic impacts. These strategies have also reduced other health risks (e.g. noise pollution) that could result in better health outcomes (Covid-19 morbidity, mental disease, non-communicable disease, road injuries, mortality, and health-related economic impacts). On the other hand, such mitigation strategies could also reduce physical activity and access to health services, worsening health outcomes. This framework is also in agreement with the WHO noise guidelines, based on the growing understanding of the health impacts of exposure to environmental noise. These guidelines emphasize the need to reduce exposure to noise at source (reduce traffic), while conserving quiet areas; coordinate approaches to control noise source and other environmental health risks ; inform and involve communities.

The impact of noise reduction on people exposed and health is only analysed in two cases :

- Koper (Čurović et al., 2021). The reduction of the activity around the port of Koper during the restrictions resulted in an estimated decrease of 20 % of people exposed to $L_{den}$ > 55 dB.
- Lyon (Munoz et al., 2020). The estimated change in DisabilityAdjusted Life Years (DALYs) for a scenario of 4dB noise decrease resulted in gains up to 55 % (i.e. 3.7 months gained). It should be noted that these results have been estimated for a long term period, not only on the 3 months of the restrictions. The authors consider the 4 dB noise reduction a feasible scenario by combining traffic reduction with low noise vehicles.

It should be noted that these estimates are only based on measures taken over a period of a few weeks, while noise impact is evaluated over a longer period.For example, a reduction of 5 dB over a period of three months would result in a 1,9 dB reduction for a period of one year -considering no further noise reduction on the remaining nine months. The consequence is that the potential health benefit will be reduced if the noise reduction is not maintained.

*Figure 5-1 Framework of Covid-19 mitigation strategies, urban health determinants. TNC transport network companies (e.g., Uber/Lyft/Cabify), E-bike electric bikes, E-scooter electric scooters. Blue spaces refer to public beaches, lakes, and riversides, among others*




These results are relevant in light of the EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'[h] (EC, 2021), which aims to reduce the number of people chronically disturbed due to noise from transport by 30 % until 2030.

[h] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400&qid=1623311742827

# 6 Published studies on Covid-19 restriction measures and air quality and urban sustainability

In 2020 and 2021, a large number of studies of the impact of Covid-19 pandemic restriction measures has been produced by scientists, but also by other stakeholders including ETC/ATNI and ETC/CCA. This body of information provides valuable information about the observed impacts, and about methods to study this unfortunate natural experiment. In this chapter we consider European studies related to air quality and European and global studies related to urban sustainability and planning. The inclusion of global studies on elements of urban sustainability reflects the relatively lower abundance of such studies in literature.

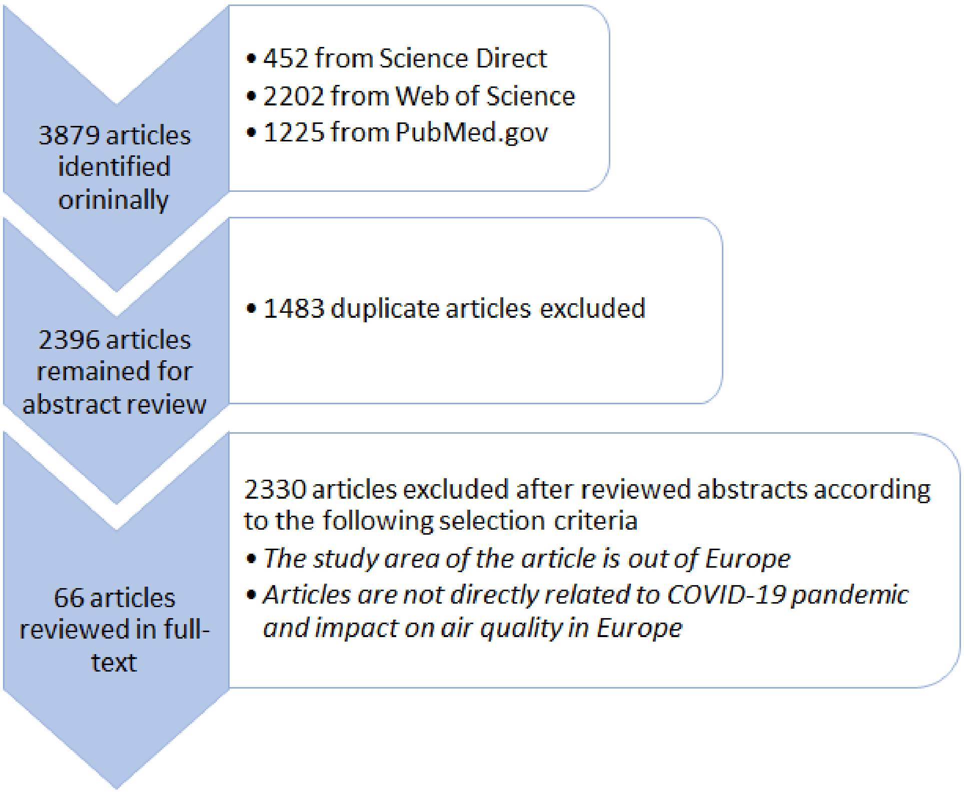
In addition to literature on the effects on air quality, we also include an overview of sources of data on air quality, in order to facilitate further analyses.

## 6.1 Summary of key literature and an overview on air quality

### *Literature review methodology*

The scientific literature on Covid-19 pandemic and air quality was obtained on 25 November 2021 by using search strings in Science Direct, Web of Science and PubMed.gov, using the Advanced Search Builder and the keywords in the following: title-abstract-keywords ((“covid” OR “coronavirus” OR “Covid” OR “SARS-CoV”) AND (“air pollut*” OR “air quality”)). Each provided 452, 2202 and 1225 articles, respectively. After removing duplications, we reviewed the abstracts for 2396 articles including 242 review articles published between 2020 and 2021 (25 November 2021). At the end, 66 selected articles published between 2000 and 2021 were reviewed in full text (Figure 6.1).

*Figure 6.1 Selection process for full scientific articles’ review*



### *6.1.2. Literature review results - Covid-19 impact on air quality*

The impact of the Covid-19 restrictions on air quality appears mixed. The previous analysis by EEA (EEA, 2020) shows clearly an initial decrease (March 2020) for ambient concentrations of $NO_2$ throughout Europe, and a decrease in $PM_{10}$ concentrations in many areas/cities though not all. In other literature, $NO_2$ was consistently found to be reduced during the restriction period, and this decline is attributed to reduction of activity in transport sector. The concentrations of $PM_{2.5}$, $PM_{10}$ and other gaseous pollutants including $SO_2$, VOCs, and $O_3$ showed more variations, because the emission sources of these pollutants or of their precursors are more varied. They include sectors, such as power plants and agriculture, have been affected differently than the transportation sector. The short-term variations in meteorological conditions and atmospheric chemical effects further complicated analysis of the changes, especially in case of statistical analyses based on monitoring data. Most available studies compare data for periods with restrictions with relevant reference periods (these vary between studies), for time intervals of relatively short duration (months). None of the studies is extrapolating the results, e.g. to annual statistics. The key findings in the literature are summarized as follows (For detail, see Table 6-1):

*$NO_2$*

Universally, $NO_2$ was the pollutant most affected by the restrictions. A significant reduction in $NO_2$ concentration under Covid-19 restrictions has been observed in many cities, regions and countries (EEA, 2020; Baldasano 2020). Measurement of $NO_2$ showed that extensive reductions happeneded in urban areas in Europe (Barré et al., 2020; Zambrano-Monserrate et al., 2020a). Locations (e.g., Italy, France, Spain,) where the restrictions were stricter show stronger reductions and, conversely, locations (e.g., Germany, Poland, Sweden) where softer measures were implemented show milder reductions in $NO_2$ pollution levels (Barré et al., 2020). These effects were likely because $NO_2$ emissions come from sources that were typically affected by the restrictions (i.e., surface traffic and non-essential industries), and were more pronounced on stations near the source, e.g., on traffic stationsa (Amouei Torkmahalleh, 2021; EEA, 2020).

*NO*

Average daily NO concentrations were found to decrese by more than 60 % at urban air quality monitoring stations and 75 % at traffic air quality monitoring stations in four European cities (Nice, Rome, Valencia and Turin) (Sicard et al., 2020).

*$PM_{2.5}$*

The $PM_{2.5}$ concentrations were not considered to change significantly (Sicard et al. 2020) in southern Europe. Urban $PM_{2.5}$ average daily concentrations were found to decrese by 3 % in Nice, by 13 % in Turin and Valencia (a stronger decrease was observed in these cities at traffic stations). The concentrations have increased by 11 % in Rome (however a decrease of 1 % was observed at traffic stations in Rome) (Sicard et al., 2020).

*$PM_{10}$*

The $PM_{10}$ concentrations were not considered to change significantly (Sicard et al. 2020) in southern Europe. Urban $PM_{10}$ average daily concentrations were found to decrese by 6 % in Nice, by 9 % in Turin and 32 % in Valencia (as for $PM_{2.5}$, a stronger decrease was observed in these cities at traffic stations). The concentrations have increased by 2 % in Rome (however a decrease of 3 % was observed at traffic stations in Rome) (Sicard et al., 2020). The $PM_{10}$ average daily concentrations decreased about 28-31 % in Barcelona (Tobías et al., 2020). The lower reduction for $PM_{10}$, compared to $NO_2$ reduction, 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 (Tobías et al., 2020). $PM_{10}$ average daily concentrations were not significantly affected by the restriction measures in Northen Italy. This could be due to the fact that decreases in $PM_{10}$ emissions from traffic were compensated for by increases in emissions from domestic heating and/or from changes in the secondary aerosol formation regime (Putaud et al,. 2021a).

*Nanoparticles*

Nanoparticles concentration (in the size range from 10 nm to 800 nm) measured as total particle number was reduced in two regional stations in Southern Italy (Dinoi et al., 2021).

*$O_3$*

The $O_3$ 8-hour and daily average daily maximum concentrations increased in cities, e.g., Paris (Petit et al., 2021)， Nice, Rome, Valencia and Turin (Sicard et al., 2020). The increase in $O_3$ concentrations is mainly explained by an unprecedented reduction in NOx emissions leading to a lower $O_3$ titration by NO (Petit et al., 2021; Sicard et al., 2020; Tobías et al., 2020).

*CO*

Decrease of CO levels was analyzed in 11 Spanish cities. A clear decrease during restriction periods was found for Barcelona, Santiago de Compostella and Sevilla, for the eight other cities, the decrease was not significant (Briz-Redón et al., 2021) .

*$SO_2$*

One study was found about $SO_2$, for Barcelona, where the main source is shipping. A small decline in concentrations was observed in Barcelona during the restriction measures, but the observed levels are very low, also before any restrictions were implemented (Tobías et al., 2020).

*BC*

BC concentration was reduced during the restriction period in Barcelona (Tobías et al. 2020). BC emissions were reduced during the restriction period in Westen, Southern and Northern Europe coutries (e.g., Italy, Germany, France, Spain, ) (Evangeliou et al., 2021). BC emissions were slightly enhanced in Eastern Europe and remained unchanged in Scandinavia during the restrictions, due to increased residential combustion, as people had to stay home and temperatures at that time were the lowest of the last 5 years (Evangeliou et al., 2021).

*Table 6.1 Overview of the key findings on Covid-19 and air quality in Europe*

| Pollutant(s) | Key findings | Study area | Key reference(s) in literature |
|---|---|---|---|
| $NO_2$ | $NO_2$ is the pollutant mostly affected by the Covid-19 pandemic. | Global | (Amouei Torkmahalleh 2021) |
| | Significant $NO_2$ reductions were observed throughout the region; assessment was done using both monitoring data and CTM modelling (similar to Chapter 2), comparison period was within March-April 2020, compared to average data for similar periods in 2015-2019. | EEA member countries and associated countries (38) | (EEA, 2020) |
| | Reductions in $NO_2$ concentrations in Barcelona and Madrid during March 2020 were 50 % and 62 %, respectively. | Barcelona and Madrid, Spain | (Baldasano 2020) |
| | Locations where the restrictions was stricter show stronger reductions (e.g., down to 60 % in Madrid) and, conversely, locations where | Main European urban areas | (Barré et al. 2020) |

| Pollutant(s) | Key findings | Study area | Key reference(s) in literature |
|---|---|---|---|
| | softer measures were implemented show milder reductions in $NO_2$ pollution levels (e.g., around 16 % in Stockholm). | | |
| | The average $NO_2$ column drop amounts to 20 % to 38 % relative to the same period in 2019.Period with restrictions within March-April 2020. | Westen Europe | (Bauwens et al., 2020) |
| | $NO_2$ concentrations decreased as a consequence of the restrictions by 30 % and 40 % on average at urban and regional background sites, respectively. Period with restrictions 17 February–24 May 2020 was compared to the same period for 2019. | Northern Italy | (Putaud et al. 2021a) |
| | $NO_2$ declines were observed with reductions of 50 %, 34 %, and 20 % at urban traffic, urban background, and rural background stations, respectively. March-April 2020 compared to the same period of 2019. | Rome, Italy | (Bassani et al. 2021) |
| | A significant decrease in $NO_2$ concentrations over Rome, Madrid, and Paris, the first cities in Europe to implement strict quarantine measures. 14-25 March 2020 compared to same period of 2019. | Rome, Madrid, and Paris | (Zambrano-Monserrateet al., 2020a) |
| | Lockdown measures are responsible for a 50 % reduction in $NO_2$ levels on average. | Spain (more than 50 Spanish provinces and islands) | (Petetin et al., 2020) |
| | Significant reductions of $NO_2$ levels were achieved in most cities. Restricion period March 15 2020 to April 12 2020 compared to the same period of 2019. | Spain (11 cities) | (Briz-Redón, et al., 2021) |
| | $NO_2$ concentration was reduced by half during the restrictions (more windy and wet) period. 16 February 2020 to 13March 2020 (pre-restrictions) was compared to 14 to 30 March 2020 (restrictions). | Barcelona | (Tobías et al., 2020) |
| | Reductions in $NO_2$ is about 53 % at urban stations and 65 % at traffic stations, restriction period in April 2020 compared to similar time periods of 2017-2019. | Europe (four cities (Nice, i.e., Rome, Valencia and Turin) | (Sicard et al., 2020) |
| | $NO_2$ concentrations during the restrictions period March-May 2020 were found to be lower with respect to the 5-year average (2015-2019) | UK | (DEFRA,2020) |
| | Compared to 2015-2019, reductions in $NO_2$ in April 2020 is between 60 % (Spain) and 22 % | Urban and suburban areas in Europe | (Solberg et al., 2021) |

| Pollutant(s) | Key findings | Study area | Key reference(s) in literature |
|---|---|---|---|
| | (Poland), gradually being reduced throughout August. | | |
| NO | Reductions in NO is about 63 % at urban stations and 78 % at traffic stations, restriction period in April 2020 compared to similar time periods of 2017-2019. | Europe (four cities (Nice, i.e., Rome, Valencia and Turin) | (Sicard et al., 2020) |
| $NO_X$ | The concentrations of $NO_X$ and traffic-related carbonaceous aerosols dropped by 42 %–66 % during the restriction period. | Paris (France) | (Petit et al., 2021) |
| $PM_{2.5}$ | Globally, $PM_{2.5}$ declined during the Covid-19 restrictions . | Global (5 continents, 34 countries, 141 cities) | (Amouei Torkmahalleh, 2021) |
| | Decline in $PM_{2.5}$ associated with partial restrictions in many cities. | Global (9 major cities, i.e., New York, Los Angeles, Zaragoza, Rome, Dubai, Delhi, Mumbai, Beijing and Shanghai) | (Chauhan and Singh, 2020) |
| | Reductions in $PM_{2.5}$ is about 8 %, restriction period in April 2020 compared to similar time periods of 2017-2019. | Europe (four cities (Nice, i.e., Rome, Valencia and Turin) | (Sicard et al., 2020) |
| | $PM_{2.5}$ did not show any significant difference. For UK, the restrictions period March-May 2020 was compared a 5-year average (2015-2019) of the same period. For Athens, 12.3.2020-12.4. 2020 when restrictions were put in place, is compared to period 1.1.2020-10.3.2020 | UK | (DEFRA, 2020) |
| | | Athens | (Eleftheriadis et al., 2021) |
| $PM_{10}$ | Decrease of $PM_{10}$ levels were found in some cities. Restricion period March 15 2020 to April 12 2020 compared to the same period of 2019. | Spain (11 cities) | (Briz-Redón, et al., 2021) |
| | Both increases and decreases were observed throughout the region; assessment was done using both monitoring data and CTM modelling (similar to Chapter 2), comparison period was within March-April 2020, compared to average data for similar periods in 2015-2019. | EEA member countries and associated countries (38) | (EEA, 2020) |
| | $PM_{10}$ decreased but in a much lower proportion compared to $NO_2$, BC, $O_3$, causes for the lower abatement are still unknown. 16 February 2020 to 13March 2020 (pre- | Barcelona | (Tobías et al., 2020) |

| Pollutant(s) | Key findings | Study area | Key reference(s) in literature |
|---|---|---|---|
| | restrictions) was compared to 14 to 30 March 2020 (restrictions). | | |
| | Reductions in $PM_{10}$ is about 8 %, restriction period in April 2020 compared to similar time periods of 2017-2019. | Europe (four cities (Nice, i.e., Rome, Valencia and Turin) | (Sicard et al, 2020) |
| | $PM_{10}$ concentrations were not significantly affected by restriction measures. Period with restrictions 17 February–24 May 2020 was compared to the same period for 2019. | Northen Italy | (Putaud et al., 2021a) |
| Ultrafine nuclei particles or nanoparticles | Ultrafine nuclei particles showed a significant reduction in the period 12.3.2020-12.4. 2020 when restrictions were put in place, compared to period 1.1.2020-10.3.2020. | Athens | (Eleftheriadis et al., 2021) |
| | Different percentage reductions in total particle number concentrations are observed. | Lecce and Lamezia Terme, Italy | (Dinoi et al., 2021) |
| | PM1 concentrations dropped by 14 % during the restriction period | Paris (France) | (Petit et al., 2021) |
| $O_3$ | Globally, $O_3$ increased during the Covid-19 restrictions . Increased $O_3$ concentrations during the restrictions has facilitated SOA (secondary organic aerosol) formation. | Global (5 continents, 34 countries, 141 cities) | (Amouei Torkmahalleh, 2021) |
| | Increases of $O_3$ pollution levels were found in several cities. Restricion period March 15 2020 to April 12 2020 compared to the same period of 2019. | Spain (11 cities) | (Briz-Redón et al., 2021) |
| | $O_3$ concentrations increased by around 50 % during the restrictions (more windy and wet) period. 16 February 2020 to 13March 2020 (pre-restrictions) was compared to 14 to 30 March 2020 (restrictions). | Barcelona | (Tobías et al., 2020) |
| | An increase in the $O_3$ concentrations at both the urban and regional background sites. Period with restrictions 17 February–24 May 2020 was compared to the same period for 2019. | Northern Italy | (Putaud et al., 2021a) |
| | Daily $O_3$ mean concentrations increased at urban stations by 24 % in Nice, 14 % in Rome, 27 % in Turin, 2.4 % in Valencia. The restriction period in April was 2020 compared to similar time periods of 2017-2019. | Europe (four cities (i.e., Nice, Rome, Turin and Valencia ) | (Sicard et al., 2020) |
| | $O_3$ concentrations increased by 20 %. Restriction period 17 March 2020 to 11 May 2020 was compared to varying reference periods (same dates, years from 2012 to 2019). | Paris (France) | (Petit et al., 2021) |

| Pollutant(s) | Key findings | Study area | Key reference(s) in literature |
|---|---|---|---|
| | $O_3$ was significantly increased. Restrictions period March-May 2020 was compared to pre-restrictions reference using several methodologies. | UK | (DEFRA, 2020) |
| CO | Decrease of CO levels were found in some cities. Restricion period March 15 2020 to April 12 2020 compared to the same period of 2019. | Spain (11 cities) | (Briz-Redón et al., 2021) |
| $SO_2$ | Decrease of $SO_2$ levels were found in some cities. Restricion period March 15 2020 to April 12 2020 compared to the same period of 2019. | Spain (11 cities) | (Briz-Redón et al., 2021) |
| | No systematic change was found for $SO_2$, levels are very low. 16 February 2020 to 13March 2020 (pre-restrictions) was compared to 14 to 30 March 2020 (restrictions). | Barcelona | (Tobías et al., 2020) |
| BC | BC emissions declined by 23 kt in Europe (20 % in Italy, 40 % in Germany, 34 % in Spain, 22 % in France) during restrictions compared to the same period in the previous 5 years. | Europe | (Evangeliou et al., 2021) |
| | BC concentration was reduced by half during the restrictions period (more windy and wet). 16 February 2020 to 13March 2020 (pre-restrictions) was compared to 14 to 30 March 2020 (restrictions). | Barcelona | (Tobías et al., 2020) |
| Nitrate ($NO_3^-$) | Nitrates showed the most significant reduction especially during the 2nd restriction period (40–50 %). Restriction perions 1st Period 11/3- 22/3 2020 and 2nd Period 23/3–12/4 2020 are compared to a reference period 1/1–10/3 2020. | Athens | (Eleftheriadis et al., 2021) |
| | Particulate nitrate decreased by 45 % Restriction period 17 March 2020 to 11 May 2020 was compared to varying reference periods (same dates, years from 2012 to 2019). | Paris (France) | (Petit et al., 2021) |
| Carbonaceous aerosol (Composition spans the range from organic carbon (BC), to 'Black' or 'Elemental' | Carbonaceous aerosol showed an increase of 10–2 % of average before showing a decline (5-30 %). Restriction perions 1st Period 11/3- 22/3 2020 and 2nd Period 23/3–12/4 2020 are compared to a reference period 1/1–10/3 2020. | Athens | (Eleftheriadis et al., 2021) |
| | Secondary organic aerosols (SOAs), decreased by 25 %. Restriction period 17 March 2020 to 11 May 2020 was | Paris (France) | (Petit et al., 2021) |

| Pollutant(s) | Key findings | Study area | Key reference(s) in literature |
|---|---|---|---|
| carbon ("BC" or "EC")) | compared to varying reference periods (same dates, years from 2012 to 2019). | | |

The above overview can be summarized as follows.

The studies for Europe, published before the cut-off date for the literature overview, focus on air quality developments based on data for a relatively shorter period of time (several weeks or months). This is clearly reflecting the response of the scientific community to provide rapid assessments.

The data analyses are based in observational data on air quality from in-situ air quality networks and from satellites, and on statistical and CTM modeling, and compare data gathered from periods with restrictions with varying reference data. The choice of reference reflects among other, the recognized need to take the meteorological variability into account for accurately assessing the impact of the restrictions on air quality levels, in particular at fine spatial and temporal scales. This is crucial if we wish to reliably quantify the health implications of the restrictions due to reduced air pollution (Petetin et al. 2020).

Restrictions and resulting changes in emissions reduced exposure to pollutants mainly associated with transport, and could provide global-scale health benefits. However, other changes and changes in inputs to atmospheric chemistry led to somewhat increased $O_3$ and other changes that may have somewhat reduced those benefits.

The restrictions are asociated with substantial economic costs and with other health issues (depression, suicide, spousal abuse, drug overdoses, etc.). Thus, any similar reductions in air pollution would need to be obtained without these extensive economic and other consequences produced by the imposed activity reductions (Amouei Torkmahalleh 2021).

A comprehensive framework will be needed to fully assess the effects of restrictions on air quality and human health, in order to describe the dependencies of the environmental, economic and social changes and resulting societal impacts.

## 6.2 Databases providing access to data on air quality

Data obtained from ground-level air quality monitoring stations and meterological monitoring stations are available from several, often interconnected and harmonized, sources. In addition, the COPERNICUS provides a growing number of services that allow to include also satellite observations in the analyses. Table 6.2 provides an overview of these data sources that may be relevant for further analyses in Europe.

*Table 6.2 Overview of data sources on Covid-19 and air quality in Europe*

| Name | Data description | Key reference(s) in literature |
|---|---|---|
| European Environmental Agency (EEA) air quality e-Reporting | The EEA's air quality database consists of a multi-annual time series of air quality measurement data and calculated statistics for a number of air pollutants. It also contains meta-information on the monitoring networks involved, their stations and measurements, air quality modelling techniques, as well as air quality zones, assessment regimes, compliance attainments and air quality plans and programmes reported by the EEA member and cooperating | (EEA, 2021a; EEA, 2021c) |

| Name | Data description | Key reference(s) in literature |
|---|---|---|
| | countries and other voluntary reporting countries. Data are easily downloadable, and can also be analyzed directly using the viewer. | |
| ACTRIS (The Aerosol, Clouds and Trace Gases Research Infrastructure) observational data | ACTRIS released a set of atmospheric measurement data during the Covid-19 pandemic, including:<br>30 sites with aerosol in situ measurements providing mainly absorption and scattering coefficient, size and/or number distribution. A few sites with high time resolution aerosol chemical composition.<br>12 sites with trace gases in situ data providing VOCs and NOX measurements.<br>17 sites with particle light absorption measurement.<br>24 sites with aerosol remote sensing data providing profiles with backscattering and extinction coefficient.<br>11 cloud remote sensing sites providing profile information of 9 various cloud properties. | (Evangeliou et al., 2021; Saponaro 2021) |
| EBAS (a database with atmospheric measurement data) | EBAS is a database infrastructure developed and operated by NILU – Norwegian Institute for Air Research. It is designed to document, quality assure, secure long-term storage and provide users for access to atmospheric composition data generated by international and national frameworks and research projects. It serves as a database or contributes to the following activities : EMEP, ACTRIS, WMOs Global Atmospheric Watch, Svalbard Integrated Arctic Earth Observing System SIOS, Arctic Monitoring and Assessment Program AMAP, Helsinki Convention HELCOM . | http://ebas.nilu.no |
| GHOST (Globally Harmonised Observational Surface Treatment) | GHOST is a project dedicated to the harmonization of global surface atmospheric observations and metadata for the purpose of facilitating quality-assured comparisons between observations and models within the atmospheric chemistry community. For Europe, the source of air quality monitoring data in the GHOST is the EEA AQ e-reporting and EBAS. | (Bowdalo, forthcoming; Petetin et al., 2020) |
| Copernicus Atmosphere Monitoring Service Regional (CAMS) ensemble model forecasts | The operational CAMS ensemble model forecasts provide regular predictions of hourly, daily mean & maximum concentrations. Over the course of 2020, the operational forecast did not account for restriction measures, but the daily analyses included assimilation of in situ data, and thus they did take into account the effect of restriction measures. Besides, CAMS produced a set of emission scenario with/without restrictions which has been used in an ensemble of regional models under the CAMS Policy Service. | (Putaud et al., 2021b) |

## 6.3 Summary of literature and an overview on urban sustainability and urban planning

This section gathers the lessons learnt from Covid-19 related restriction experiences described in literature on urban sustainability and urban planning. Six main thematic topics of relevance for urban sustainability are in focus: Mobility changes, Work and housing spaces, Commerce and shopping, Recreational and open green spaces, the role of Digitalization, and Governance. The studies to include were identified using the above focal areas as keywords in literature search.

The key papers from 2020 and 2021 are gathered from each of these six thematic topics. Table 6.3 provides an overview of the main reported findings and the key lessons learnt in the literature on urban sustainability issues. Unlike other parts of this report, here we included also non-European studies, as literature for Europe is relatively scarce.

*Table 6.3 Overview of the lessons learnt from Covid-19 related restriction measures on urban sustainability and urban planning*

| Thematic topic | Issue/lesson learnt | Country | Key reference(s) in literature |
|---|---|---|---|
| **Mobility** | With the decrease in use of public transport there is not enough road space for private vehicles. Modal shift to active travel is needed. | France, Italy, Spain | (Orro et al., 2020; Pisano, 2020) |
| | The pandemic may have increased negative attitudes toward public transport. Use of public transport significantly declined. Active travel or private vehicles use was preferred. | Global Europe | (Falchetta, 2020; Sharifi and Khavarian-Garmsir, 2020) |
| **Work and housing spaces** | Increased working from home. | Europe | (Reuschke and Felstead, 2020) |
| | Increased energy consumption due to increased working from home. | Spain | (Monzón-Chavarrías et al., 2021) |
| | Increased house sales in rural areas and increased purchases of suburban/rural second homes. | Global | (Kakderi et al., 2021; Sharifi and Khavarian-Garmsir, 2020) |
| | There may be increases in emissions from working from home due to increased home energy consumption and increased non-work travel, however these impacts are uncertain. | Global Germany | (Hook et al., 2020; Moeckel, 2017) |
| **Commerce and shopping** | Regarding freight transport, some supply chains were discontinued due to factory shutdowns but there was a robust increase in home deliveries. | Europe | (Falchetta, 2020) |
| | Due to the crisis, both customers and retailers have become more interested in e-commerce. However, the former group still have a much higher interest than the latter group. | Czech Republic | (Dvorak et al., 2021) |

| Thematic topic | Issue/lesson learnt | Country | Key reference(s) in literature |
| --- | --- | --- | --- |
| | The possible weaknesses of local food systems and food security globally need to be addressed. | Global | (Galimberti et al., 2020) |
| | Smallholder food producers and urban/peri-urban agriculture may have a positive role to play in future food security and sustainable food systems. | Europe | (Galimberti et al., 2020) |
| | Increase in emissions of air pollution from home deliveries. However, the increase in emissions is not proportionate to the increase in number of parcels delivered because lower levels of road traffic during Covid restriction meant that more deliveries could be made on each delivery route. | Madrid | (Villa and Monzón, 2021) |
| | Increase in waste due to panic buying and more single-use products during pandemic. This, and the increase in e-commerce has increased plastic waste. | Global | (Bir 2020; Calma, 2020; Liang et al., 2021; Sarkodie and Owusu, 2021; Yousefi et al., 2021; Zambrano-Monserrateet al., 2020b) |
| | Food purchased online is shipped packed, so inorganic waste by households has increased.<br>Consumers increase their demand for online shopping for home delivery. Consequently, organic waste generated by households has increased. | Global | (Zambrano-Monserrate et al., 2020a) |
| | Covid-19 caused the quantity variation and composition change of municipal solid waste (e.g., organic and inorganic waste, medical waste). Covid-19 also has significant effects on waste recycling, medical waste management, quantity, and littered waste composition. | Global | (Bir 2020; Calma 2020; Liang et al. 2021; Sarkodie and Owusu 2021; Yousefi et al. 2021; Zambrano-Monserrate et al., 2020a; Zambrano-Monserrate et al., 2020b) |
| **Recreational and open green spaces** | Increased use of urban green spaces; increased outdoor recreational activity (walking, running, hiking, cycling). | Norway | (Venter et al., 2021) |
| | Open space is more important than “designed” or “equipped” space. | Poland and New Zealand | (Herman and Drozda, 2021) |
| | The pandemic has increased the value people put on greenspaces. This could increased pressure to enhance urban environments. | Europe | (Kleinschroth and Kowarik, 2020) |
| | Correlation between mental health and open spaces/being outdoors. | Global Austria | (Bratman et al., 2019; Stieger et al., 2021) |
| | Decrease of disease spread in areas with green spaces/vegetation. | US | (You and Pan, 2020) |

| Thematic topic | Issue/lesson learnt | Country | Key reference(s) in literature |
|---|---|---|---|
| **Role of digitalization** | Large potential for digitalization, with reduction of traffic in city centres improving air quality and reducing waste. | Global | (Kakderi et al., 2021) |
| | Real-time monitoring and big data analytics can help to make timely and effective, data-driven decisions. | Global | (Sharifi and Khavarian-Garmsir, 2020) |
| | The technologies exist; the main barriers appear to be the combination of resistance to new ways of working and a natural instinct to suppress data in case it reveals shortcomings. | Global | (Murray et al., 2020) |
| **Governance** | Inequality and inequitable access to services put the entire city at risk as social distancing/staying at home/improved sanitation may not be an option for the poorest groups. | Global | (Sharifi and Khavarian-Garmsir, 2020) |
| | As cities are expected to experience significant financial deficits, they may need to prioritize investments and postpone or cancel some plans that may deem less important (e.g., environmental and cultural). This may encourage engagement in collaboration networks of cities for knowledge sharing. | Global | (Kunzmann, 2020) |
| | Integrated city level governance is crucial with different departments working together towards the same vision. | Global | (Sharifi and Khavarian-Garmsir, 2020) |
| | Inequalities in urban areas contribute to higher incidences of Covid in deprived neighbourhoods. Among the vulnerable groups are the self employed, informally employed, those living in small/shared accommodation and those with chronic disorders. | Spain | (Marí-Dell'Olmo et al., 2021) |

The above literature suggests a number of changes in pollutant drivers and pressures related to the restriction measures, but without a systematic assessment framework it seems difficult to assess the individual and combined effect these changes have on air emissions, air qualiy and noise. Clearly, some developments may result in less environmental pressure but this could be offset by other developments with an opposite effect. For example, more people working from home and more flexible working hours for some reducse the overall transport demand and could also reduce e.g. congestion as people could better choose when to travel; on the other hand, more people working from home may also lead to increased individual home heating, which can lead to higher PM emissions, so that the total benefit is not fully clear. A framework similar to the one in Figure 5-1 would facilitate a more comprehensive analysis of full consequences of these developments. The presented overview provides a possible starting point for its development

# 7 Conclusions

The first analyses of impacts of measures to prevent spread of Covid-19, including those by EEA, appeared already in 2020, using the data from the first months of the restrictions ( most often within March 2020 to April/May 2020). The basis for this report is naturally wider: we have analyzed air quality for the whole year 2020 for a larger number of air pollutants. We have also brought together a number of analyses on the impact of restrictions published before November 2021, in an attempt to indicate potential lessons useful to further management of air pollution and noise in Europe. The current status of air quality and noise, combined with the ambitious goals for further reduction of harmful impacts, indicates that there is a real need to identify those measures that would bring the levels of noise and air pollutants further down compared to the current status.

Analyses of shorter-term data (not a full year), clearly show that at the beginning of the restriction measures, in the period February 2020-May 2020, there were significant changes in transport sector, resulting in reduction of nitrogen oxides and in traffic-related noise. The same development is observed in the whole of Europe. The pattern is weaker for particulate matter and for other transport-related pollutants which showed smaller reductions or even a local increase. As the period in question is the heating season in most European countries, the traffic reduction impact on PM was most likely offset by increased local heating. This is attributed (at least partly) to restrictions that included working from home or other measures keeping the inhabitants in their homes. For secondary pollutants, i.e. ozone and partly $PM_{2.5}$, such analysis is more difficult but the results clearly indicate changes in atmospheric chemistry in urban areas leading to significant increase of ozone levels.

Analyses of data for the whole of 2020 show a less pronounced effects however similar tendencies. The smaller size of the effect is due to an averaging effect: the restrictions were first imposed near simultaneously in all countries in the period covered by the shorter-term studies, and then gradually lifted and in varying degrees further imposed towards the end of the year. In most countries, the most stringent restrictions were implemented during March 2020 and were fully in place through April and parts of May of the same year. After that, the situation across Europe is more varied. This development is well captured by the stringency index for each country, which is used as one of the variables in the analyses.

The fact that similar results are obtained by nearly all available studies irrespective of methods used points to the robustness of the analyses. They were generated by approaches ranging from simple statistical approaches that are applied on monitoring data from a few air quality monitoring stations, to the most complex modeling that includes data from all available sources and observing platforms and uses advanced statistical and chemical transport modeling with multiple inputs on meteorology, air emissions and air quality observations. An overview of available open data sources on air quality shows clearly the increasing availability of observational data and services based on satellite observations which will increase the transparency and quality of analyses.

Noise related to road traffic appears to have broadly similar development as for air quality, with decreases there where there was a decrease in traffic, and with some increases that can be explained by traffic increase. Based on the studies reviewed, we propose a possible assessment framework of Covid-19 mitigation strategies.

European regulatory system that aims to achieve acceptable levels of air quality comprises not only instruments that regulate air quality directly, but also instruments that regulate total emissions of harmful pollutants on country level, and emissions from a wealth of specific sources. In this analysis, we looked in detail on the NECD. Nineteen Member States have been identified as being at risk of non-compliance with their 2030 NECD targets. Of these, 12 reported additional measures which were analyzed for potential impacts due to the recovery after the Covid-19 pandemic. Additional measures related to emissions of $NH_3$ are expected to be impacted to the greatest extent, and in four Member States (Estonia, Hungary, Luxemburg, and Slovakia) may be at greater risk of non-compliance with their $NH_3$ targets, due to travel restrictions and worker sickness affecting the agriculture sector.

Recognizing the importance of cities both for pollution pressures and for pollution governance, we have also reviewed literature that directly addresses the options cities have taken to reduce the spreading of the Covid-19 pandemics. The fragmentation of findings which are broadly consistent with the findings on air quality and noise, points to the need to develop an integrated assessment framework to capture the interplay of the most important factors and developments.

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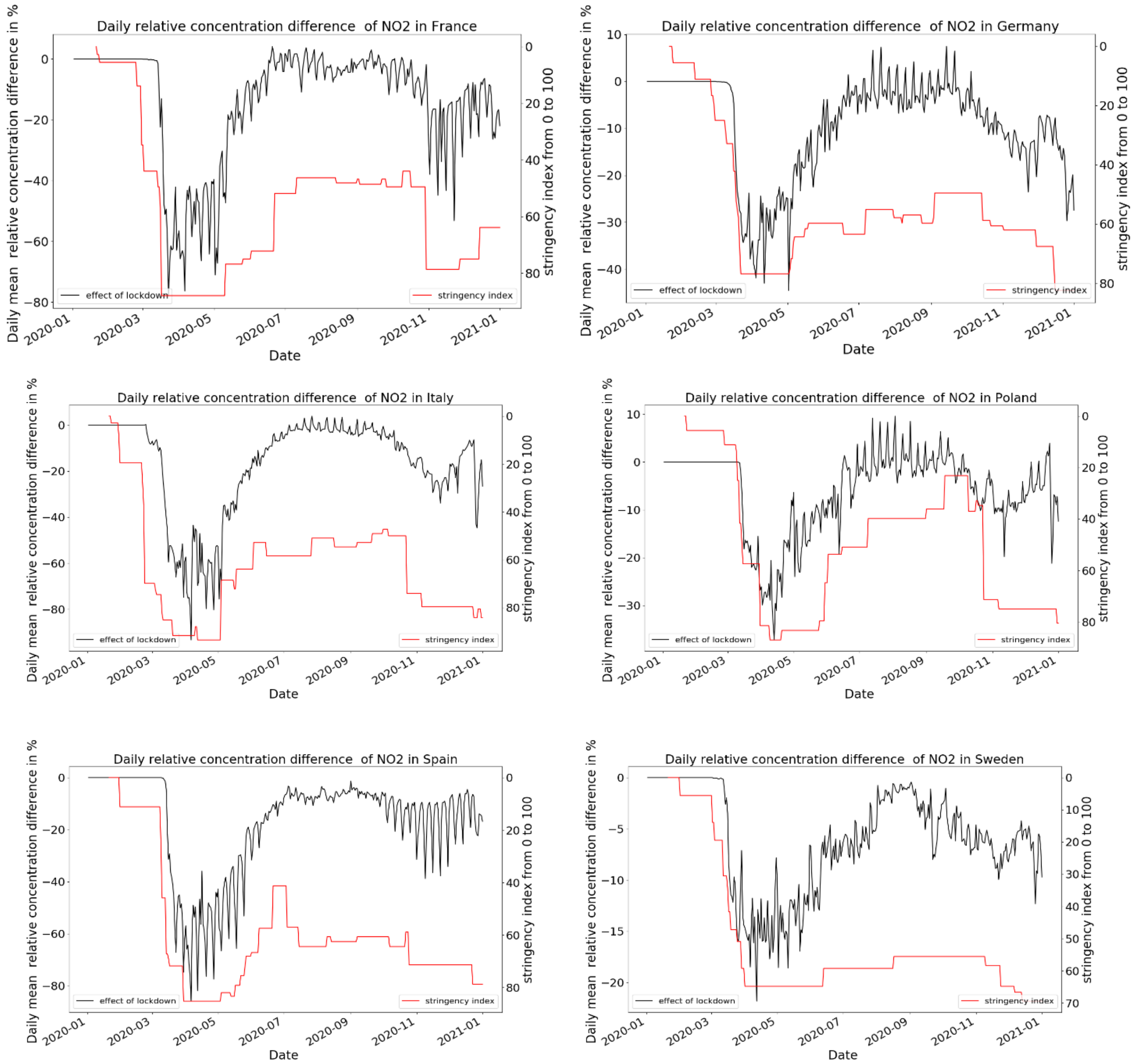
# Annex

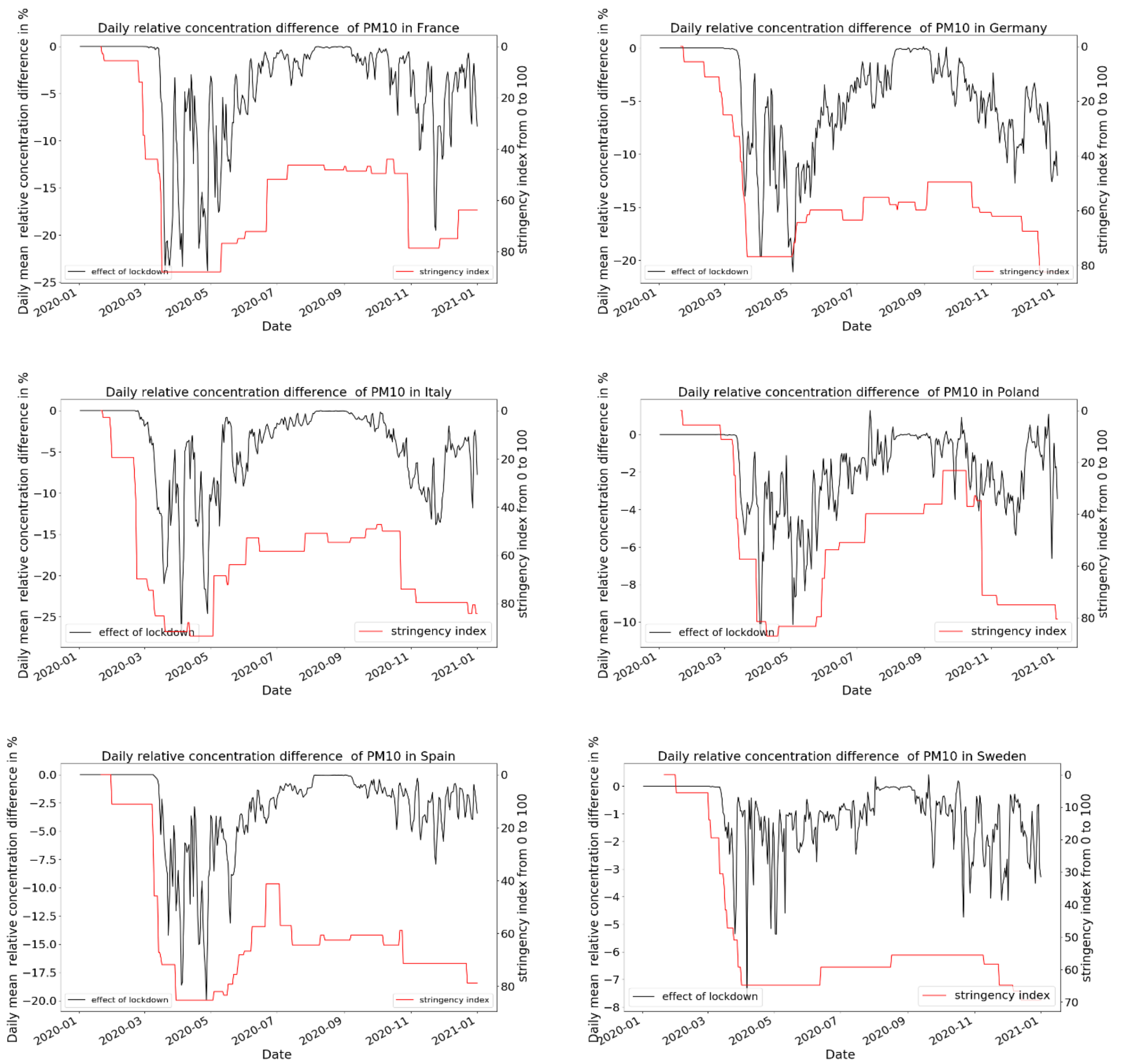
## Annex 1: $NO_2$ day-to-day evolution for countries

*Figure A.1 Time series of daily relative concentration difference (in %) of $NO_2$ (black lines) and stringency index (red lines) for Spain, France, Italy, Germany, Poland and Sweden, year 2020. Please, be aware of the different scales in y-axes*



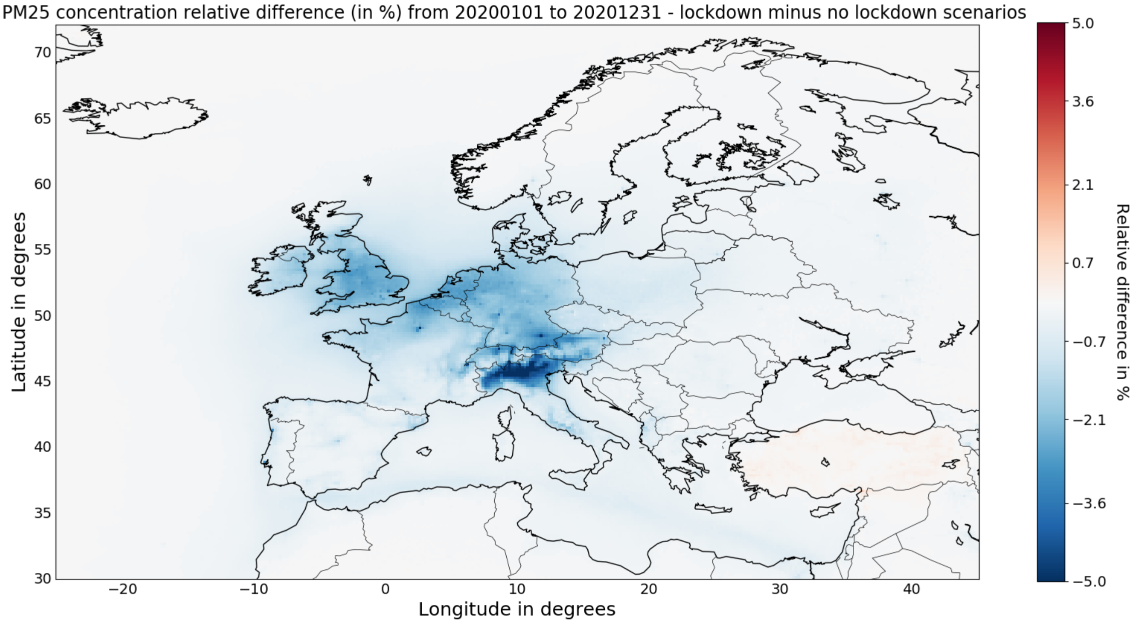
## Annex 2: $PM_{10}$ day-to-day evolution for countries

*Figure A.2 Time series of daily relative concentration difference (in %) of $PM_{10}$ and stringency index (for Spain, France, Italy, Germany, Poland and Sweden) for year 2020*



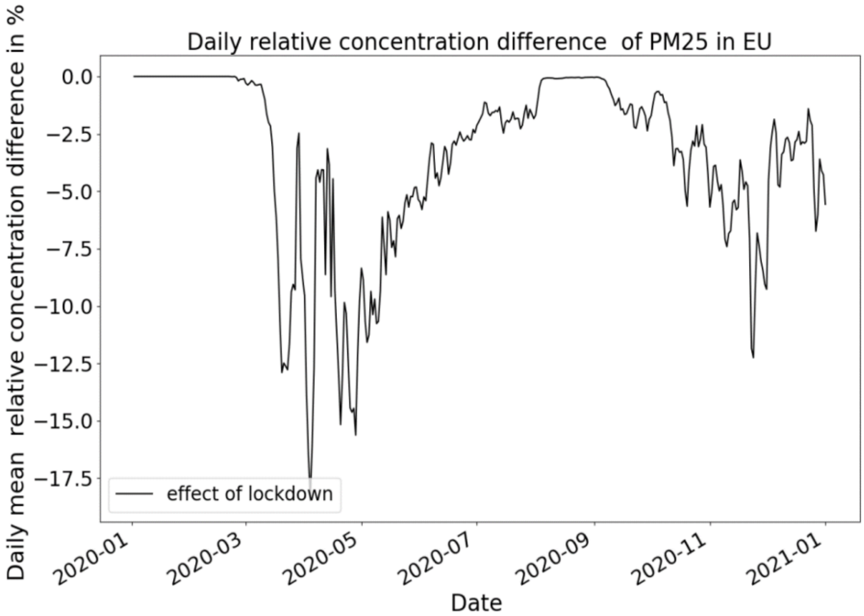
## Annex 3: Annual relative difference $PM_{2.5}$

*Figure A.3 Impact of restrictions (lockdown - BaU scenario) on annual concentrations of $PM_{2.5}$ (changes in %) in Europe for 2020*



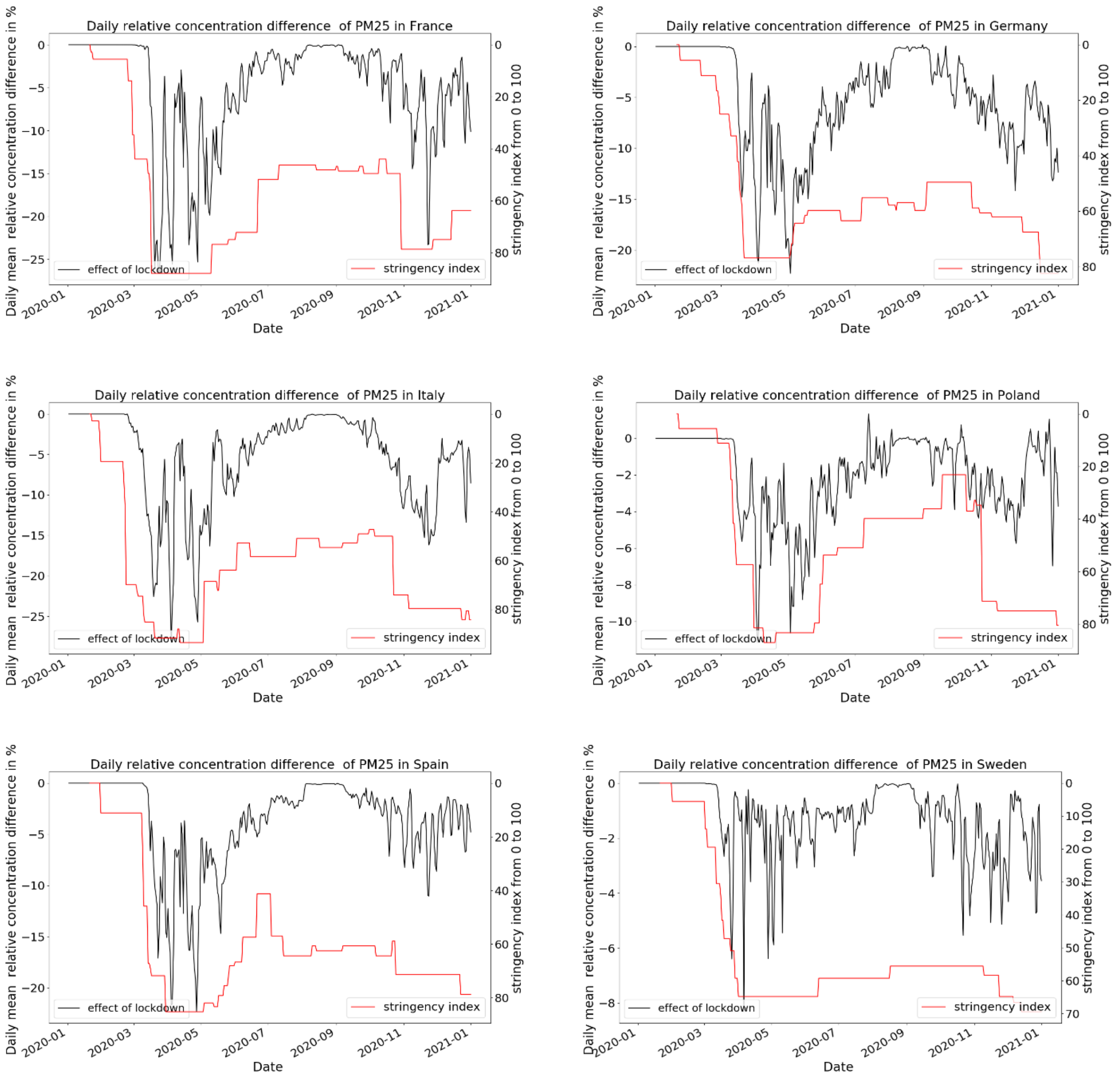
## Annex 4: $PM_{2.5}$ EU day-to-day evolution

*Figure A.4 Time series of European Union daily relative concentration difference (in %) of $PM_{2.5}$ for year 2020*



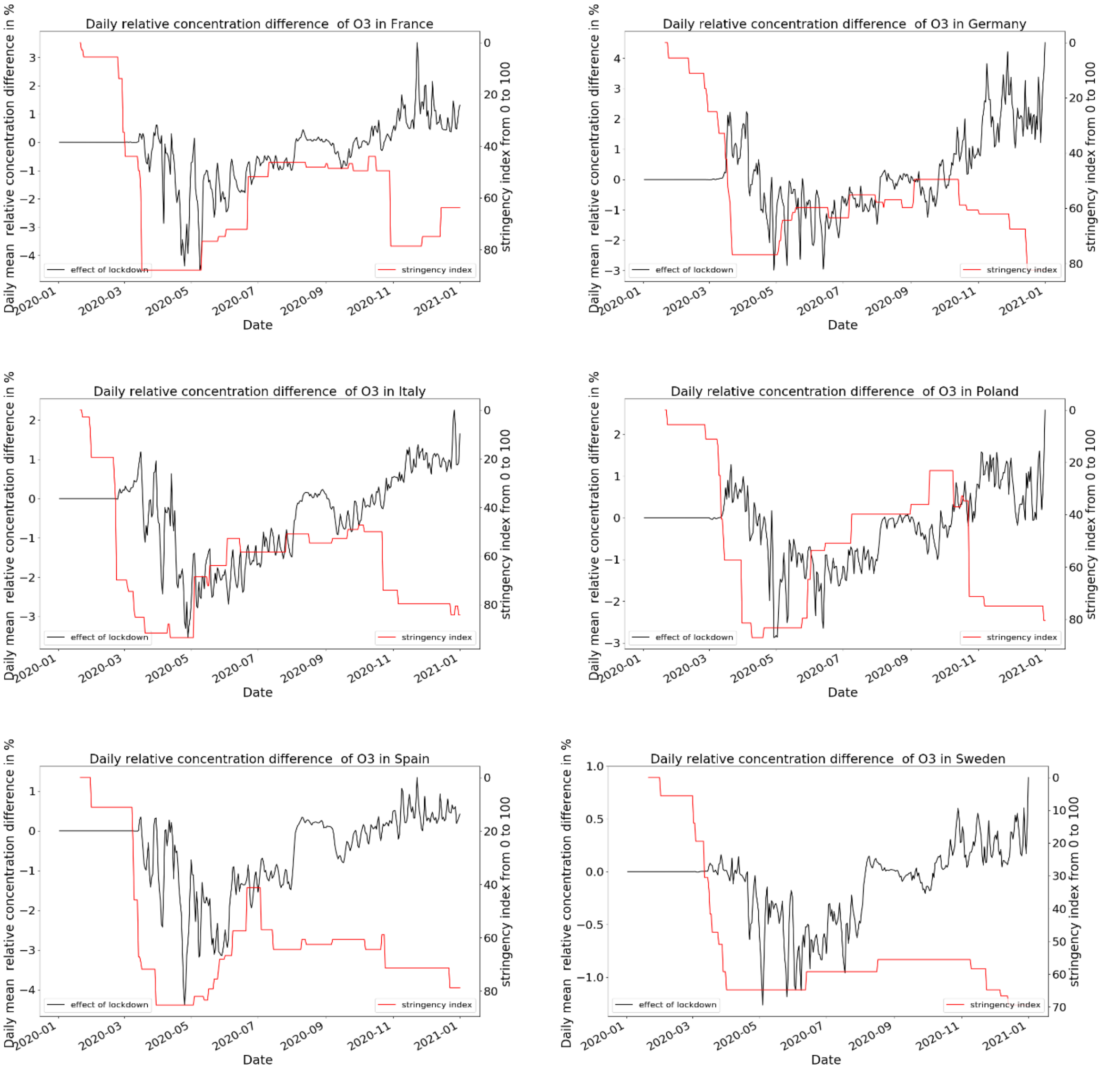
# Annex 5: day-to-day evolution for countries

*Figure A.5 Time series of daily relative concentration difference (in %) of $PM_{2.5}$ and stringency index (for France, Germany, Italy, Poland, Spain and Sweden) for year 2020*



## Annex 6: $O_3$ day-to-day evolution for countries

*Figure A.6 Time series of daily relative concentration difference (in %) of $O_3$ and stringency index (for France, Germany, Italy, Poland, Spain and Sweden) for year 2020*



## Annex 7: Results for $O_3$-8hour daily maximum

*Figure A.7 Impact of restrictions (lockdown - BaU scenario) on annual concentrations of 8H daily max $O_3$ (change in %) in Europe for 2020*

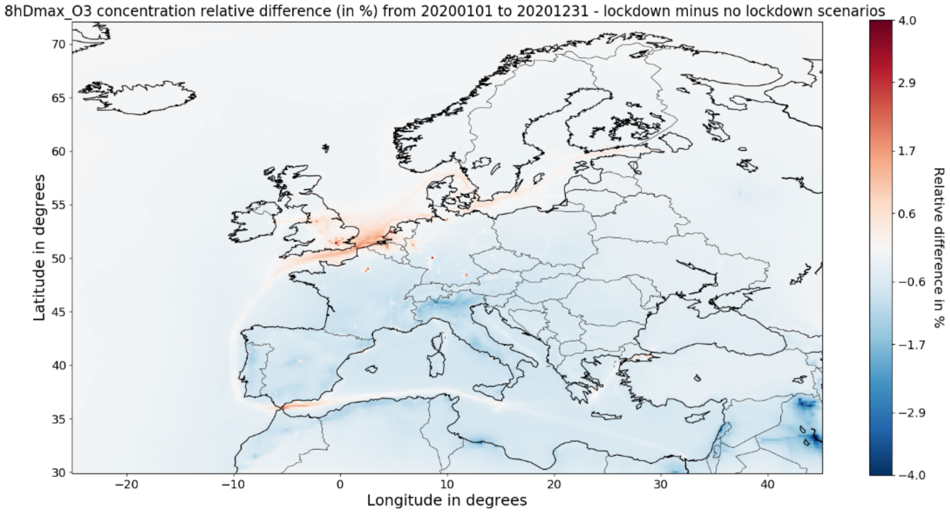



*Figure A.8 Time series of European Union daily relative concentration difference (in %) of $O_3$ 8-hour daily max for year 2020*

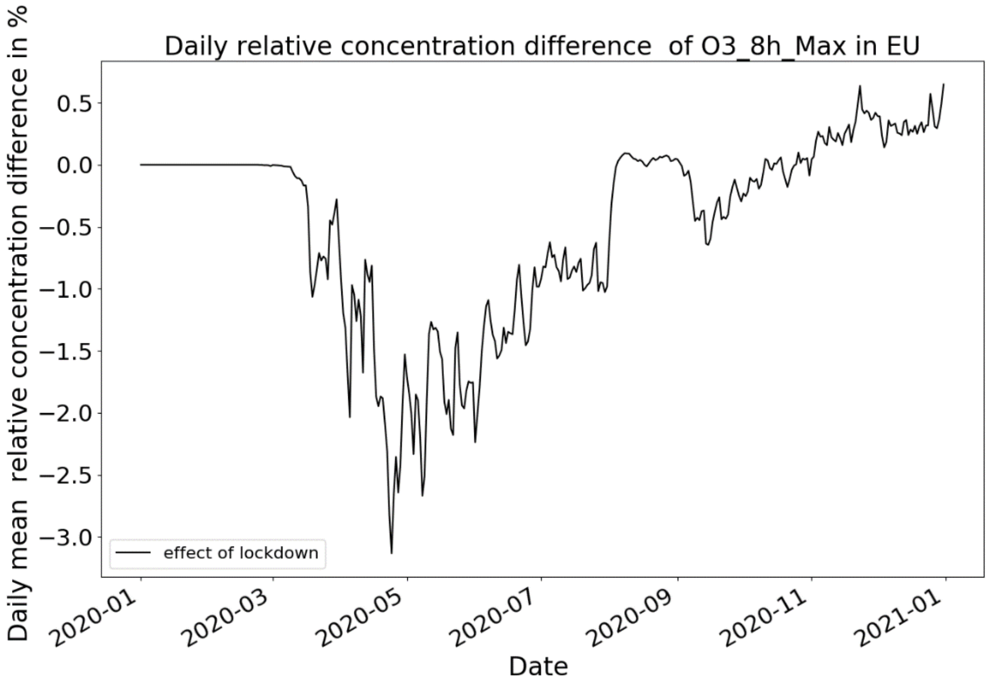
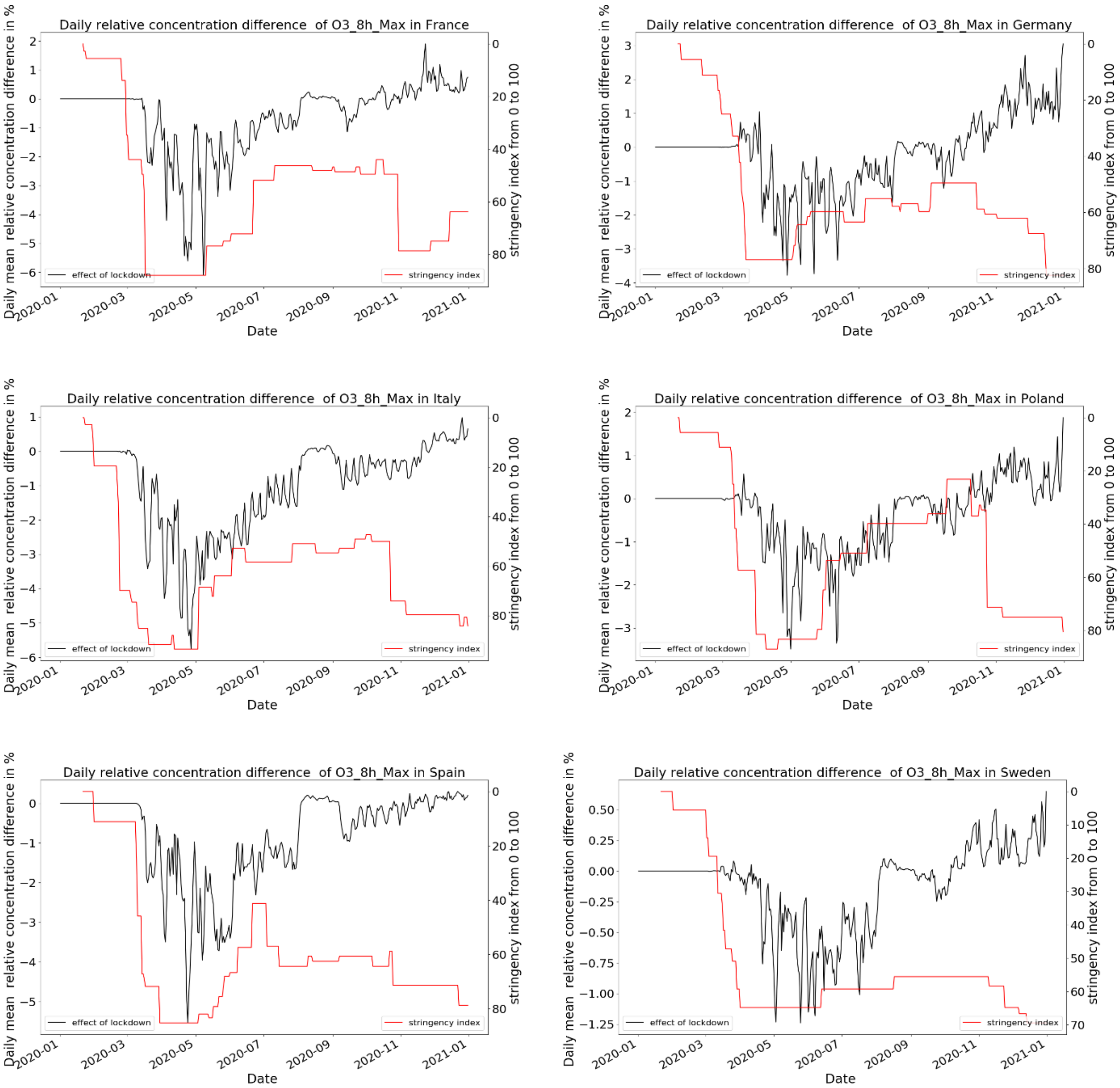
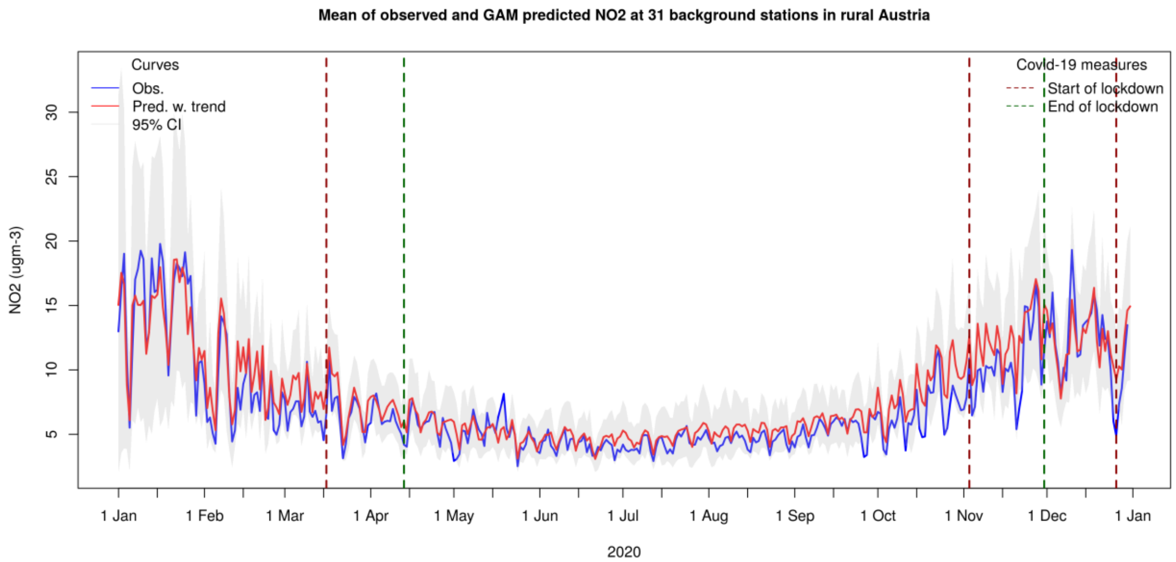


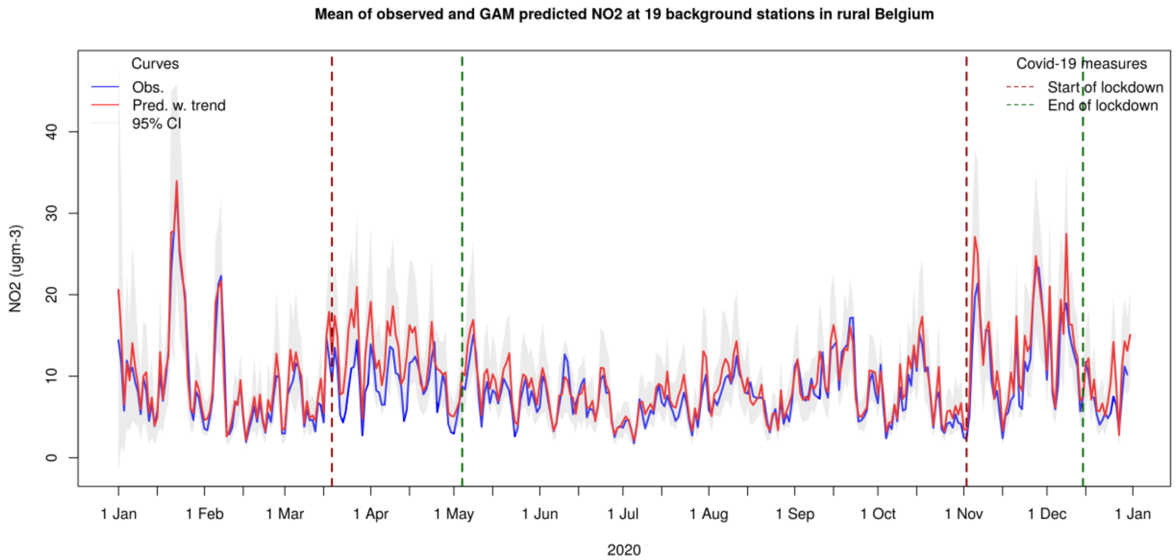
*Figure A.9 Time series of daily relative concentration difference (in %) of $O_3$-8h max and stringency index (for Spain, France, Italy, Germany, Poland and Sweden) for year 2020*

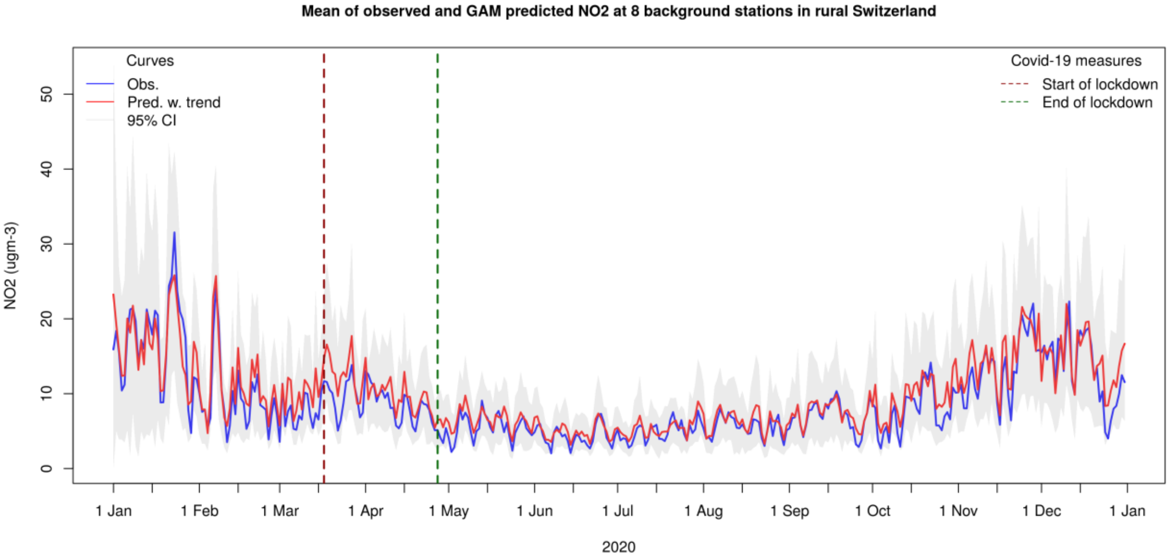


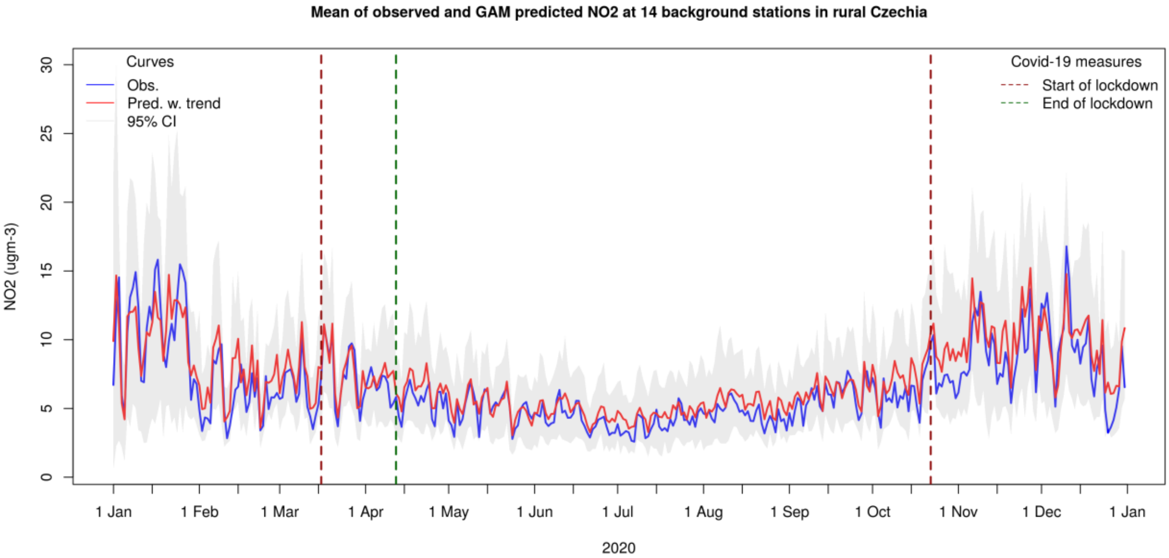
## Annex 8: Daily modelled and measured time series during 2020 for $NO_2$, $PM_{10}$, $PM_{2.5}$ and $O_3$

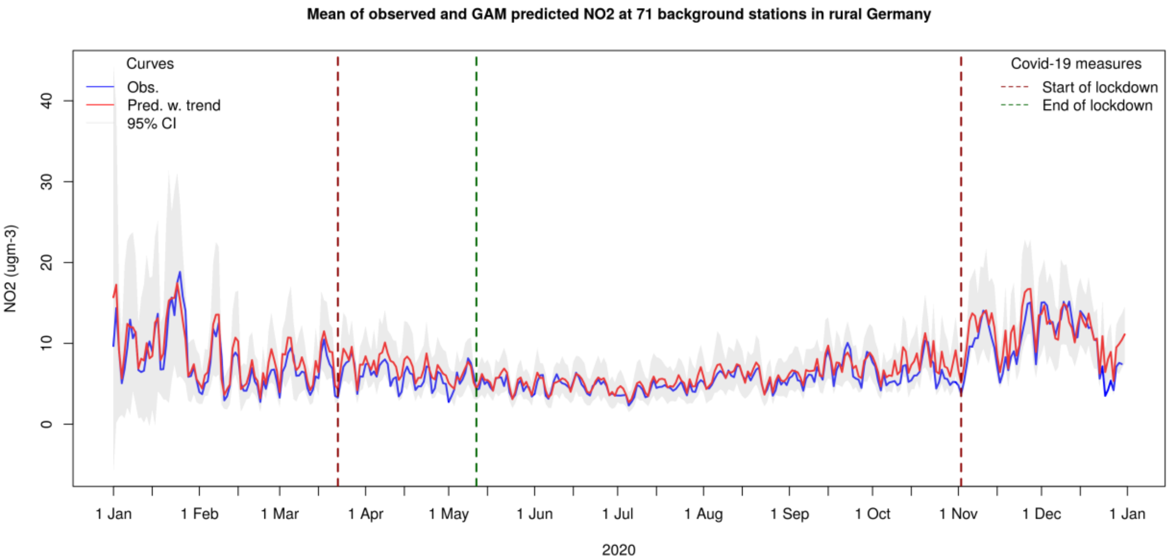
*Figure A.10   $NO_2$ rural*



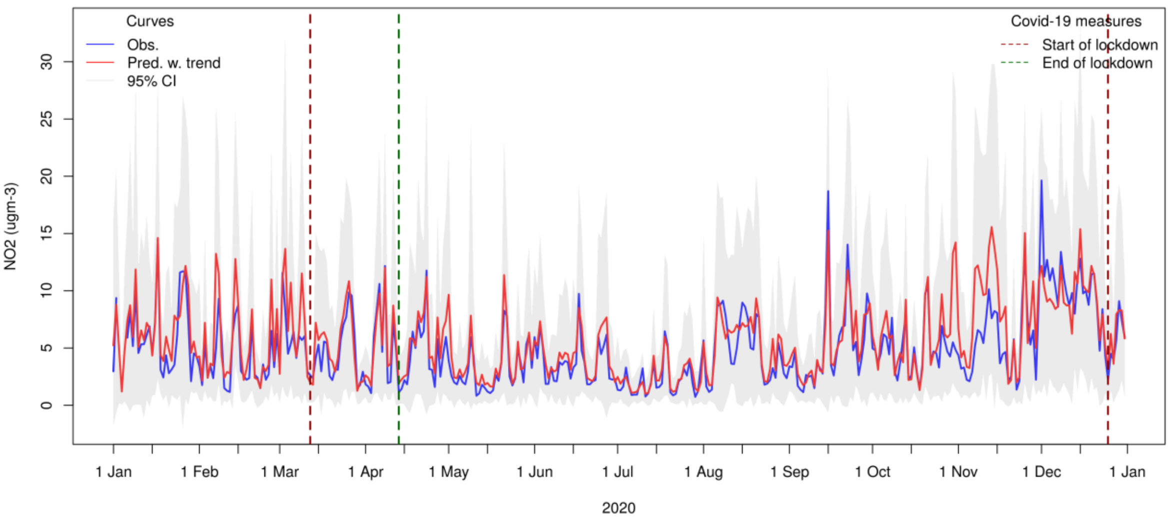




Mean of observed and GAM predicted NO2 at 8 background stations in rural Switzerland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
10
20
30
40
50
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

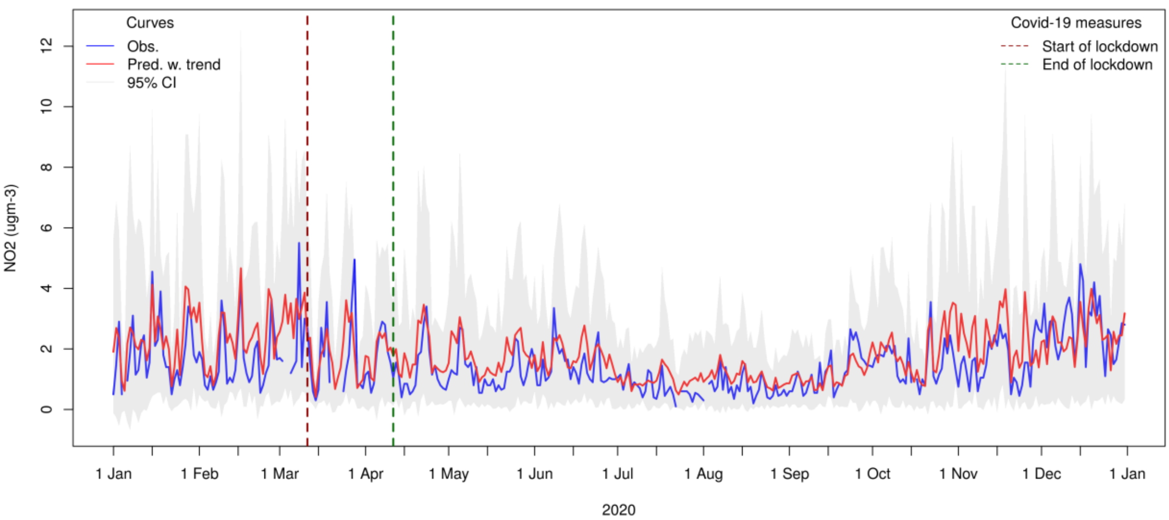

Mean of observed and GAM predicted NO2 at 14 background stations in rural Czechia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
5
10
15
20
25
30
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted NO2 at 71 background stations in rural Germany
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
10
20
30
40
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

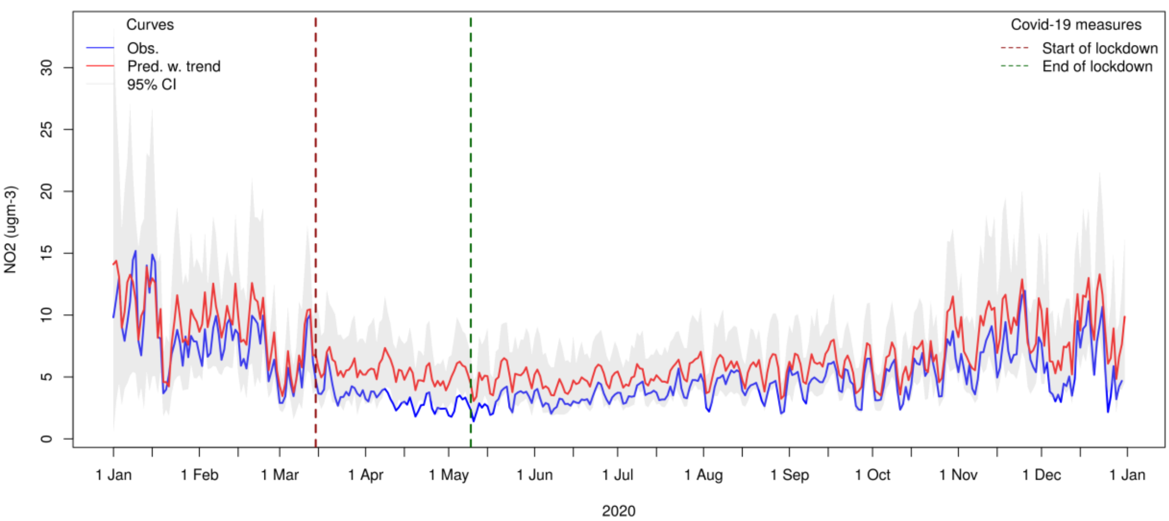
Mean of observed and GAM predicted NO2 at 3 background stations in rural Denmark

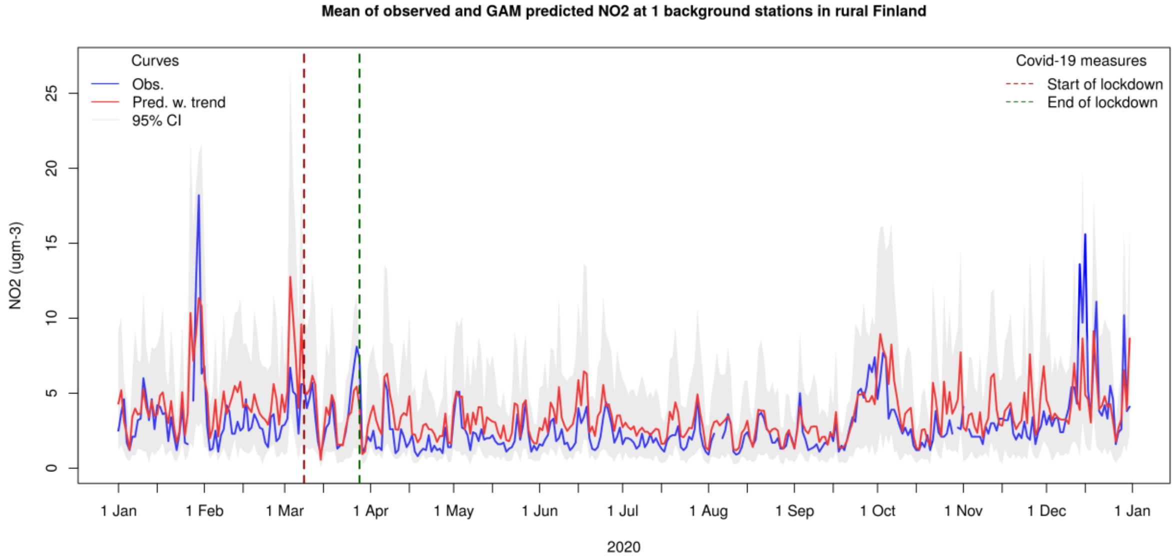


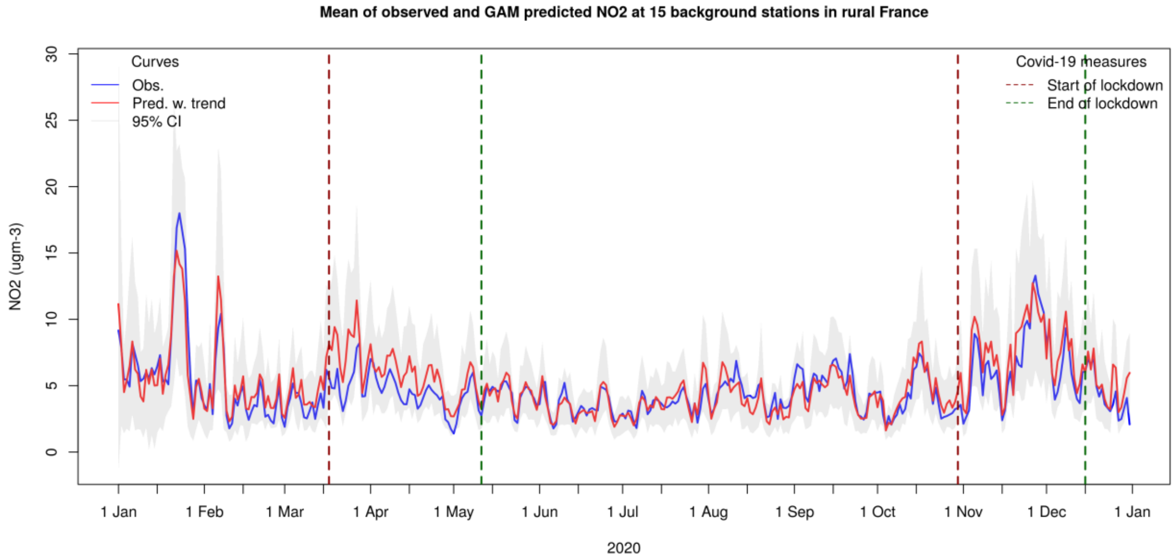

Mean of observed and GAM predicted NO2 at 2 background stations in rural Estonia

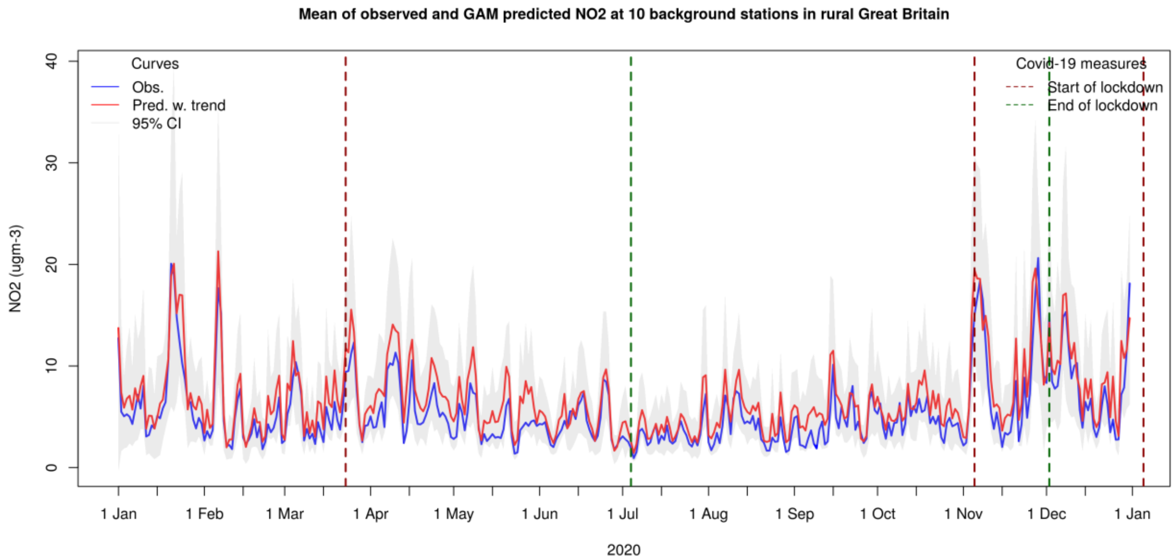



Mean of observed and GAM predicted NO2 at 18 background stations in rural Spain

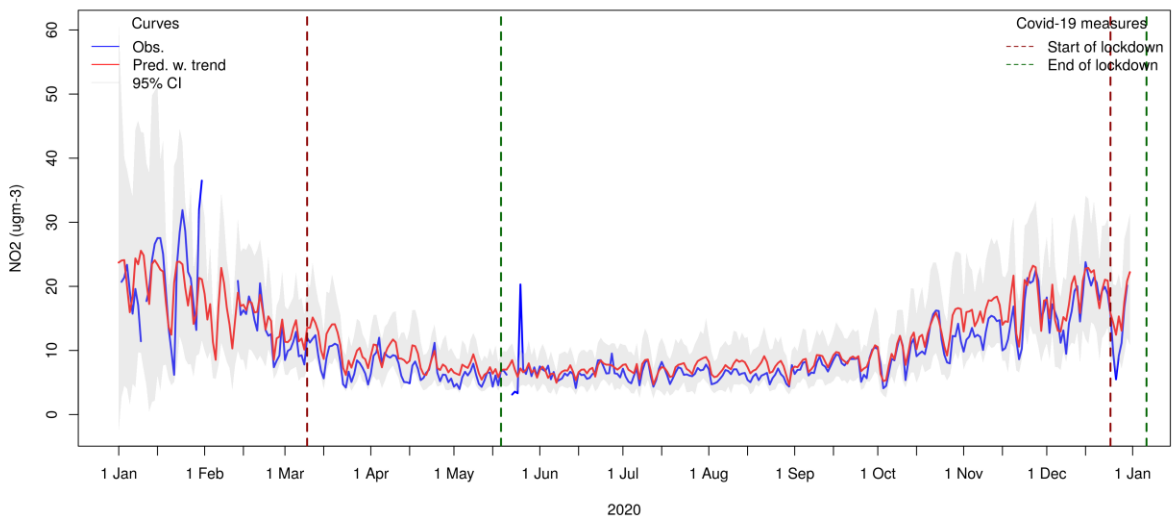



Mean of observed and GAM predicted NO2 at 1 background stations in rural Finland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
5
10
15
20
25
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

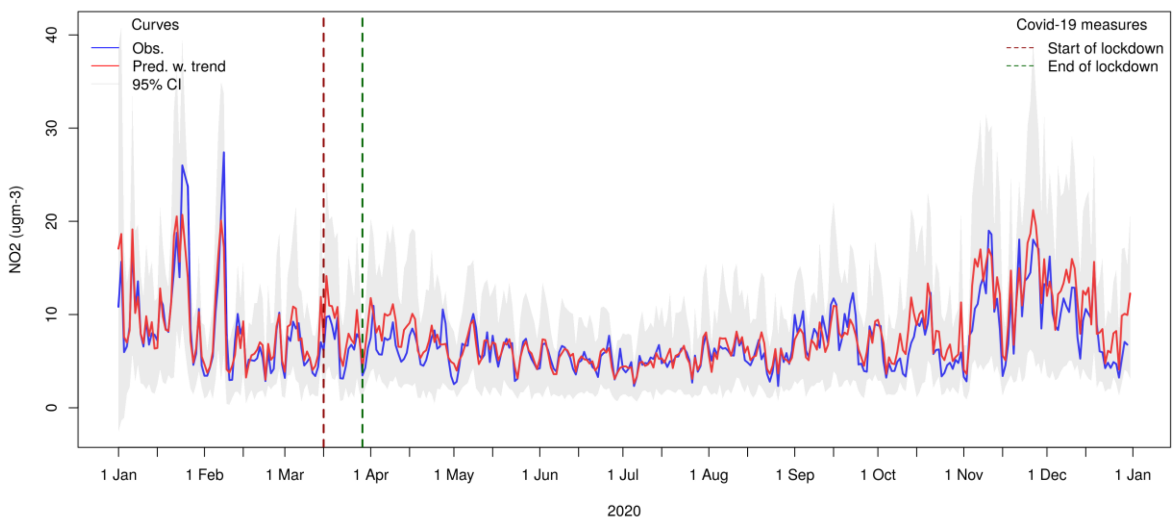

Mean of observed and GAM predicted NO2 at 15 background stations in rural France
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
5
10
15
20
25
30
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted NO2 at 10 background stations in rural Great Britain
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
10
20
30
40
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

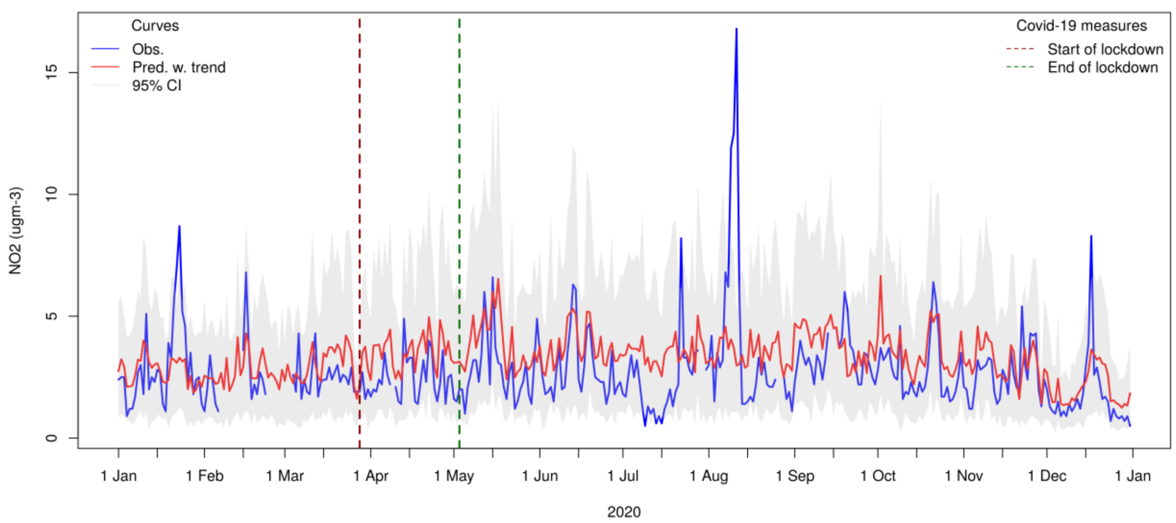
**Mean of observed and GAM predicted NO2 at 36 background stations in rural Italy**

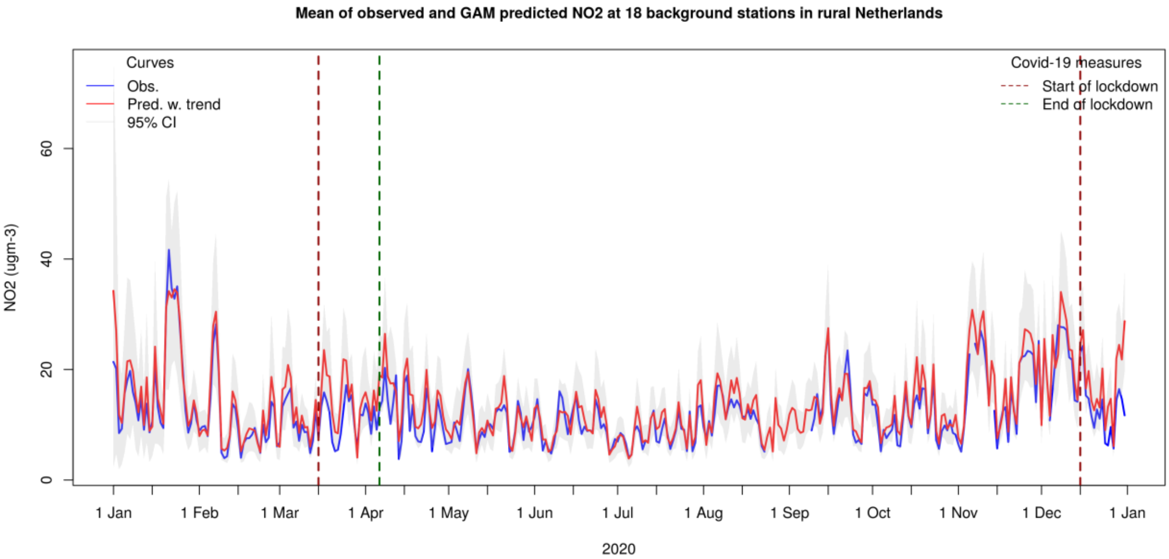



**Mean of observed and GAM predicted NO2 at 3 background stations in rural Luxembourg**

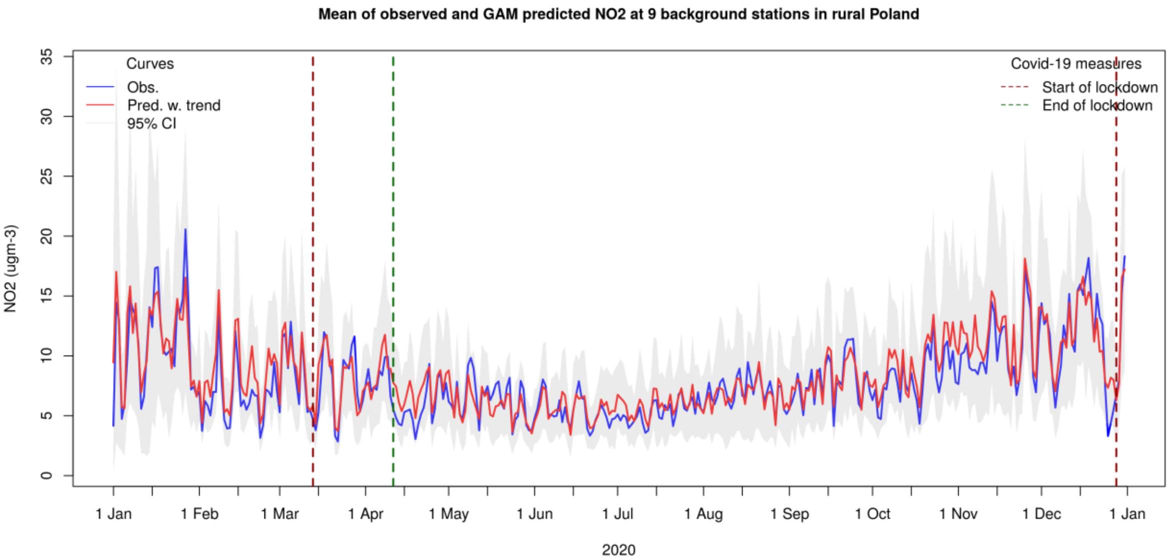



**Mean of observed and GAM predicted NO2 at 1 background stations in rural Malta**

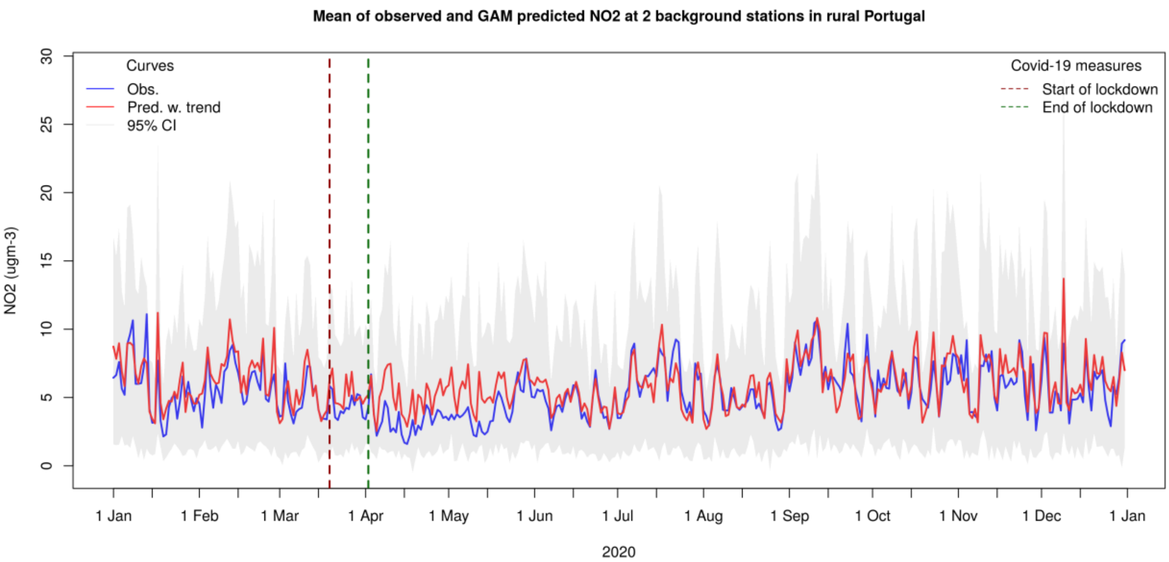




Mean of observed and GAM predicted NO2 at 18 background stations in rural Netherlands
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
20
40
60
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

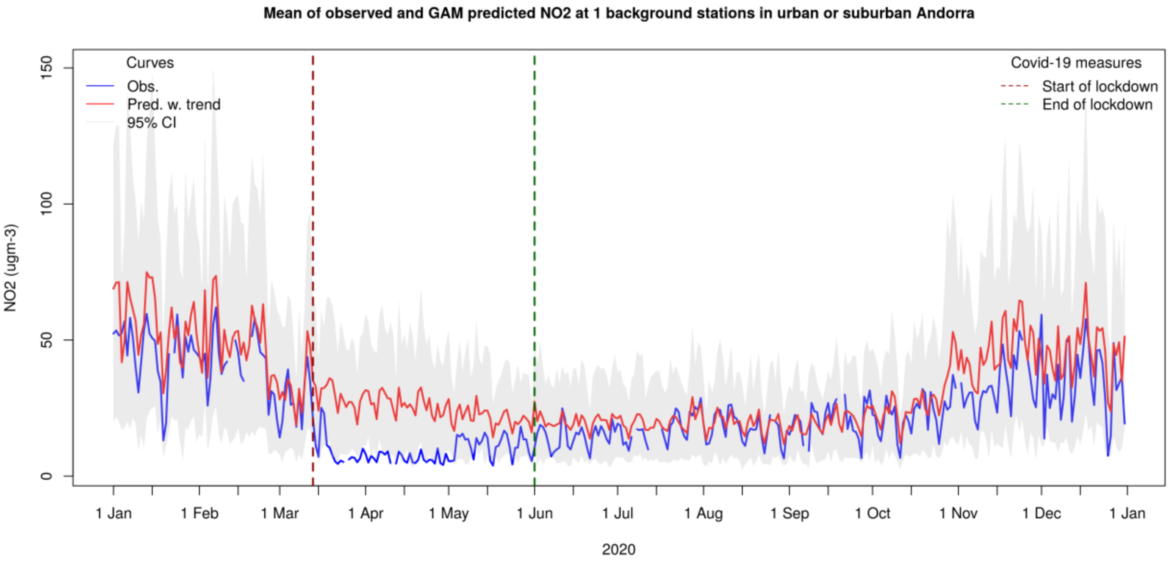



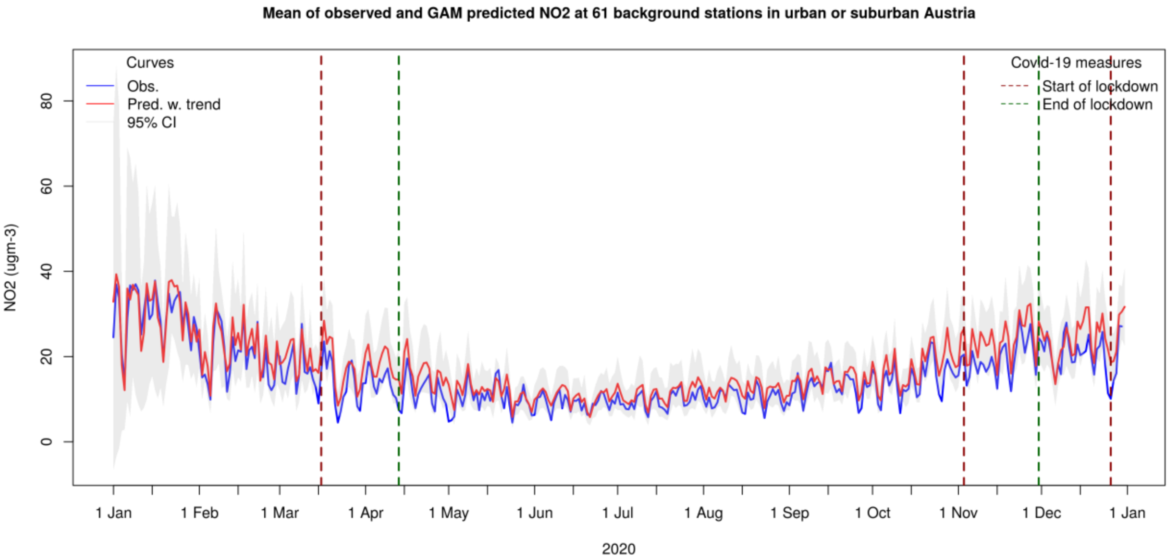
Mean of observed and GAM predicted NO2 at 9 background stations in rural Poland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
5
10
15
20
25
30
35
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

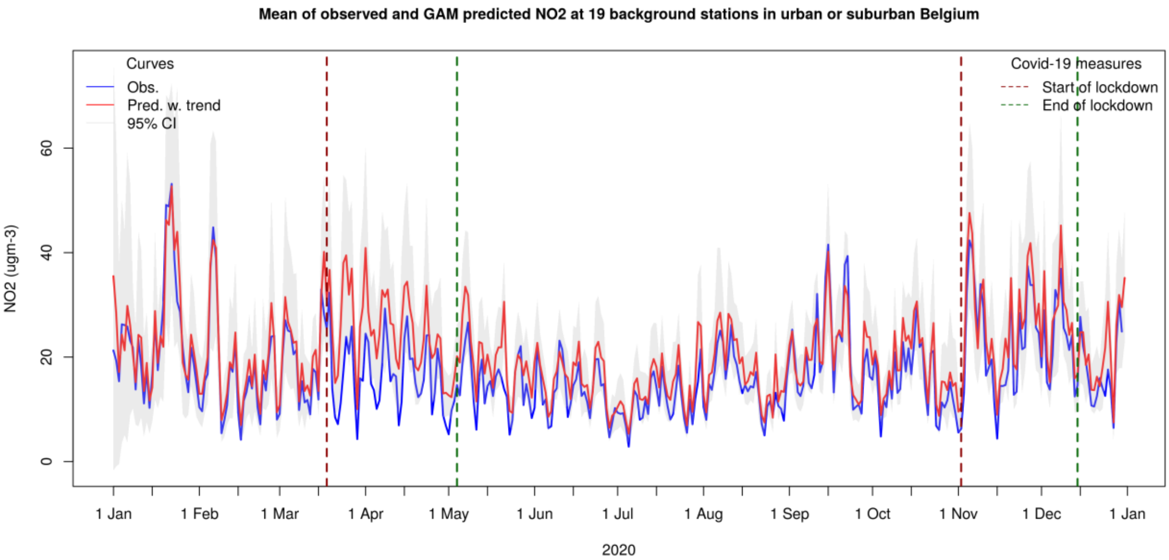



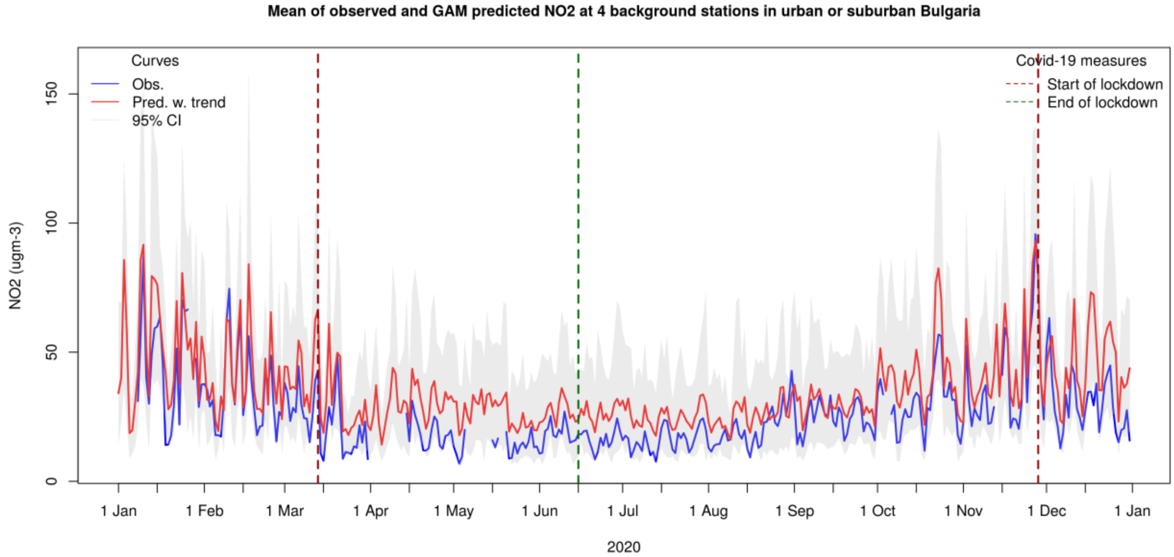
Mean of observed and GAM predicted NO2 at 2 background stations in rural Portugal
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
5
10
15
20
25
30
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

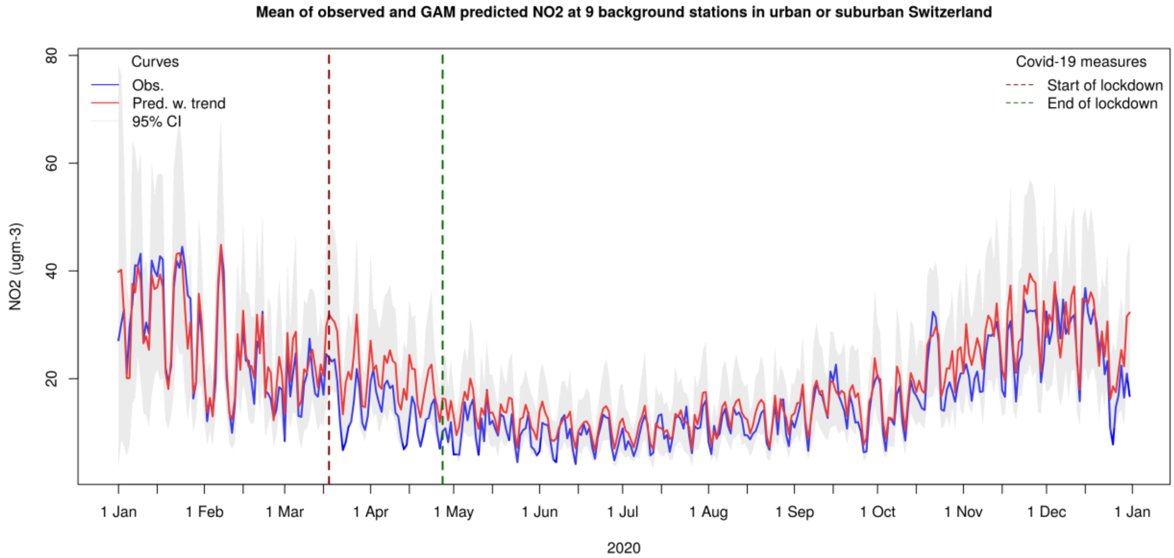
*Figure A.11 $NO_2$ suburban*

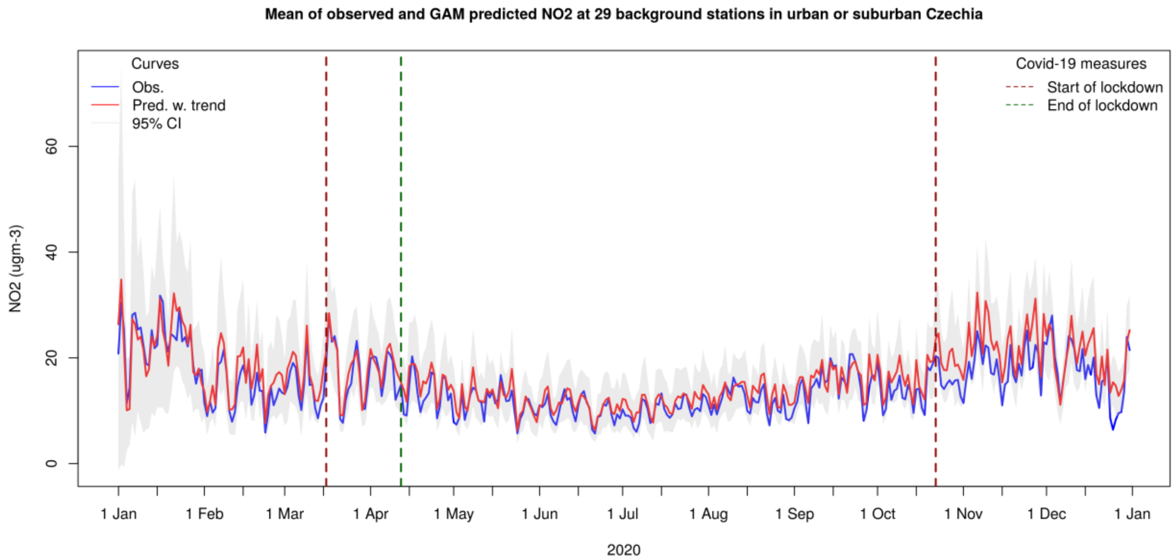


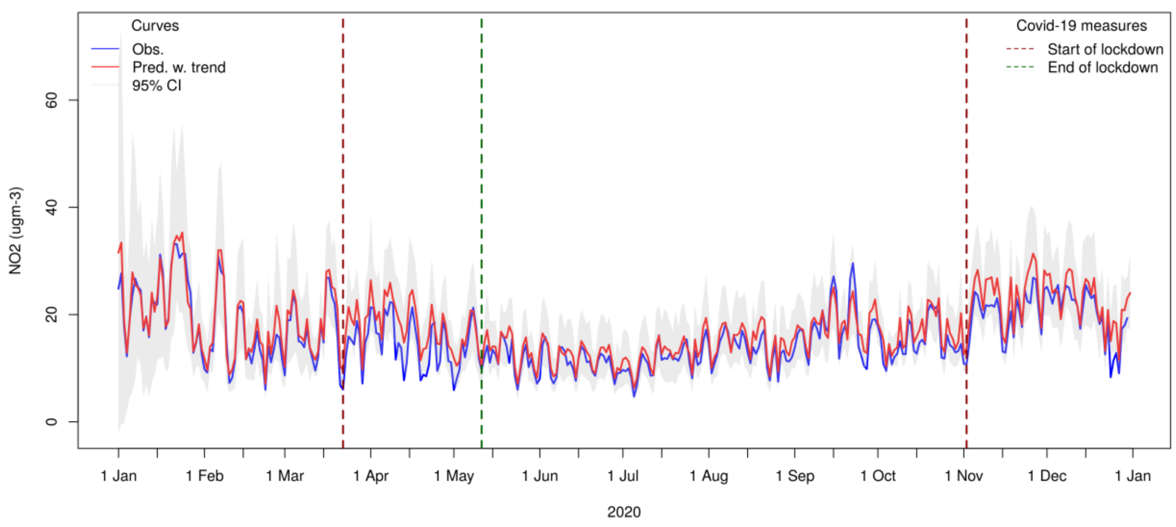




Mean of observed and GAM predicted NO2 at 4 background stations in urban or suburban Bulgaria
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

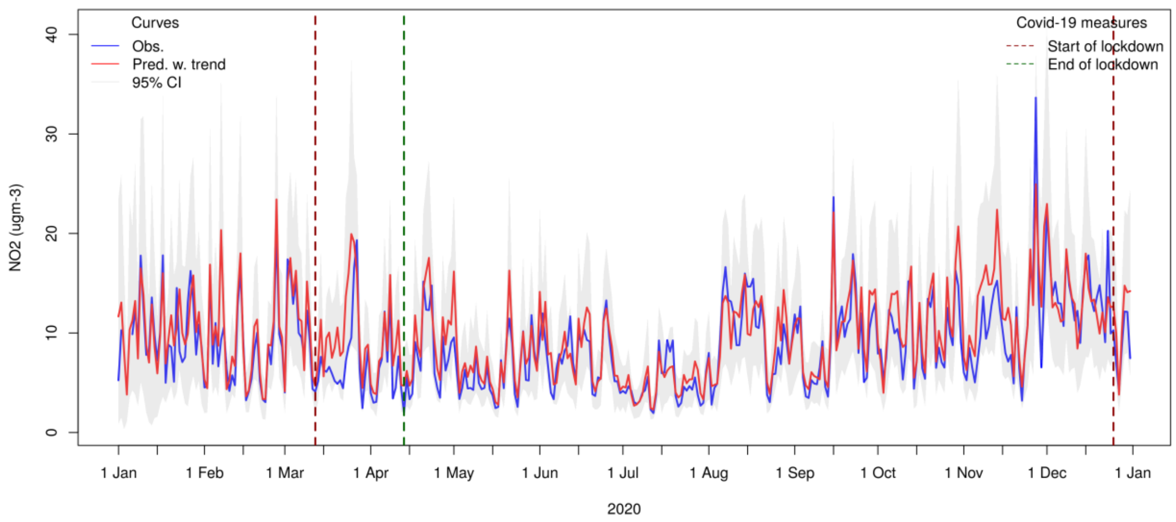

Mean of observed and GAM predicted NO2 at 9 background stations in urban or suburban Switzerland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
20
40
60
80
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted NO2 at 29 background stations in urban or suburban Czechia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
20
40
60
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

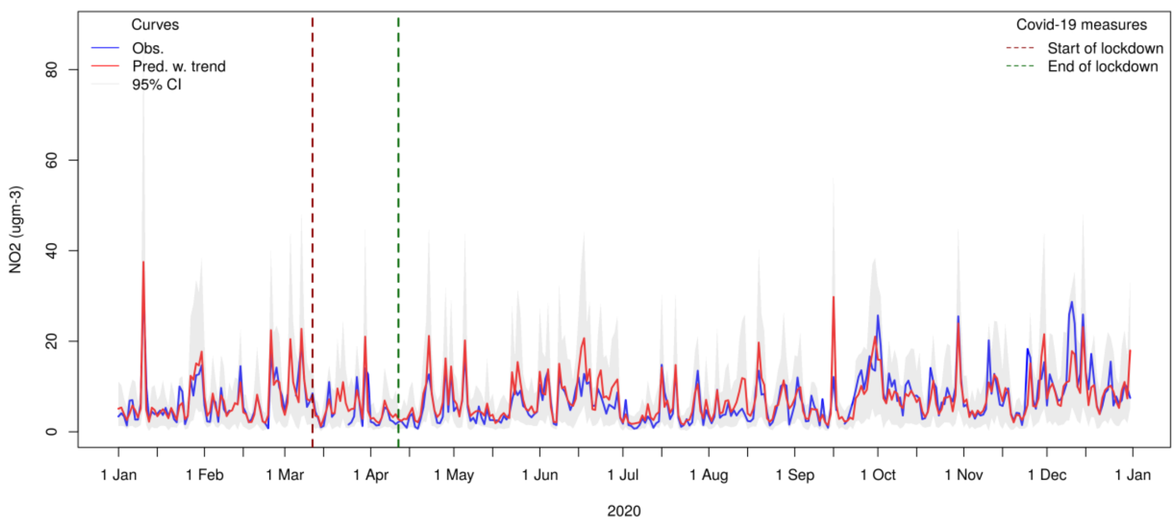
**Mean of observed and GAM predicted NO2 at 162 background stations in urban or suburban Germany**



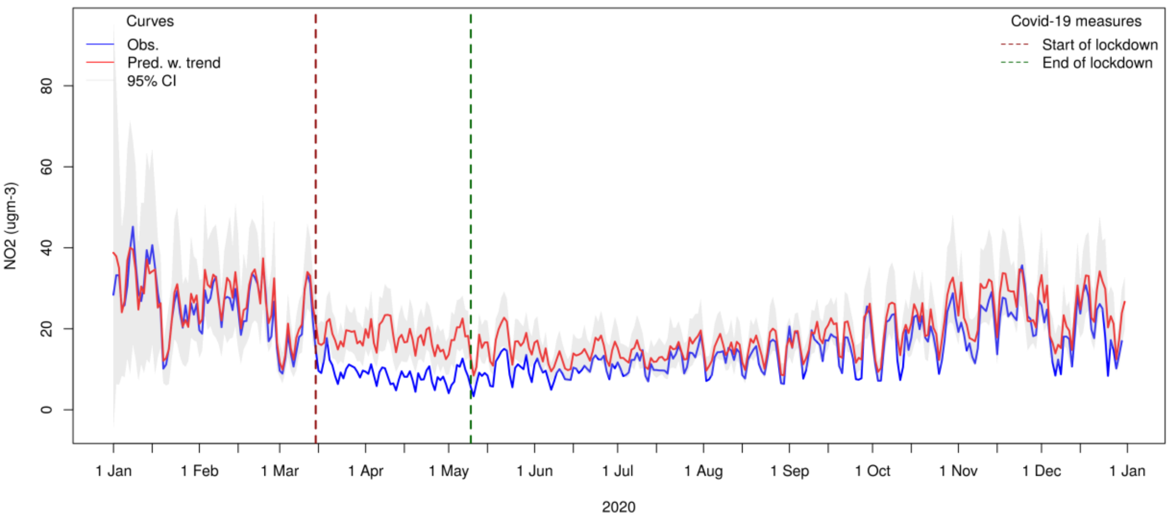

**Mean of observed and GAM predicted NO2 at 4 background stations in urban or suburban Denmark**



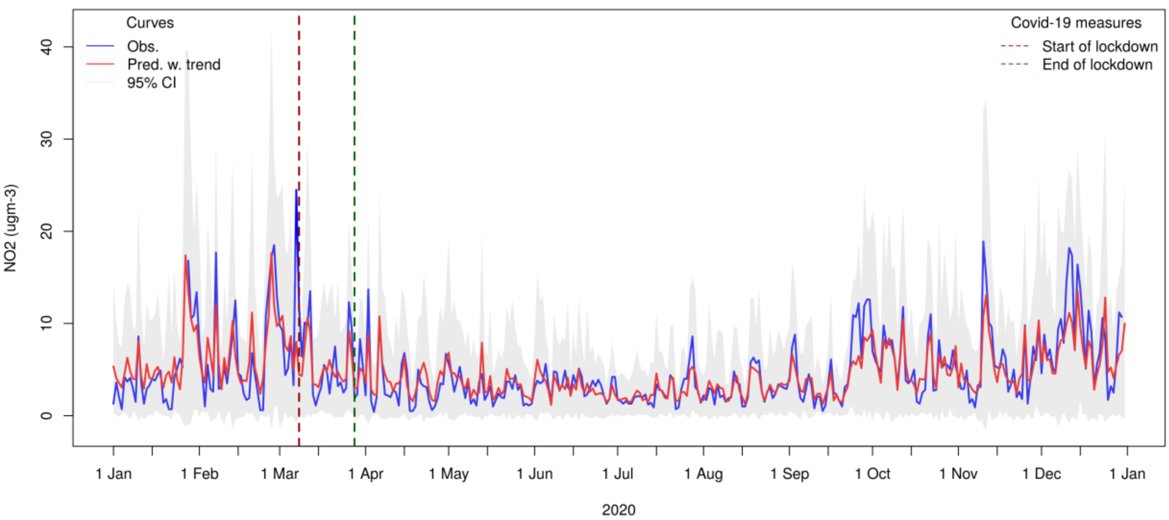

**Mean of observed and GAM predicted NO2 at 1 background stations in urban or suburban Estonia**



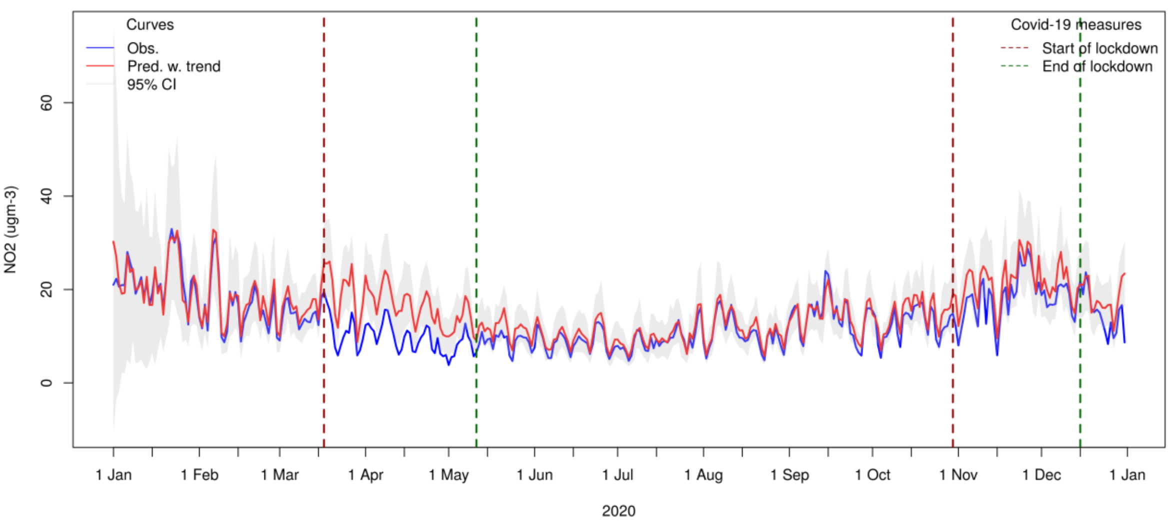
Mean of observed and GAM predicted NO2 at 102 background stations in urban or suburban Spain

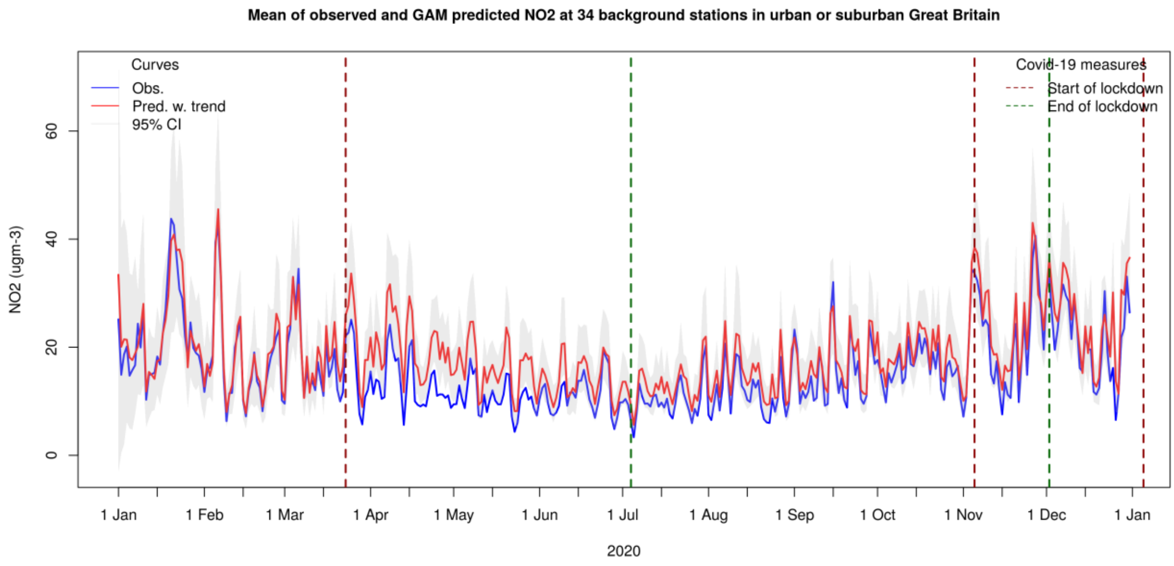



Mean of observed and GAM predicted NO2 at 1 background stations in urban or suburban Finland

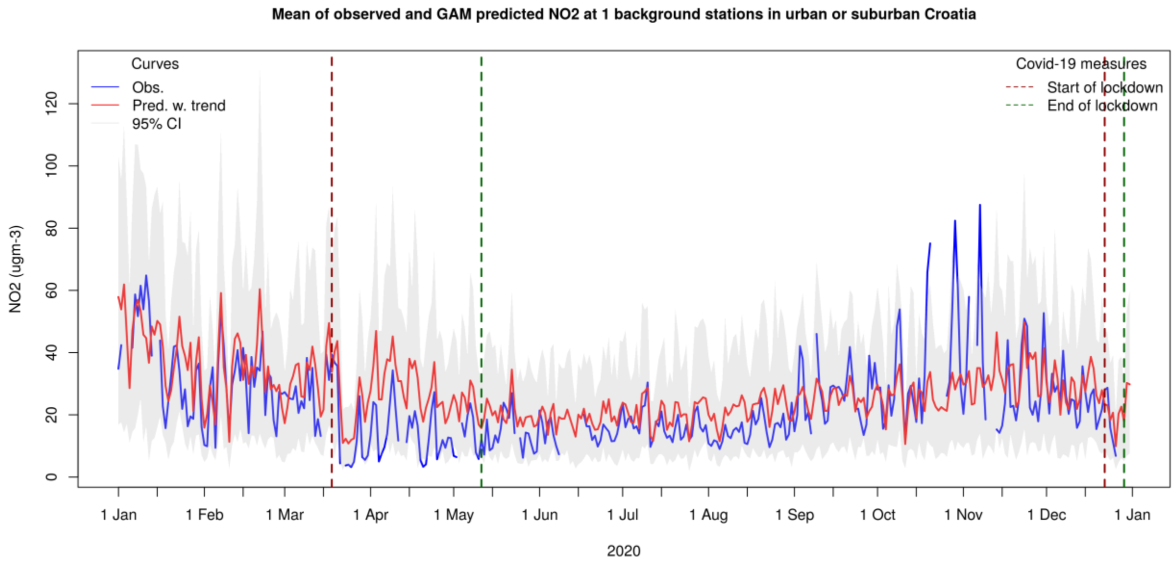



Mean of observed and GAM predicted NO2 at 184 background stations in urban or suburban France

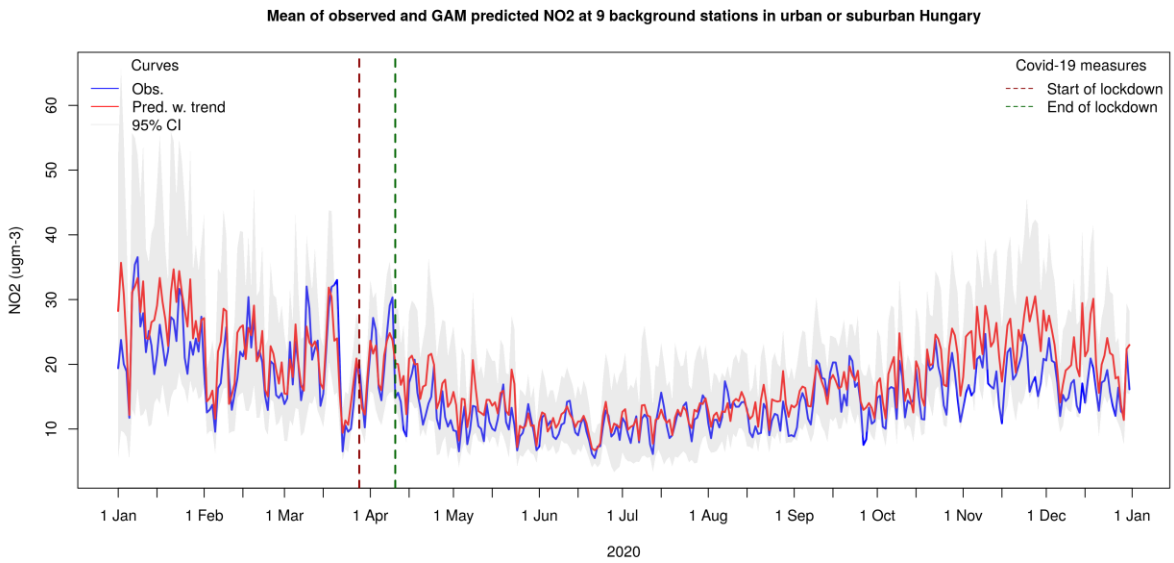




Mean of observed and GAM predicted NO2 at 34 background stations in urban or suburban Great Britain
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
20
40
60
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

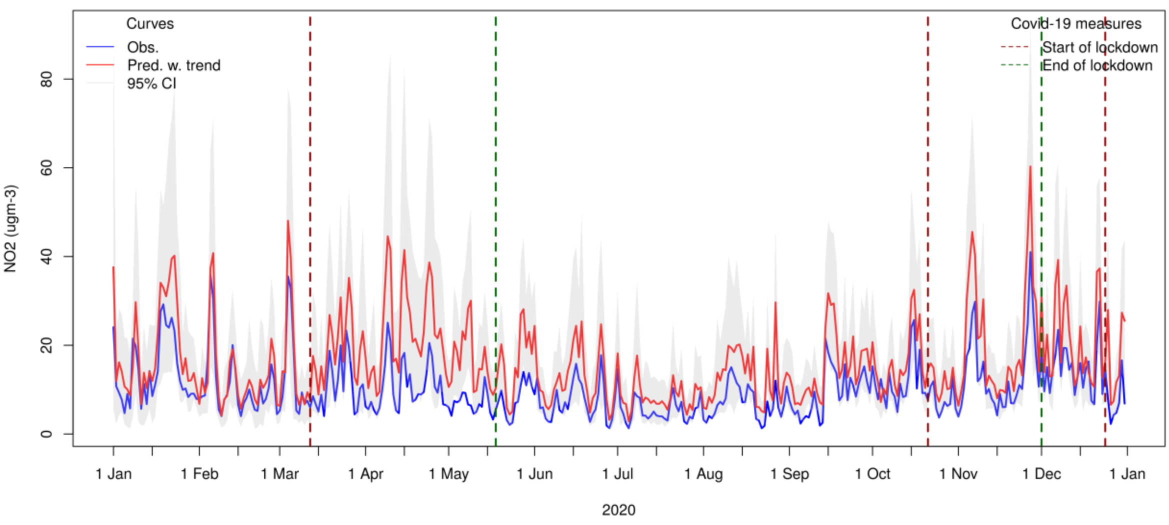



Mean of observed and GAM predicted NO2 at 1 background stations in urban or suburban Croatia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
20
40
60
80
100
120
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

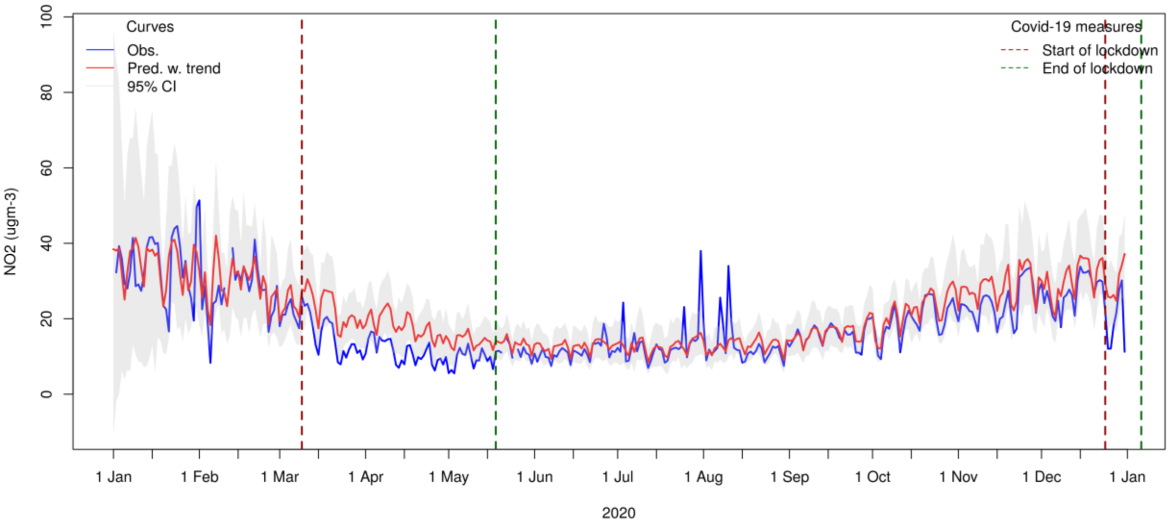



Mean of observed and GAM predicted NO2 at 9 background stations in urban or suburban Hungary
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
10
20
30
40
50
60
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

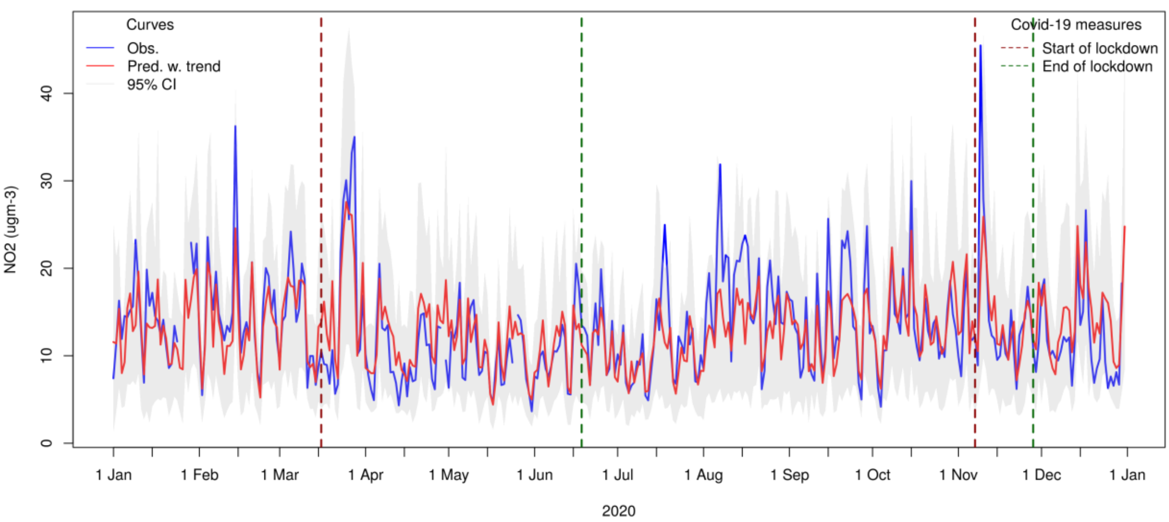
**Mean of observed and GAM predicted NO2 at 4 background stations in urban or suburban Ireland**



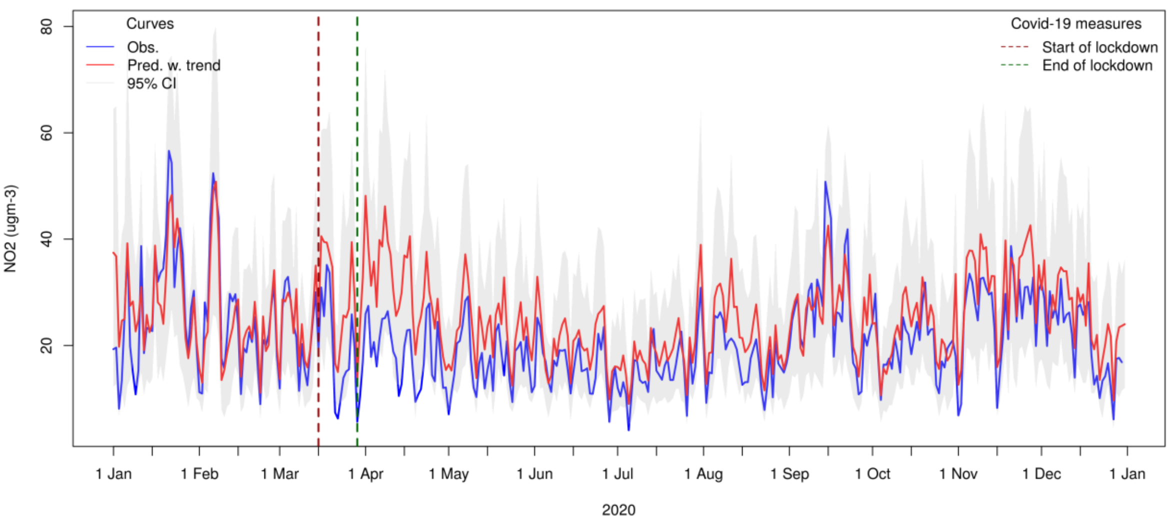

**Mean of observed and GAM predicted NO2 at 141 background stations in urban or suburban Italy**



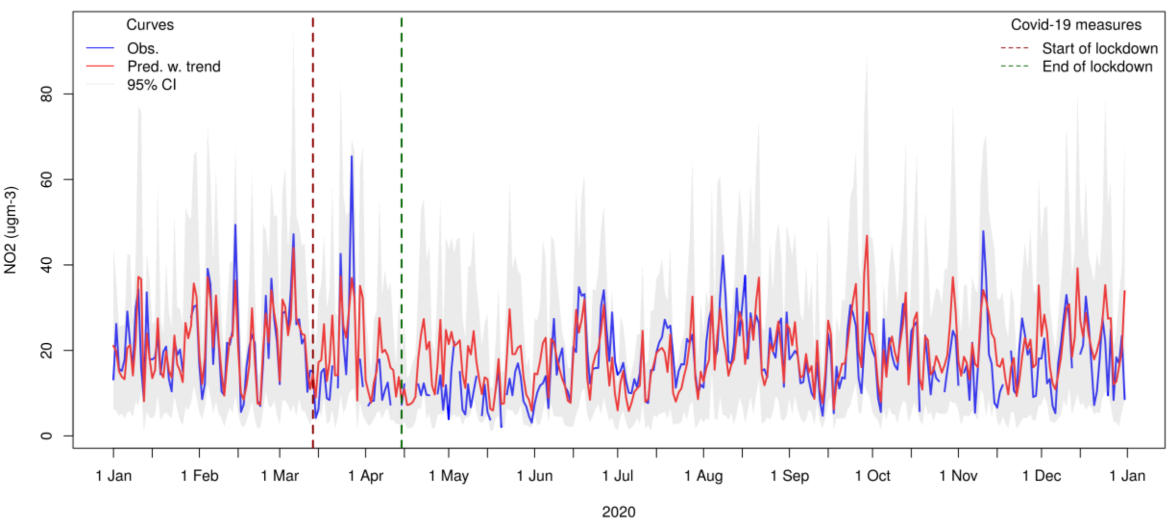

**Mean of observed and GAM predicted NO2 at 4 background stations in urban or suburban Lithuania**



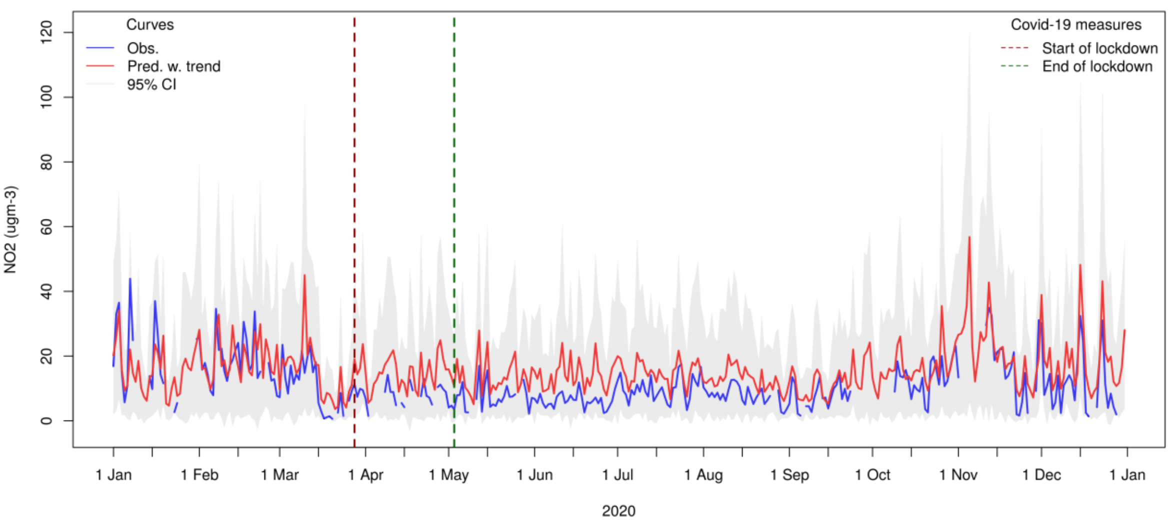
**Mean of observed and GAM predicted NO2 at 2 background stations in urban or suburban Luxembourg**



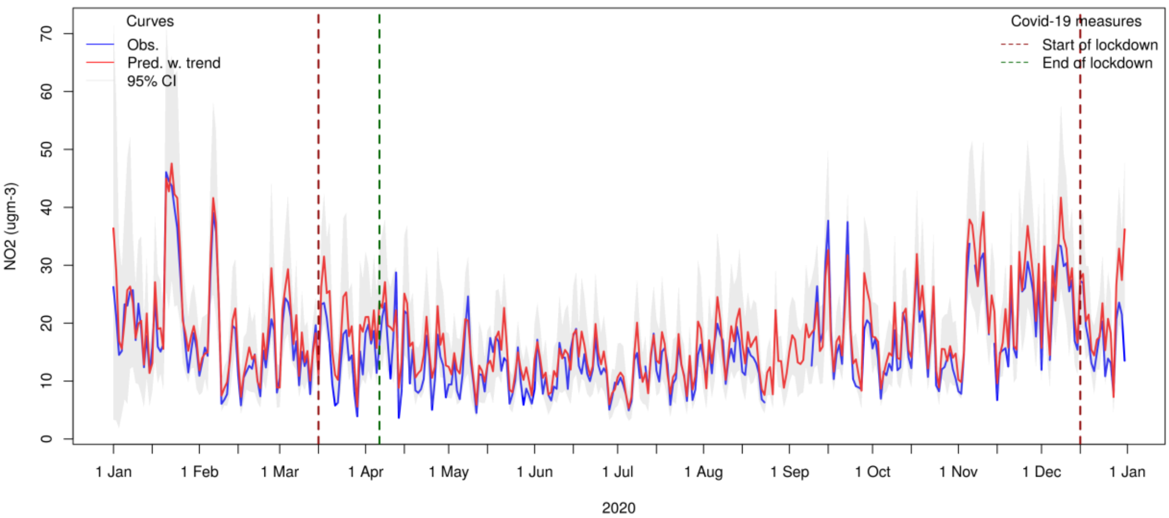

**Mean of observed and GAM predicted NO2 at 1 background stations in urban or suburban Latvia**



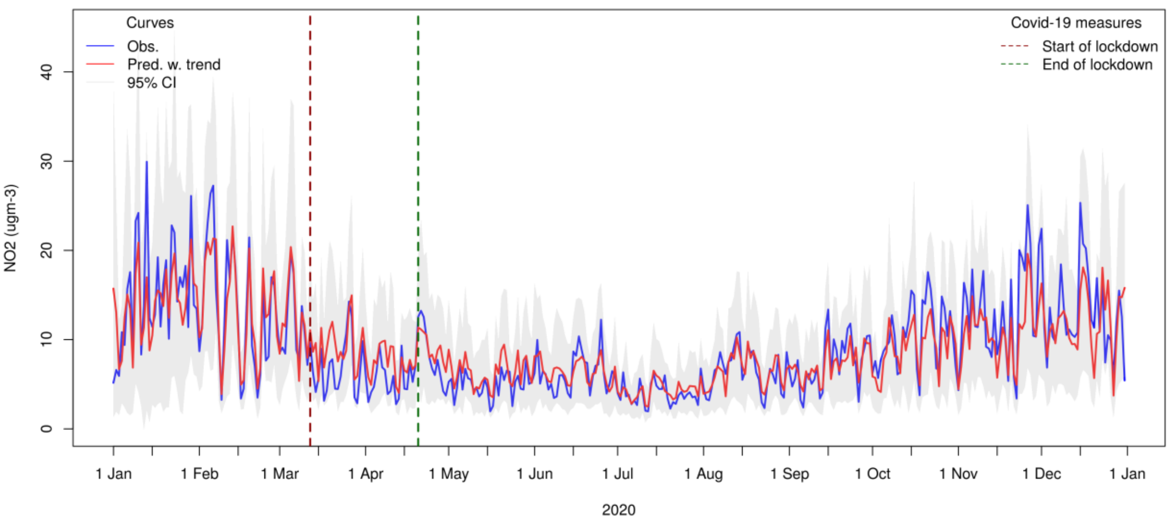

**Mean of observed and GAM predicted NO2 at 1 background stations in urban or suburban Malta**



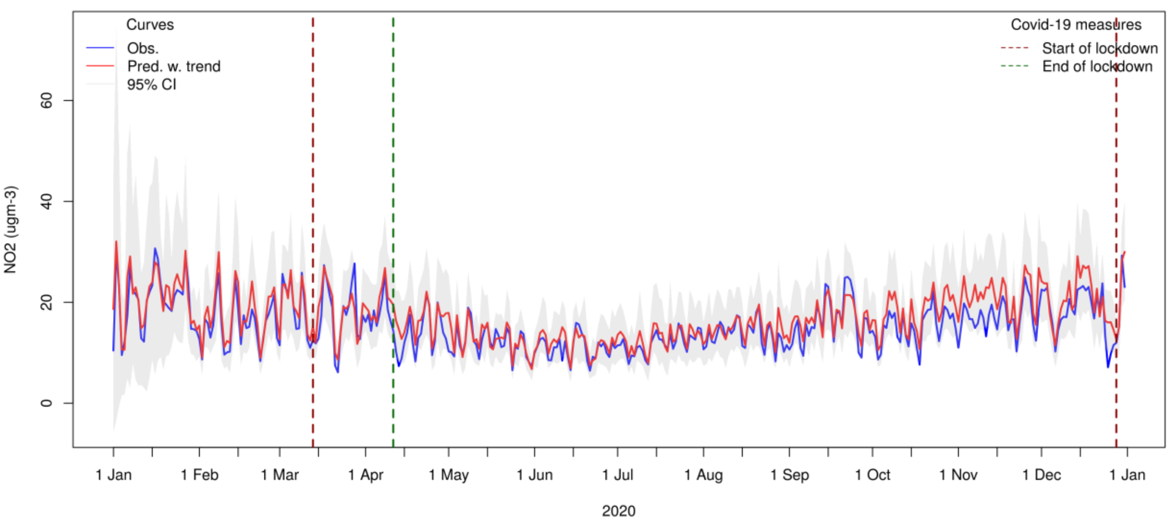
**Mean of observed and GAM predicted NO2 at 10 background stations in urban or suburban Netherlands**



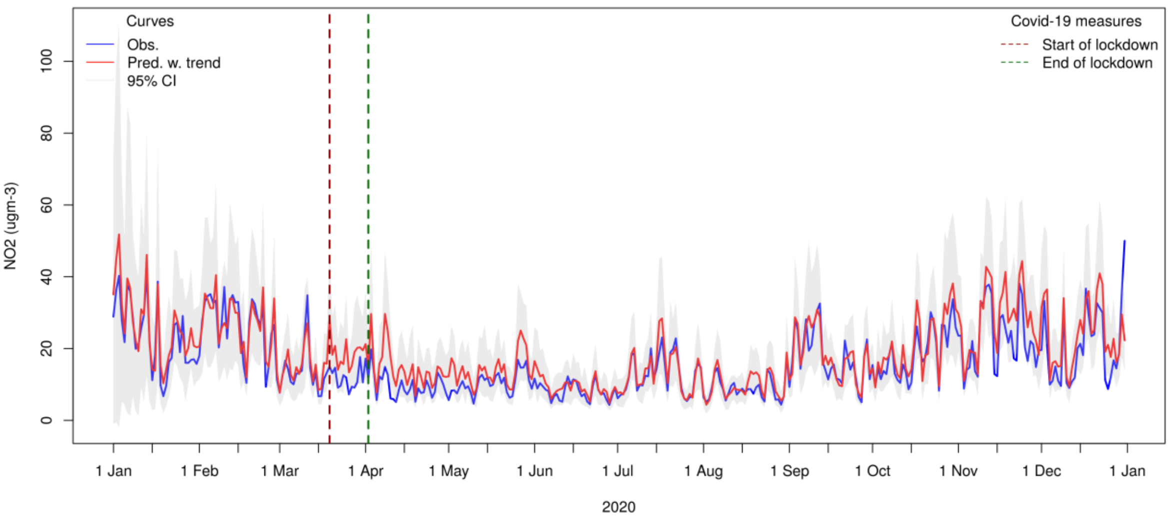

**Mean of observed and GAM predicted NO2 at 3 background stations in urban or suburban Norway**



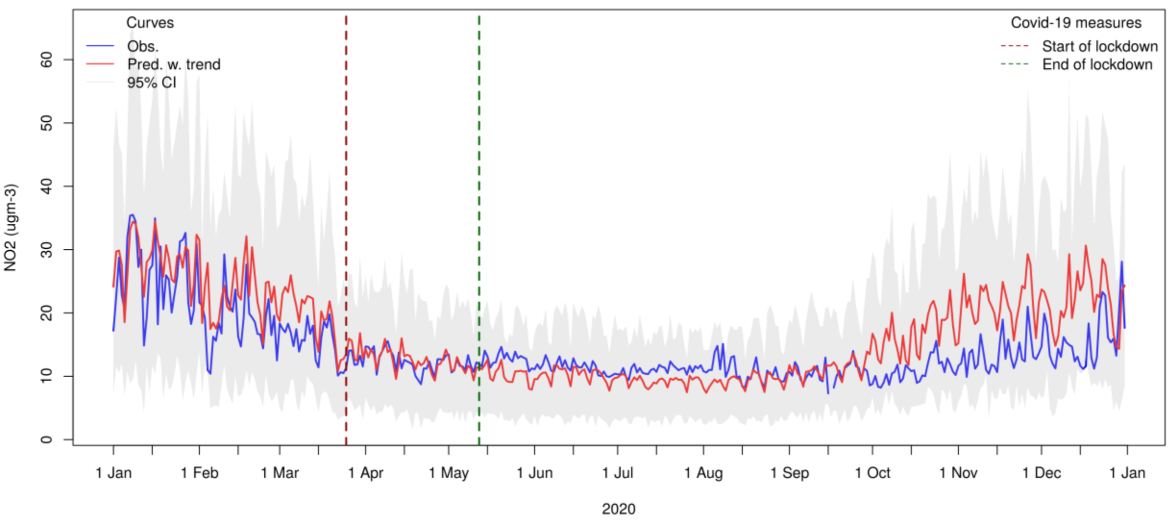

**Mean of observed and GAM predicted NO2 at 66 background stations in urban or suburban Poland**



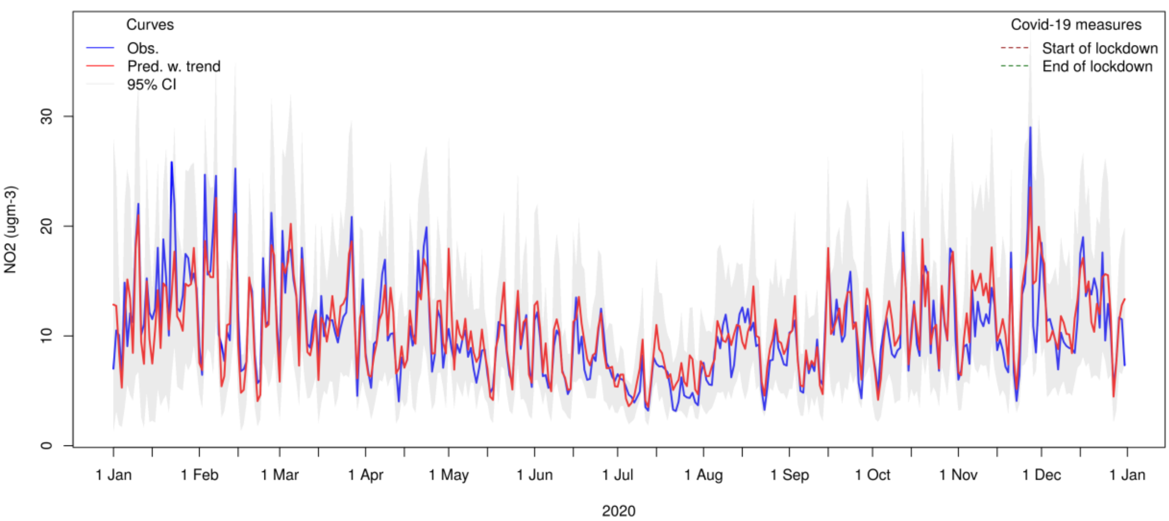
Mean of observed and GAM predicted NO2 at 9 background stations in urban or suburban Portugal



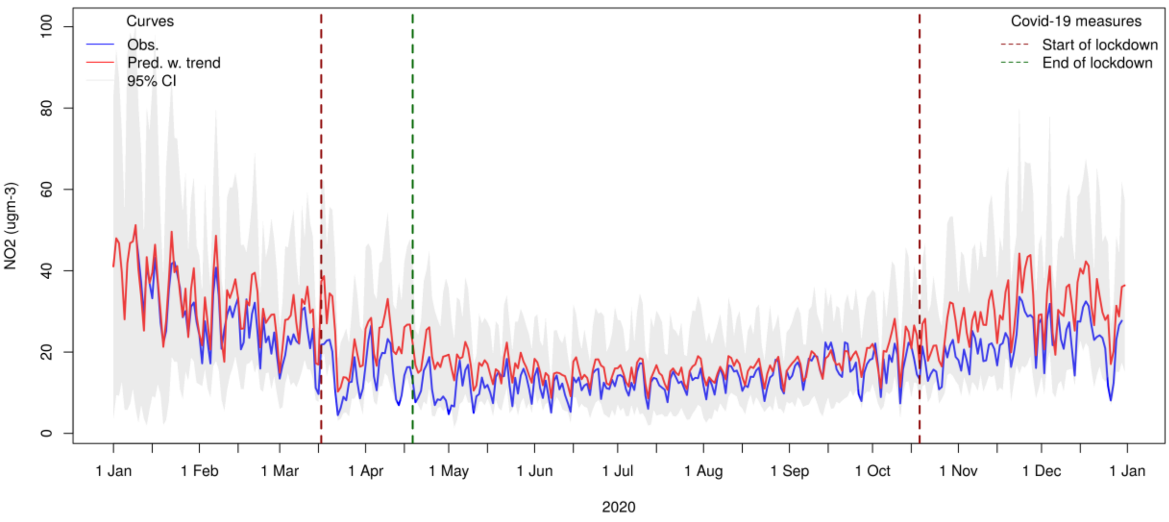

Mean of observed and GAM predicted NO2 at 2 background stations in urban or suburban Romania




Mean of observed and GAM predicted NO2 at 7 background stations in urban or suburban Sweden



Mean of observed and GAM predicted NO2 at 5 background stations in urban or suburban Slovenia




Mean of observed and GAM predicted NO2 at 2 background stations in urban or suburban Slovakia

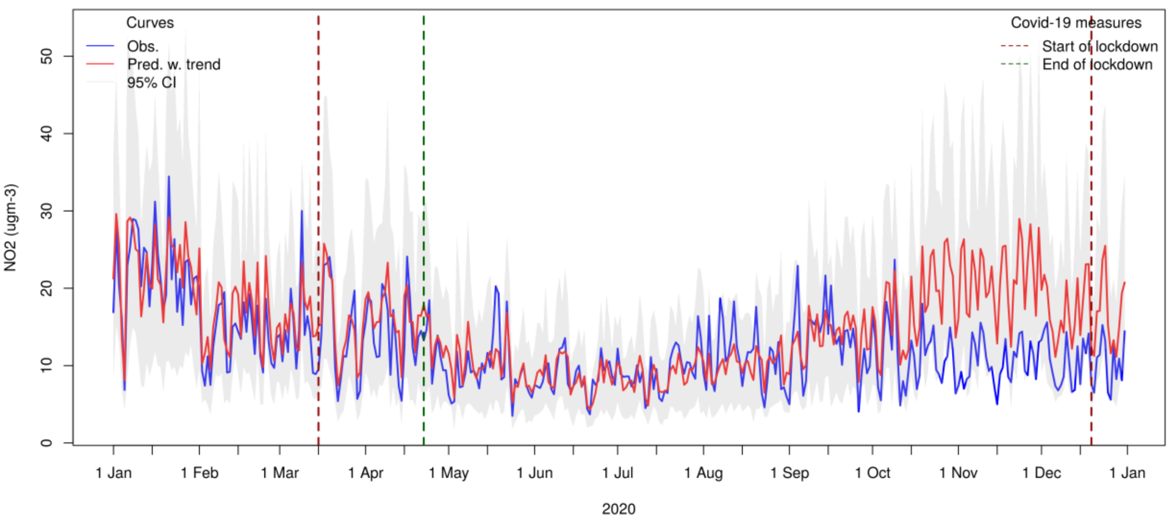
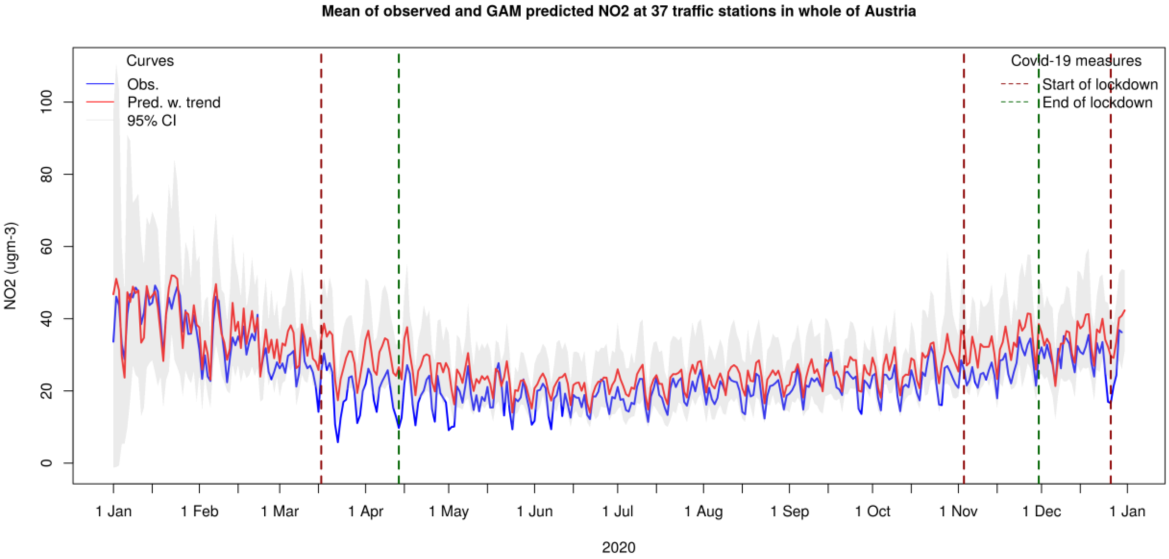
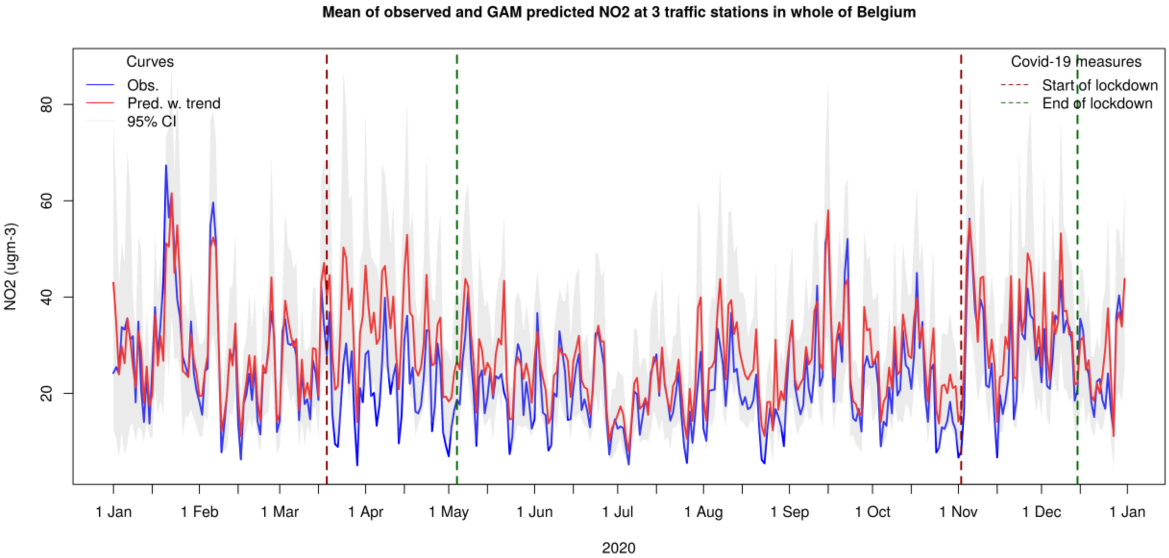
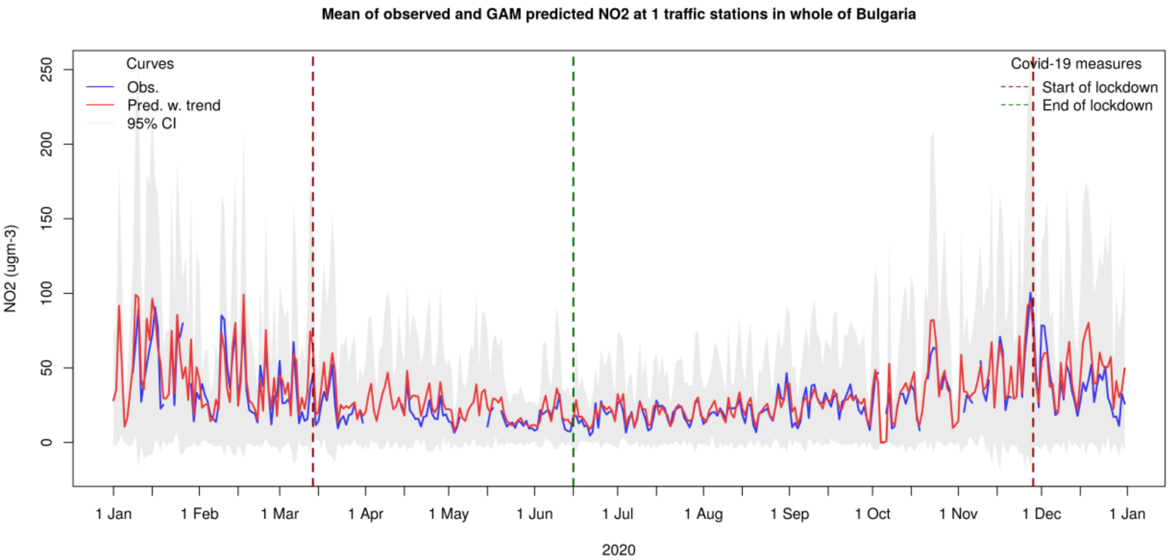


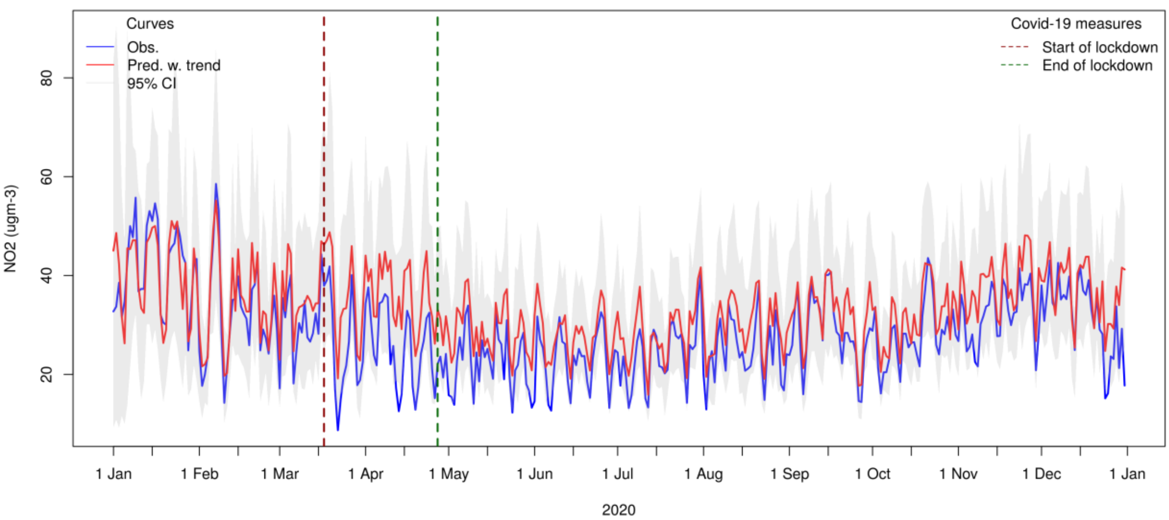
*Figure A.12 $NO_2$ traffic*



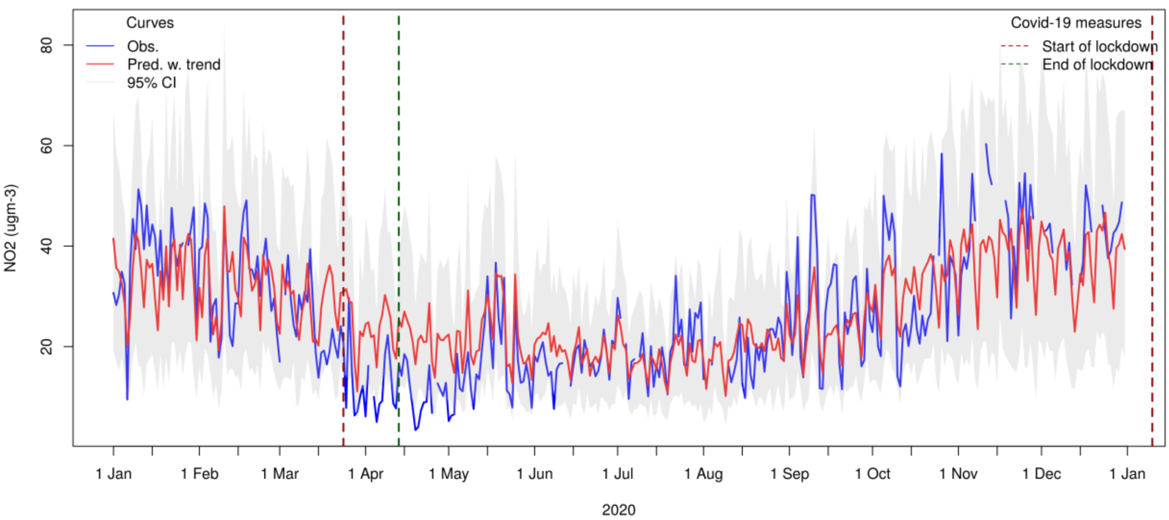



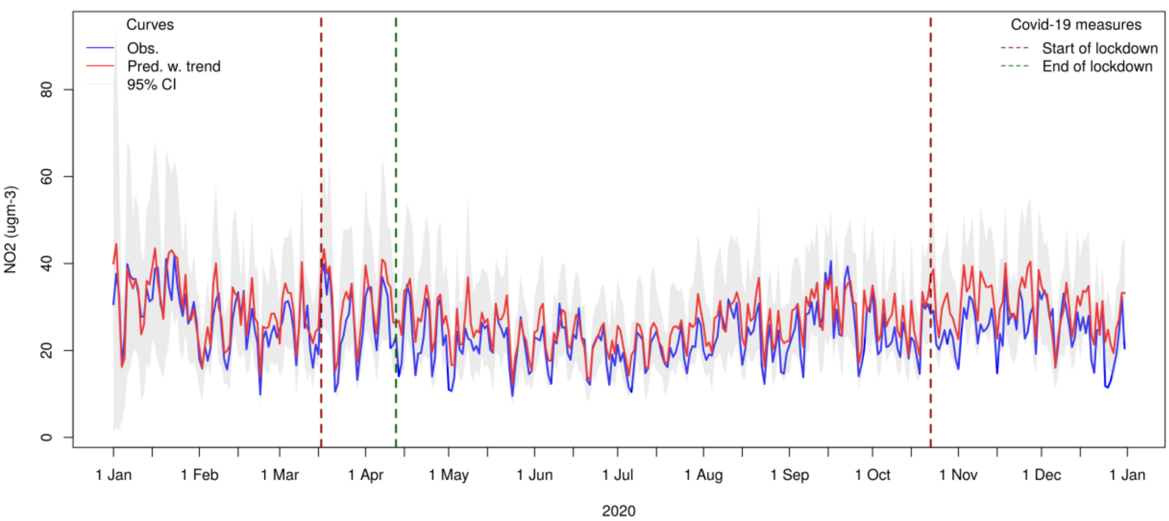
**Mean of observed and GAM predicted NO2 at 6 traffic stations in whole of Switzerland**

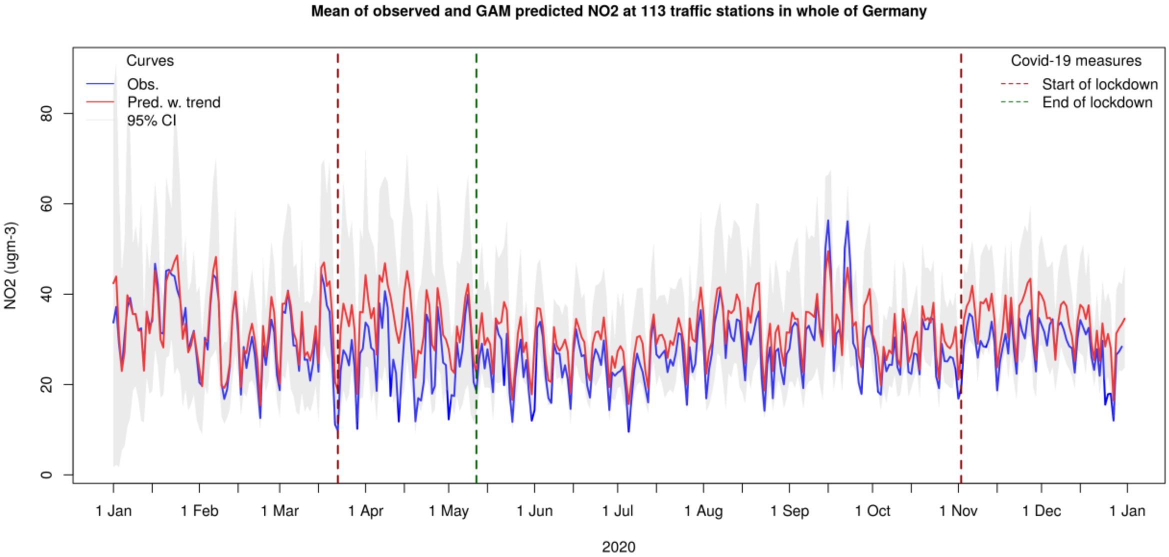


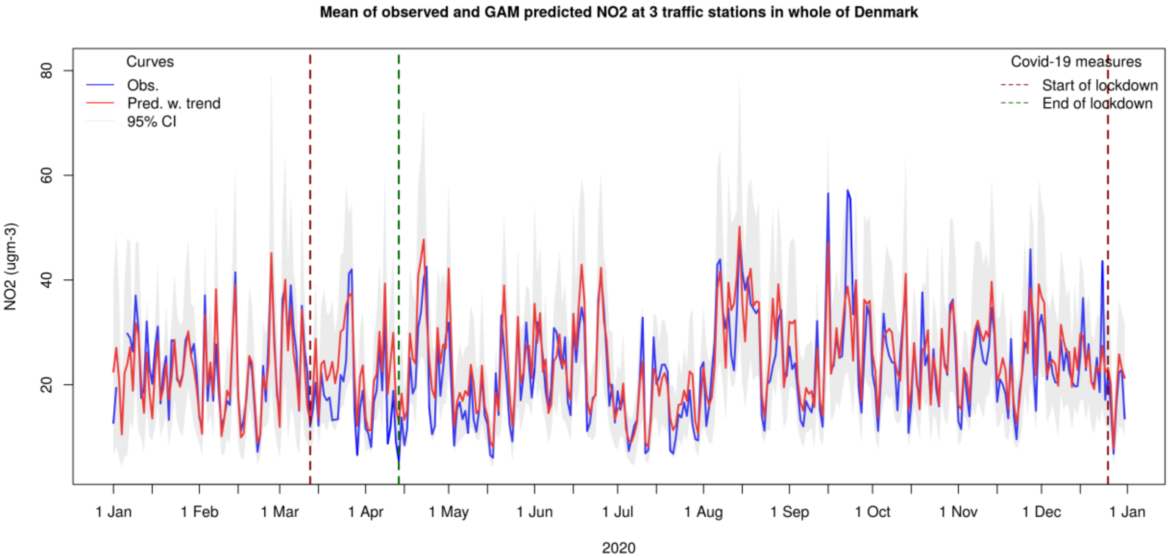

**Mean of observed and GAM predicted NO2 at 1 traffic stations in whole of Cyprus**

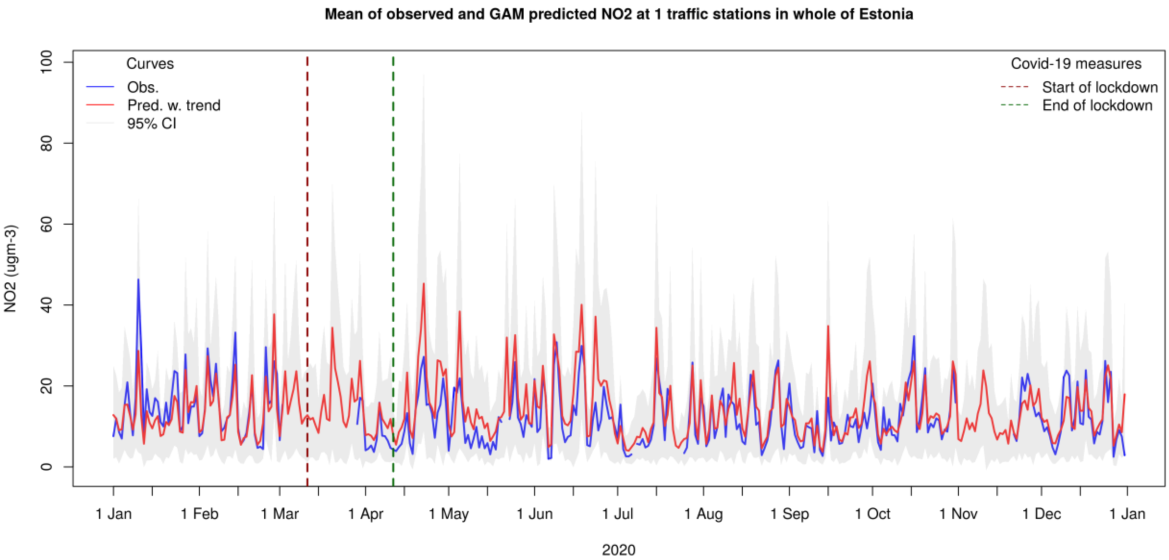


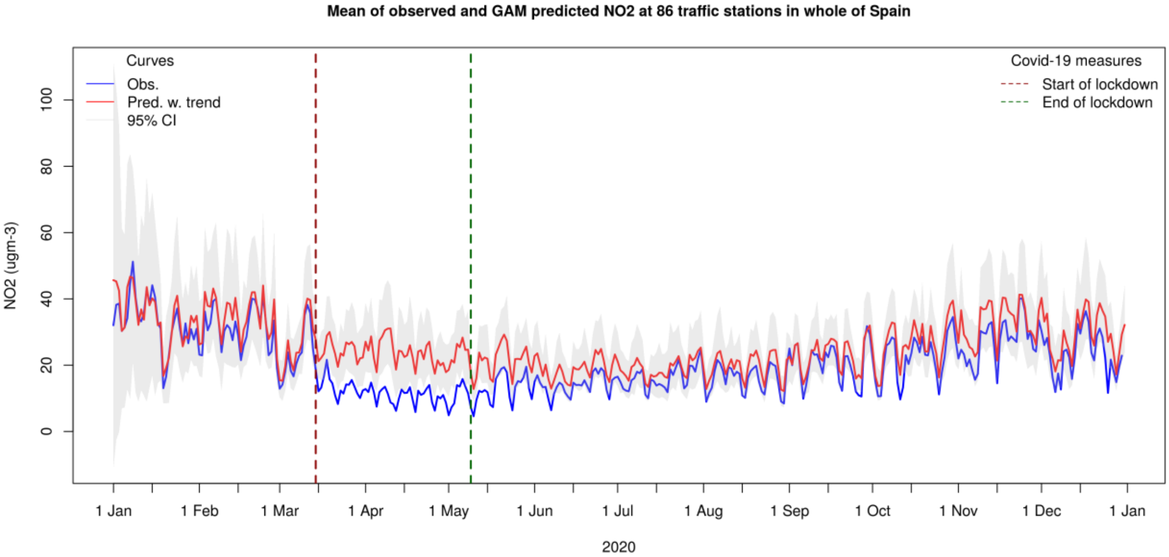

**Mean of observed and GAM predicted NO2 at 12 traffic stations in whole of Czechia**

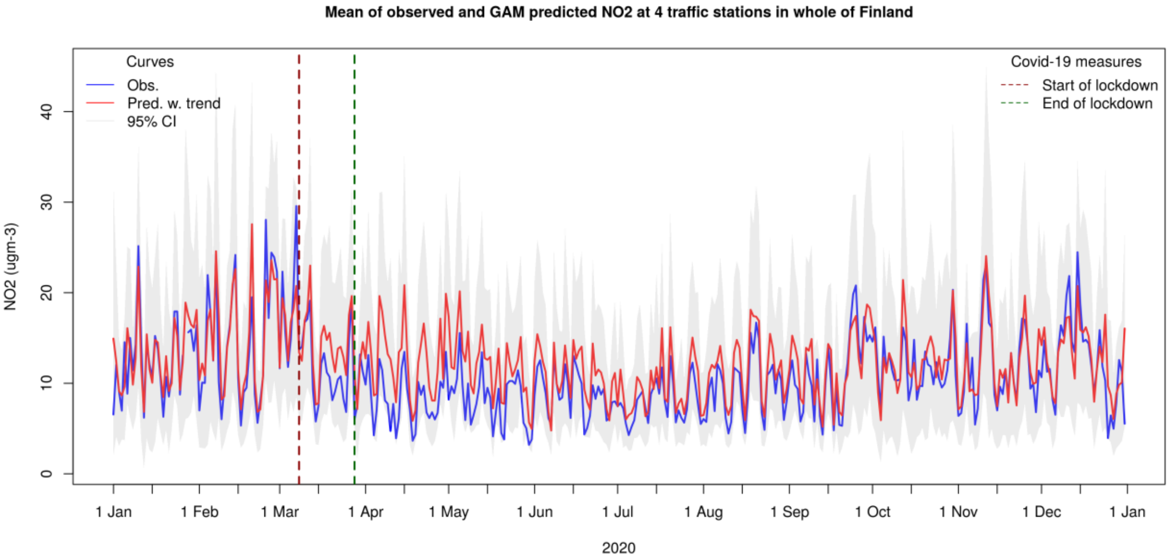


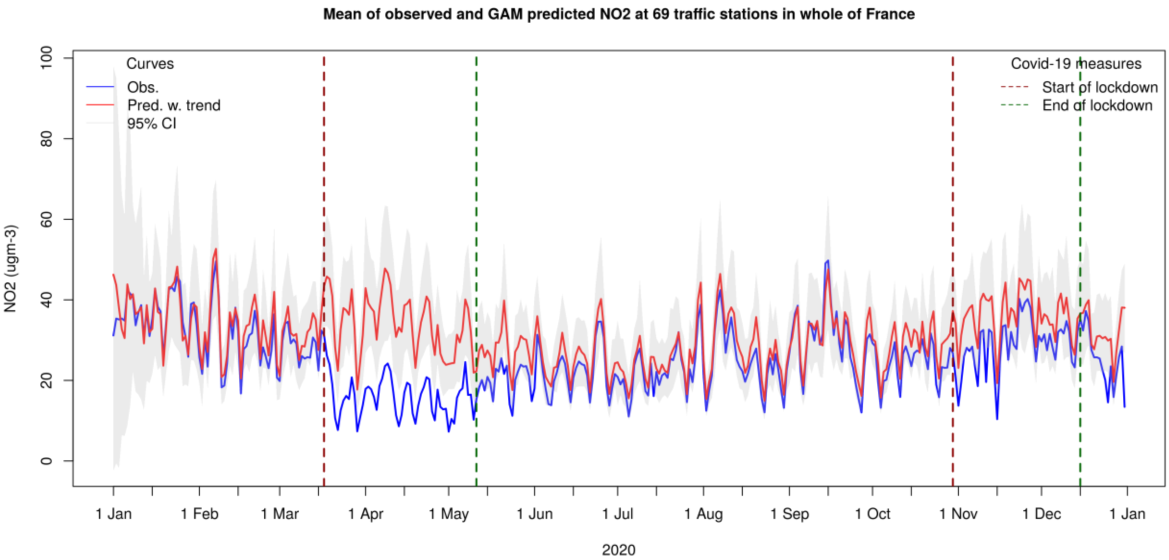

Mean of observed and GAM predicted NO2 at 113 traffic stations in whole of Germany
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
20
40
60
80
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted NO2 at 3 traffic stations in whole of Denmark
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
20
40
60
80
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

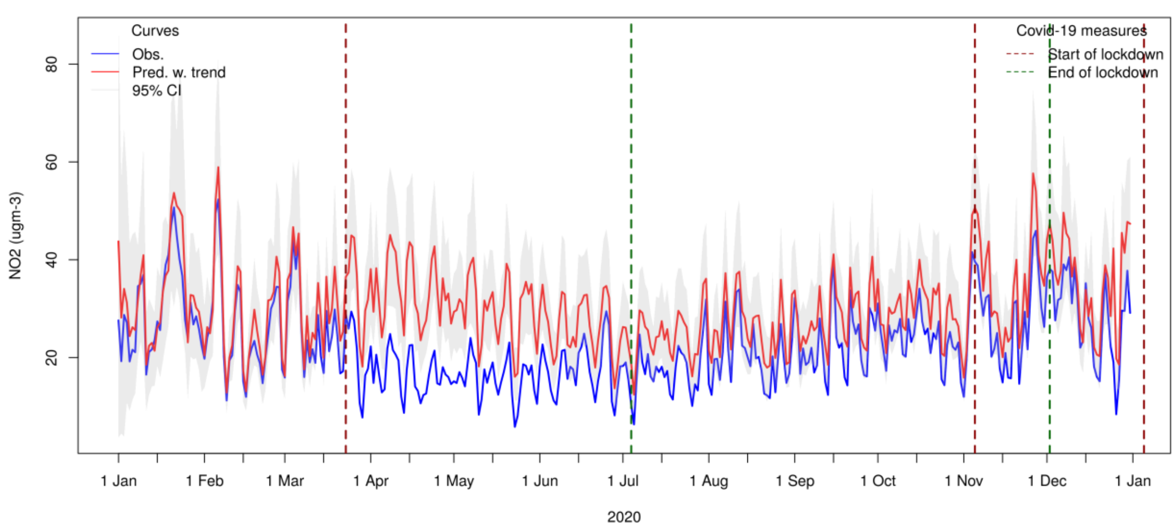

Mean of observed and GAM predicted NO2 at 1 traffic stations in whole of Estonia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
20
40
60
80
100
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted NO2 at 86 traffic stations in whole of Spain
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
20
40
60
80
100
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

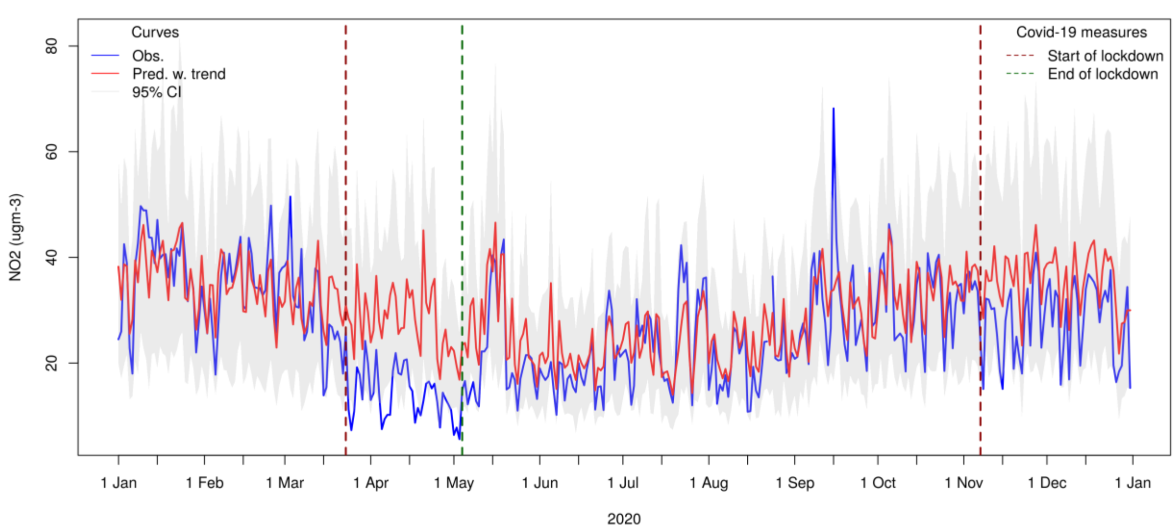

Mean of observed and GAM predicted NO2 at 4 traffic stations in whole of Finland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
10
20
30
40
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted NO2 at 69 traffic stations in whole of France
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
20
40
60
80
100
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

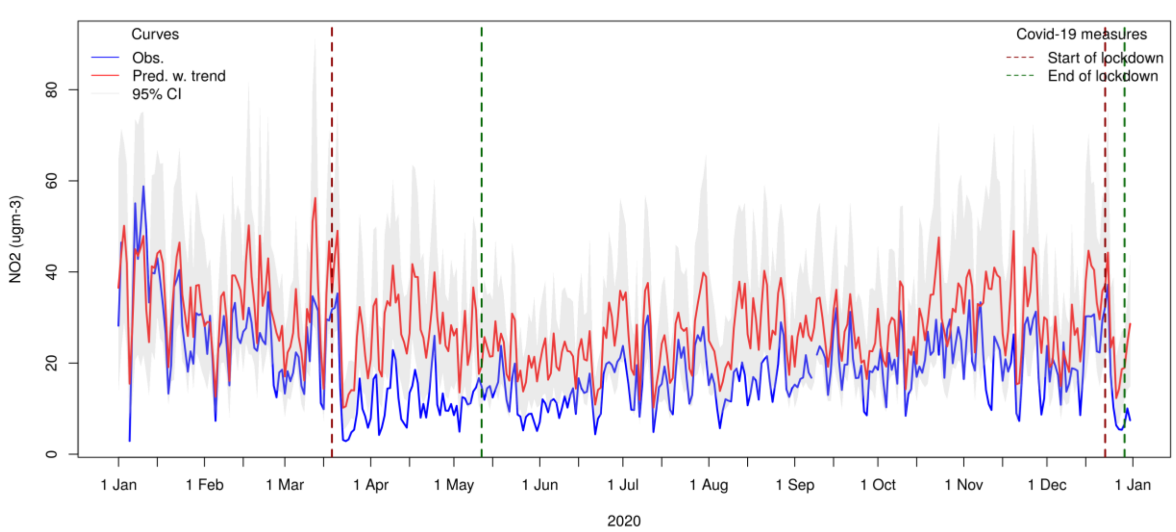
**Mean of observed and GAM predicted NO2 at 27 traffic stations in whole of Great Britain**

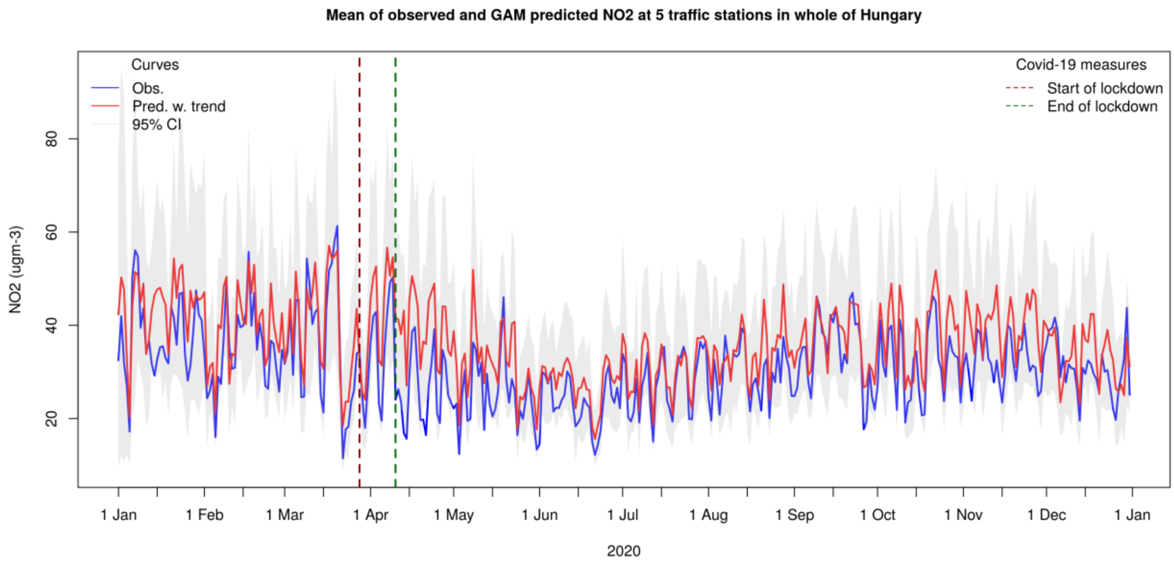



**Mean of observed and GAM predicted NO2 at 1 traffic stations in whole of Greece**

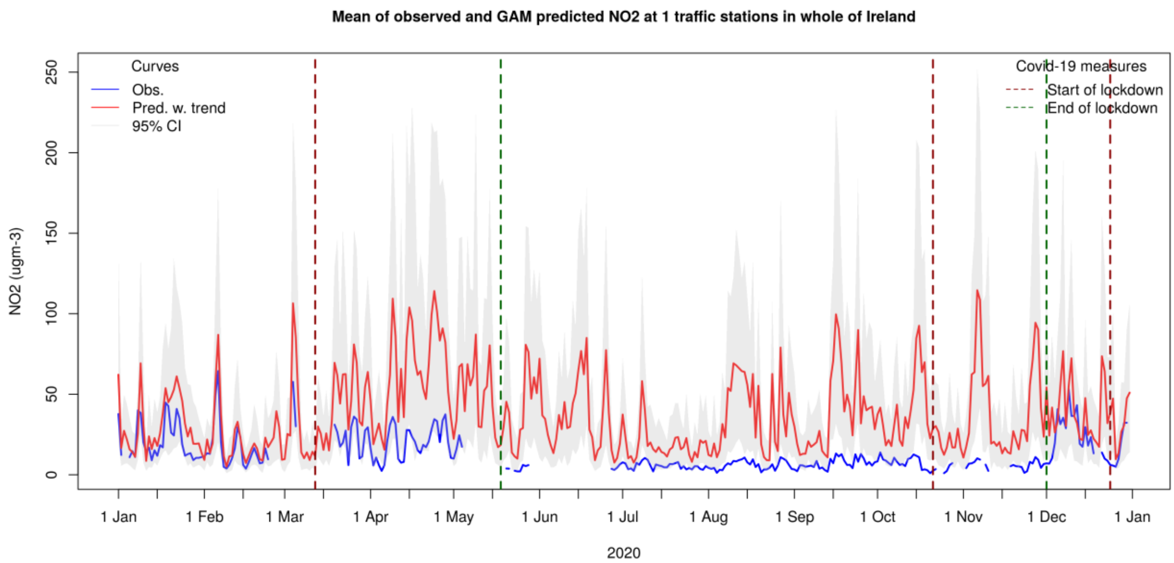



**Mean of observed and GAM predicted NO2 at 4 traffic stations in whole of Croatia**

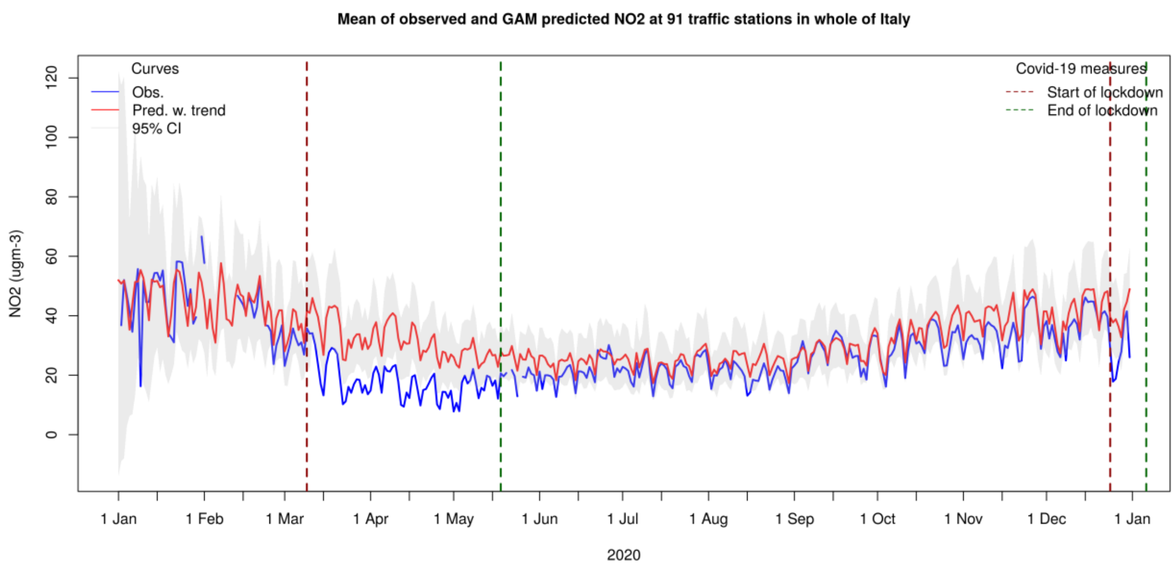




Mean of observed and GAM predicted NO2 at 5 traffic stations in whole of Hungary
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
20
40
60
80
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

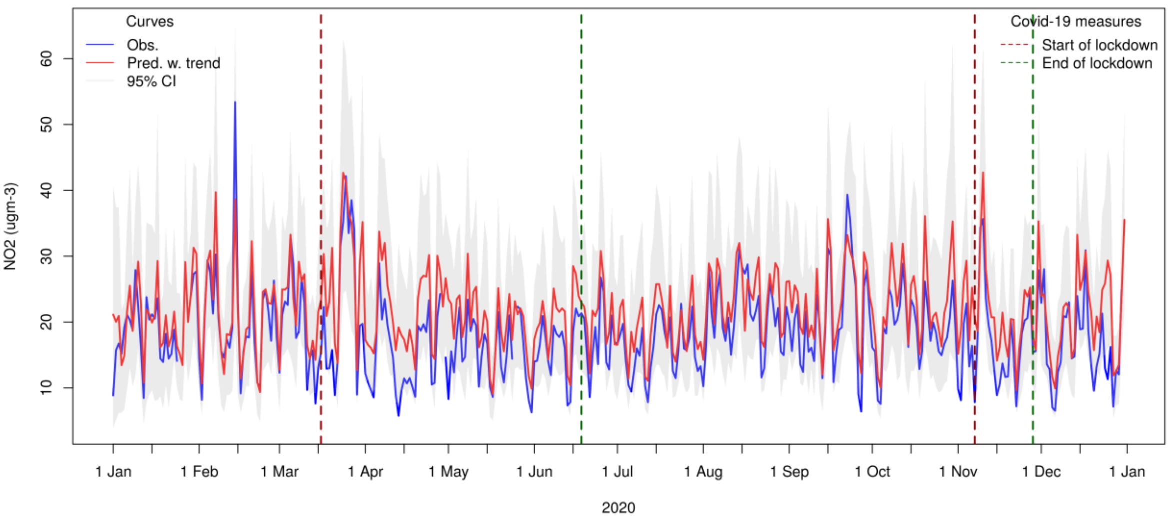



Mean of observed and GAM predicted NO2 at 1 traffic stations in whole of Ireland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
50
100
150
200
250
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

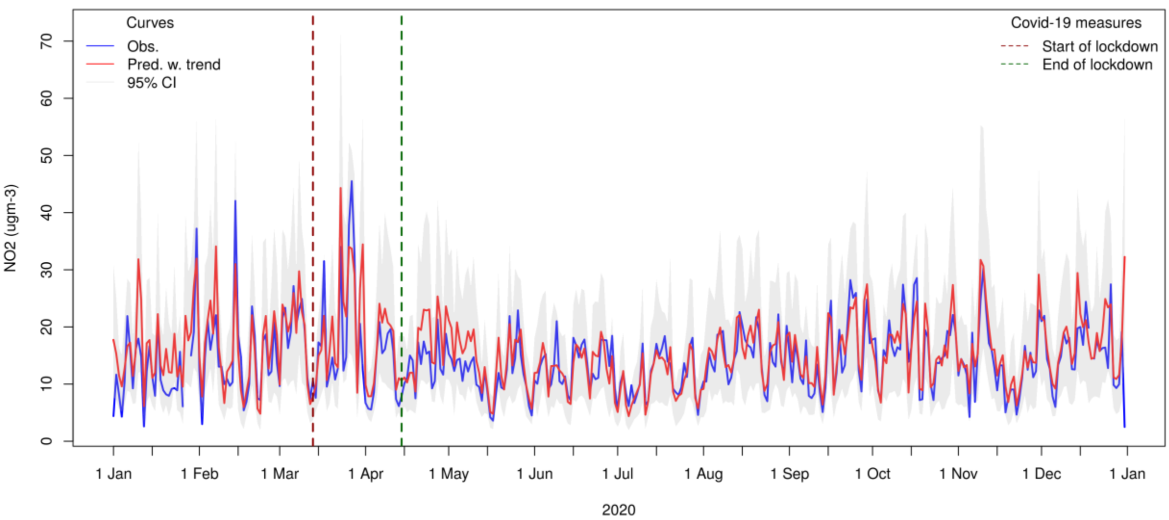



Mean of observed and GAM predicted NO2 at 91 traffic stations in whole of Italy
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
0
20
40
60
80
100
120
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

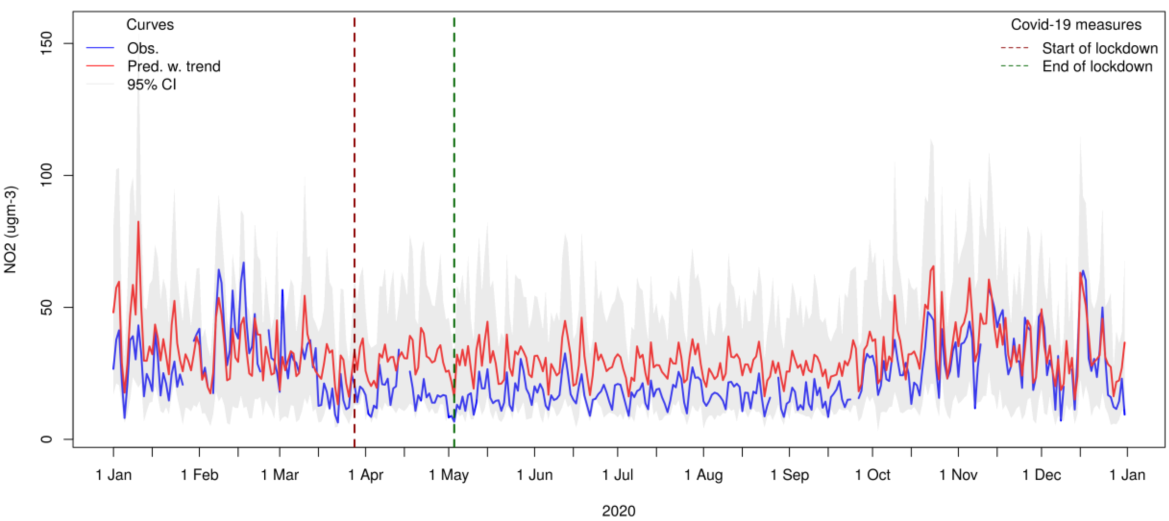
Mean of observed and GAM predicted NO2 at 5 traffic stations in whole of Lithuania

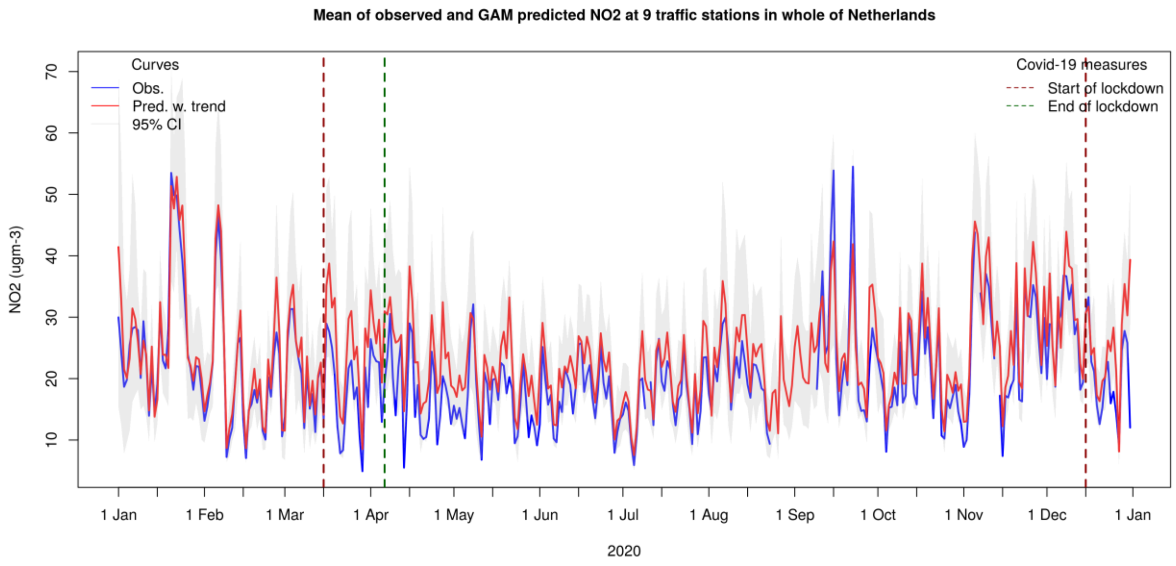



Mean of observed and GAM predicted NO2 at 2 traffic stations in whole of Latvia

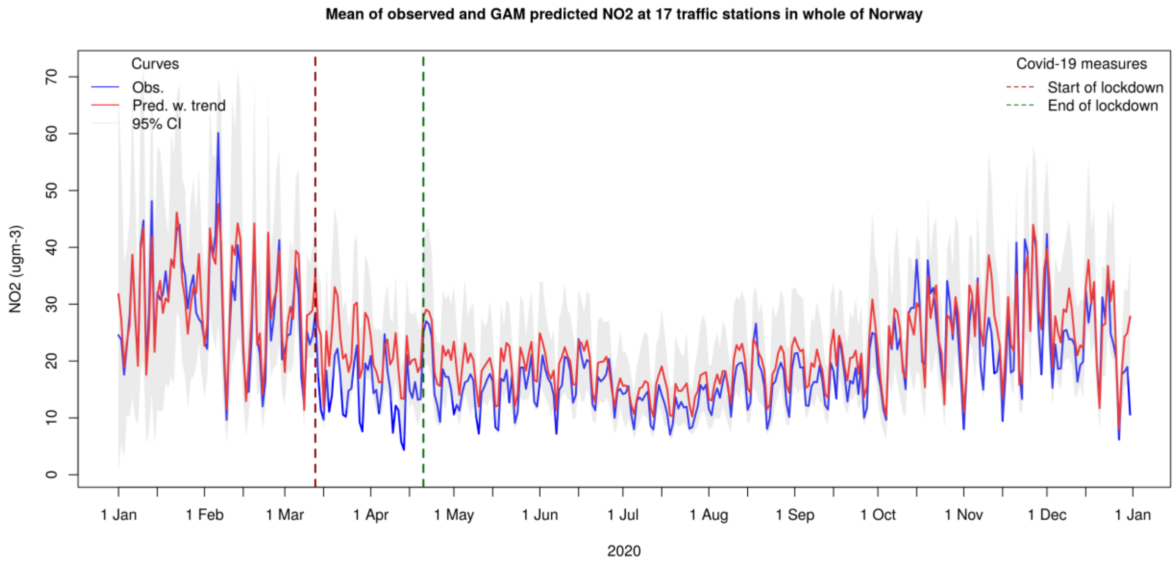



Mean of observed and GAM predicted NO2 at 1 traffic stations in whole of Malta

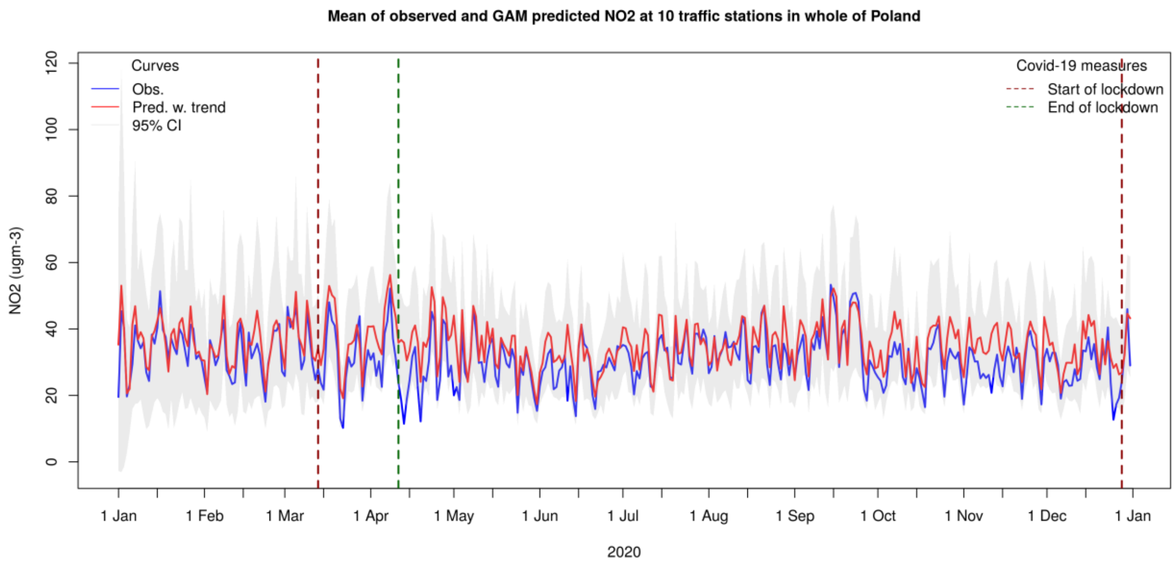




Mean of observed and GAM predicted NO2 at 9 traffic stations in whole of Netherlands
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

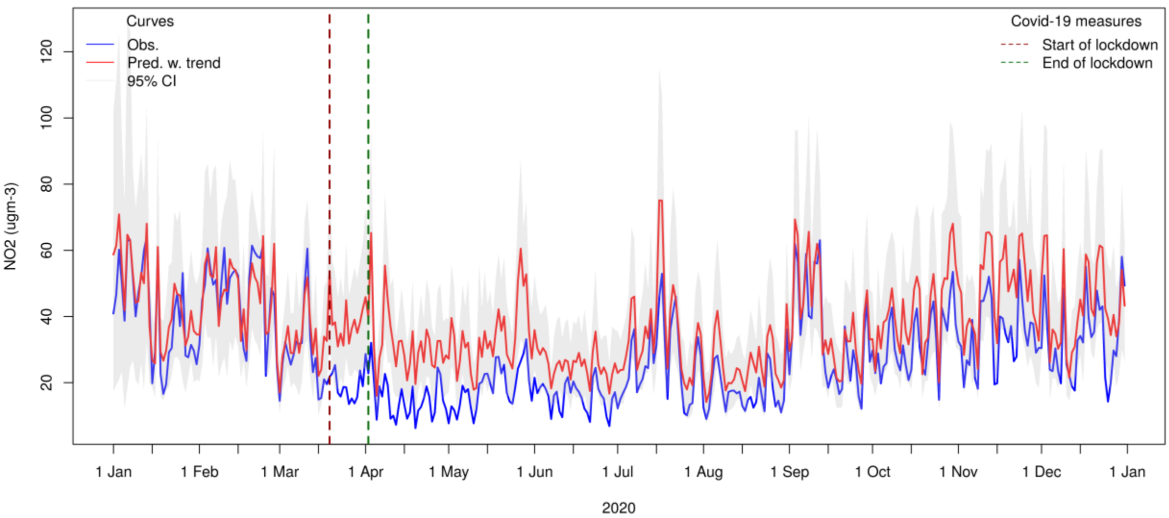



Mean of observed and GAM predicted NO2 at 17 traffic stations in whole of Norway
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

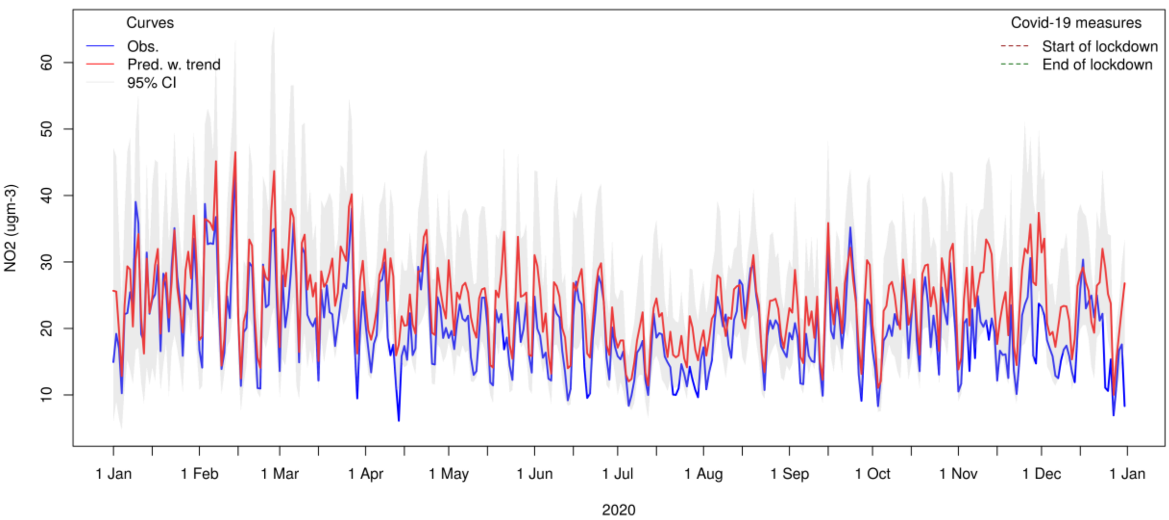



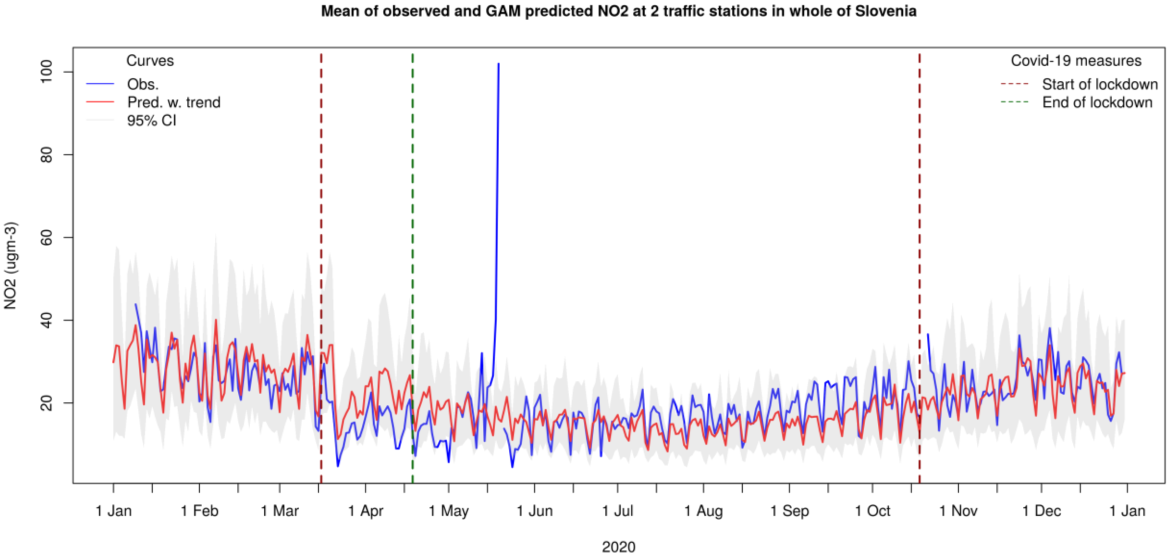
Mean of observed and GAM predicted NO2 at 10 traffic stations in whole of Poland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

Mean of observed and GAM predicted NO2 at 4 traffic stations in whole of Portugal

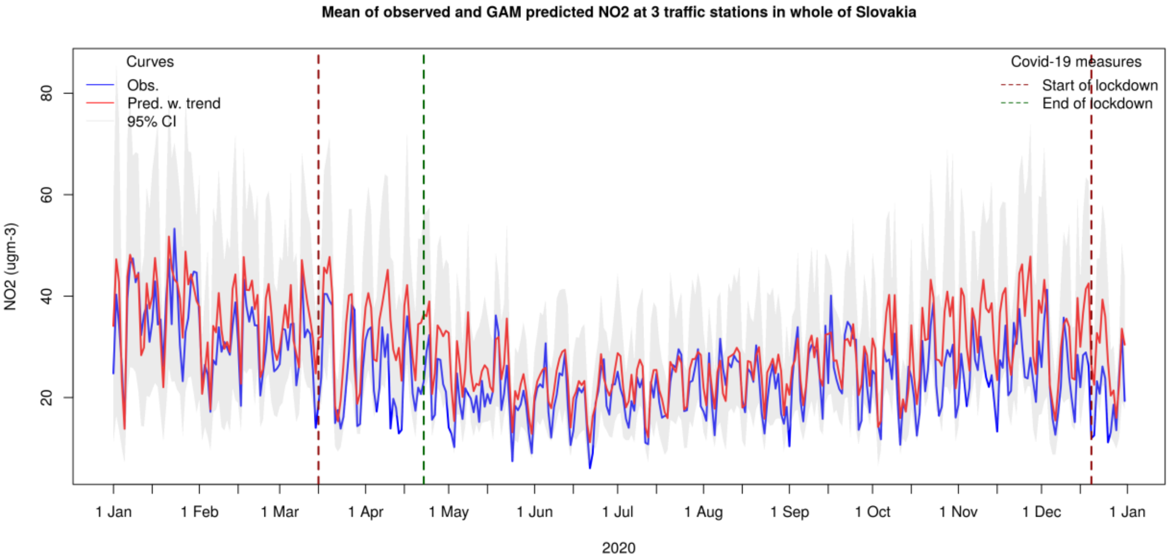



Mean of observed and GAM predicted NO2 at 10 traffic stations in whole of Sweden



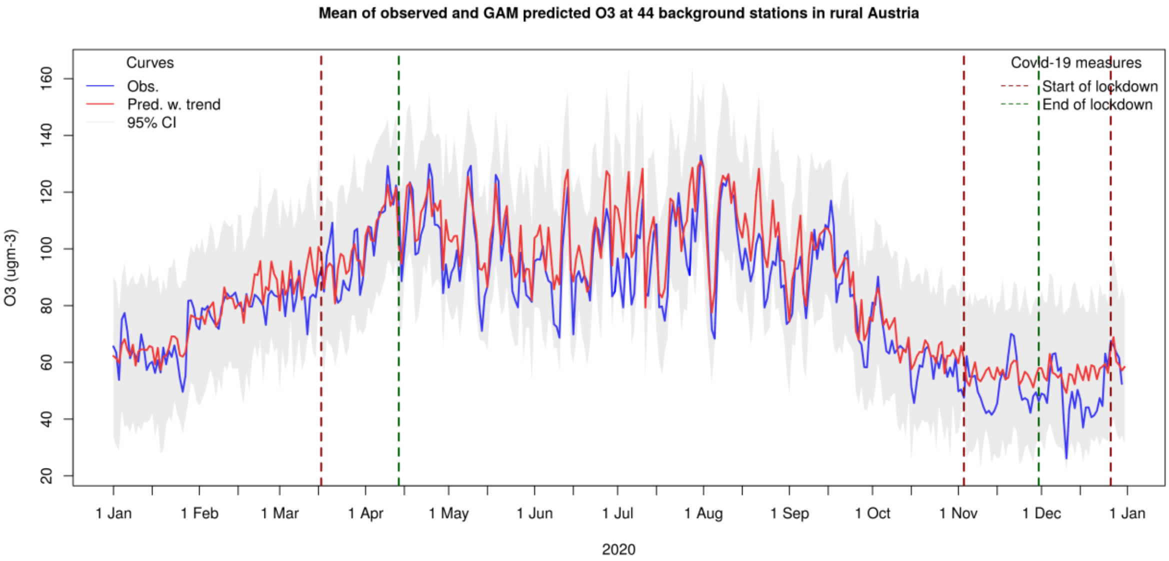


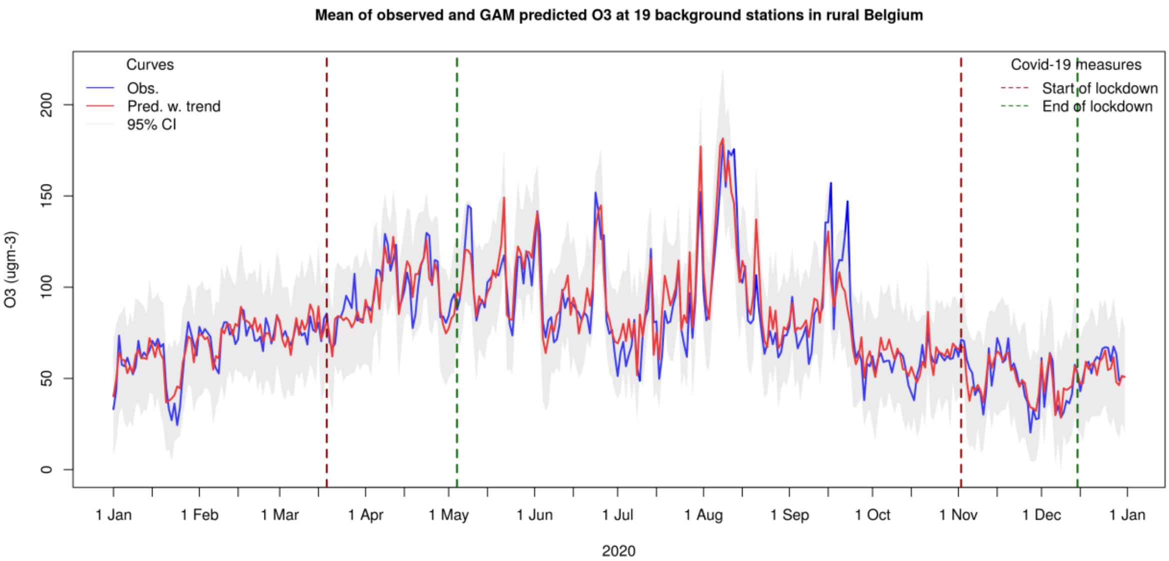
Mean of observed and GAM predicted NO2 at 2 traffic stations in whole of Slovenia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
100
80
60
40
20
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

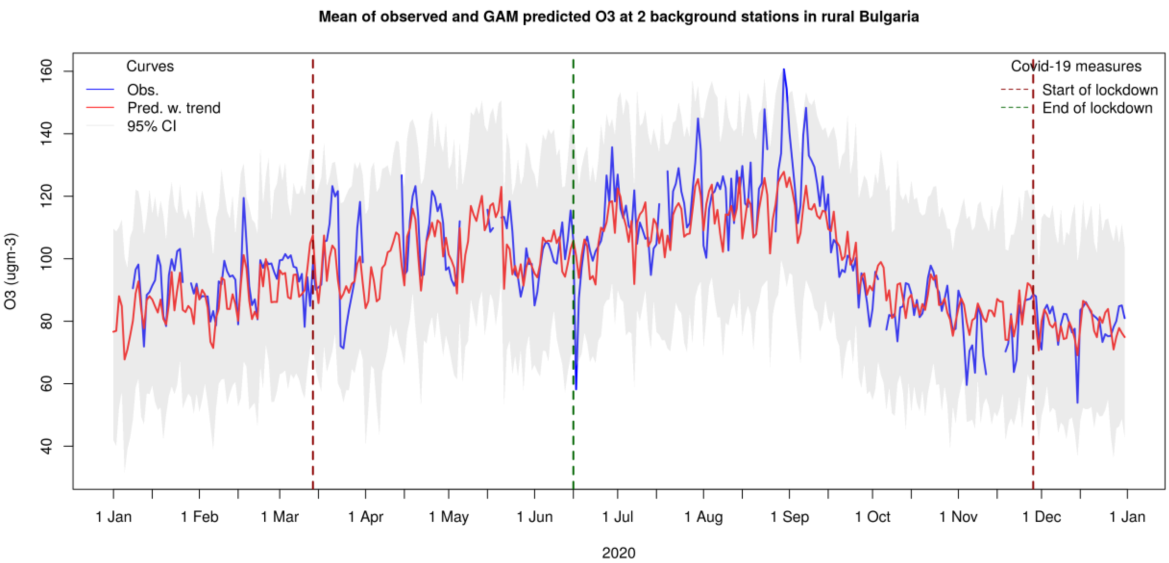



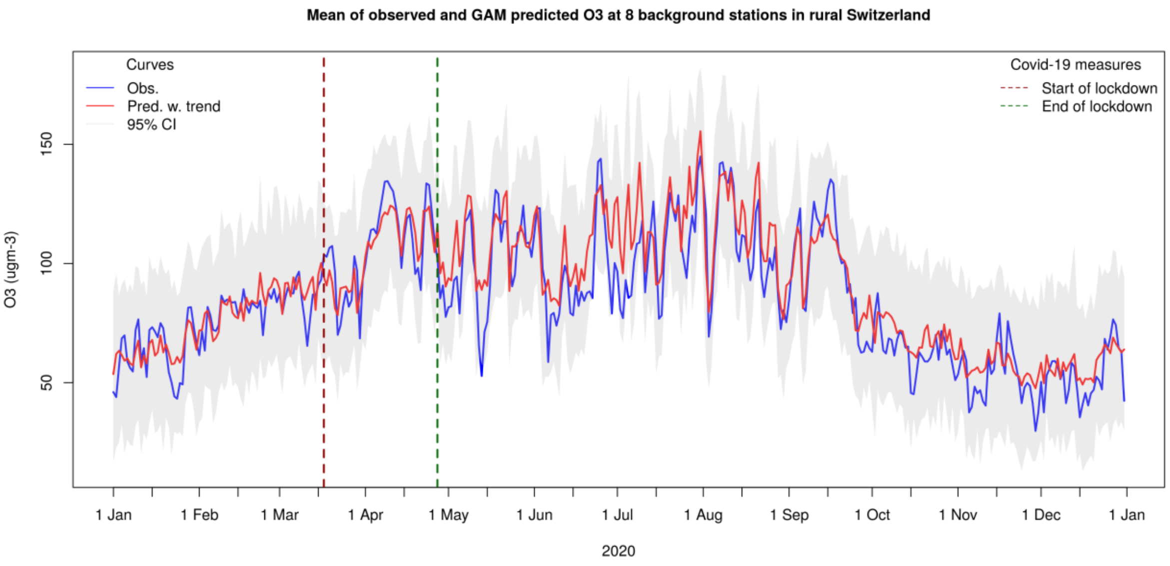
Mean of observed and GAM predicted NO2 at 3 traffic stations in whole of Slovakia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
NO2 (ugm-3)
80
60
40
20
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

*Figure A.13 $O_3$ rural*

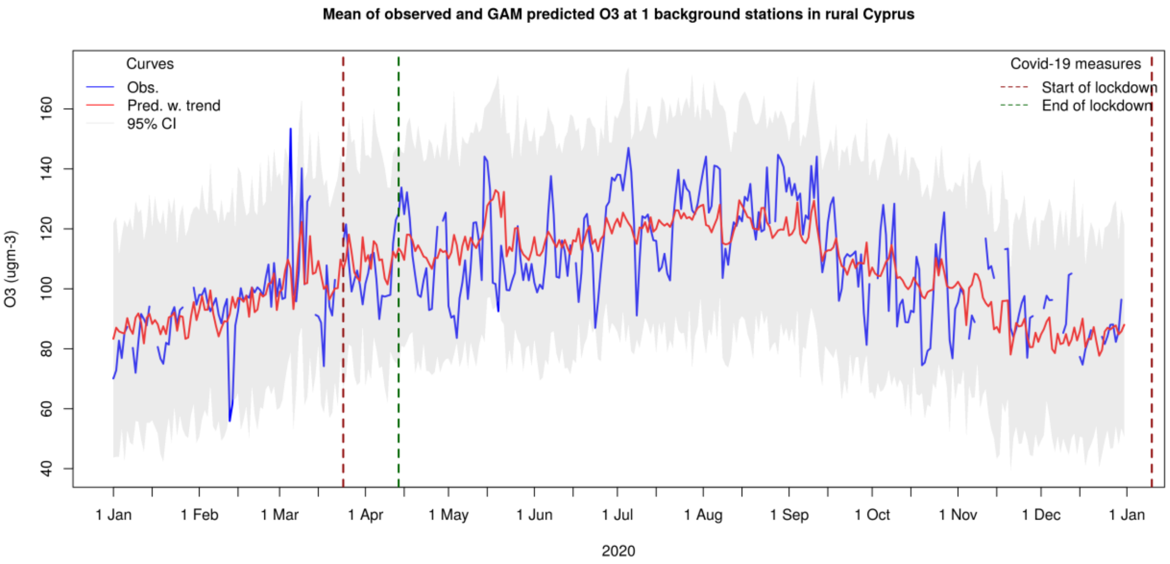


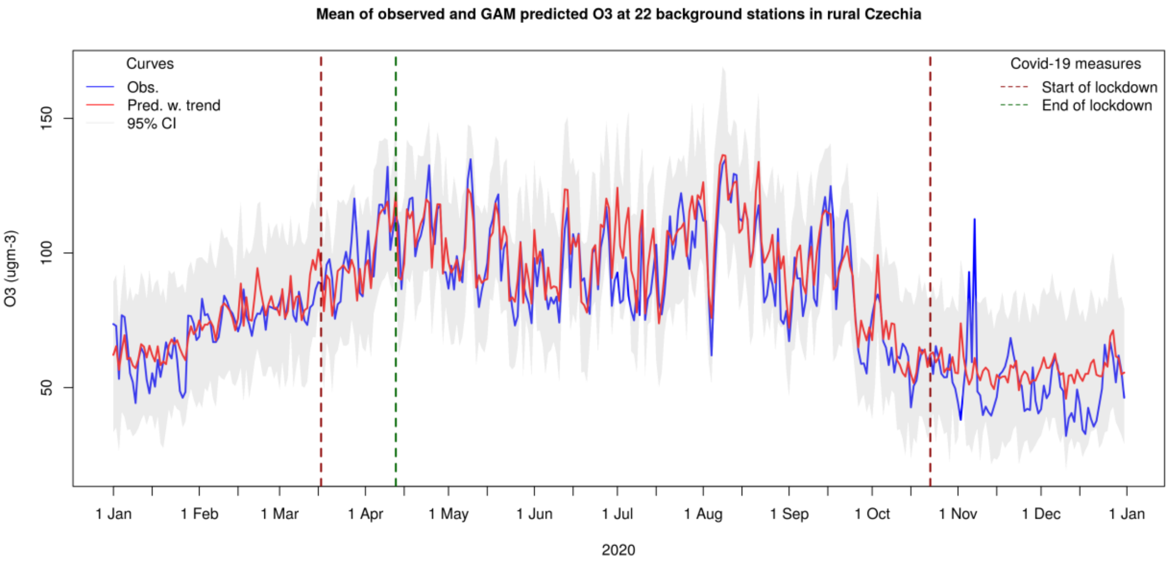





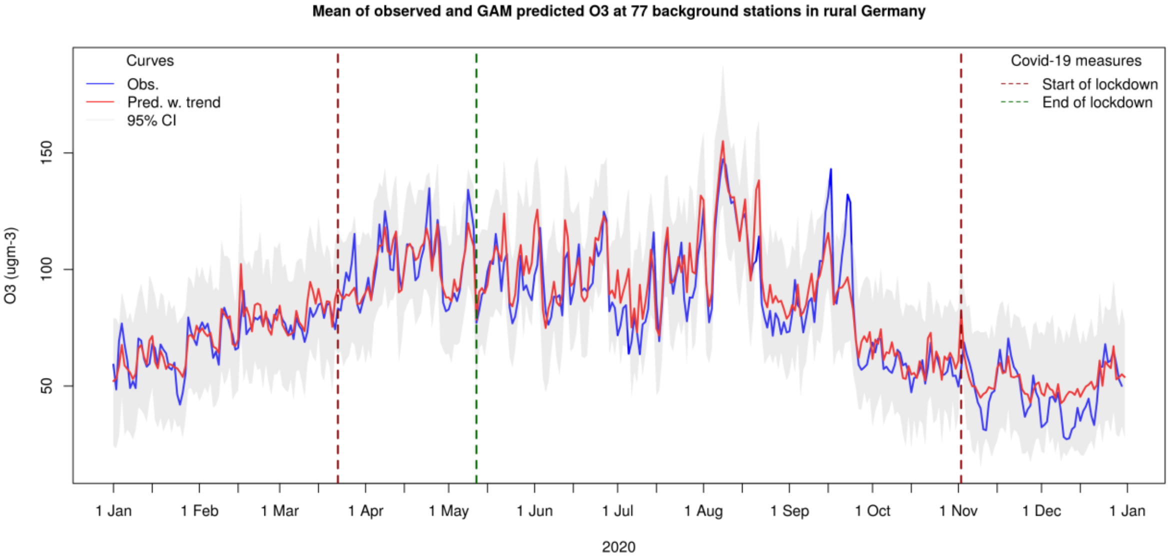
Mean of observed and GAM predicted O3 at 8 background stations in rural Switzerland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

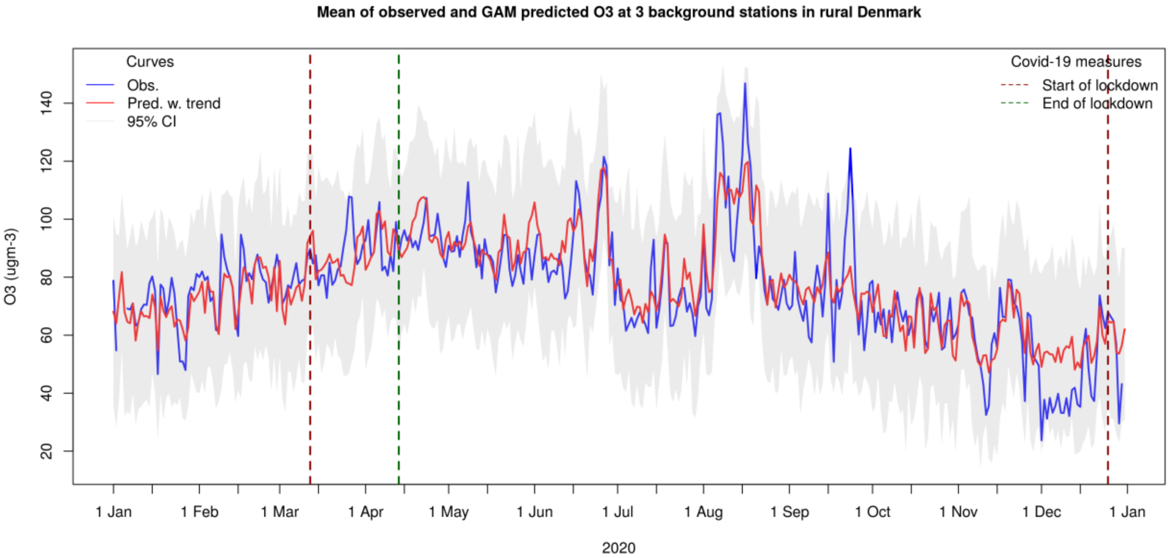



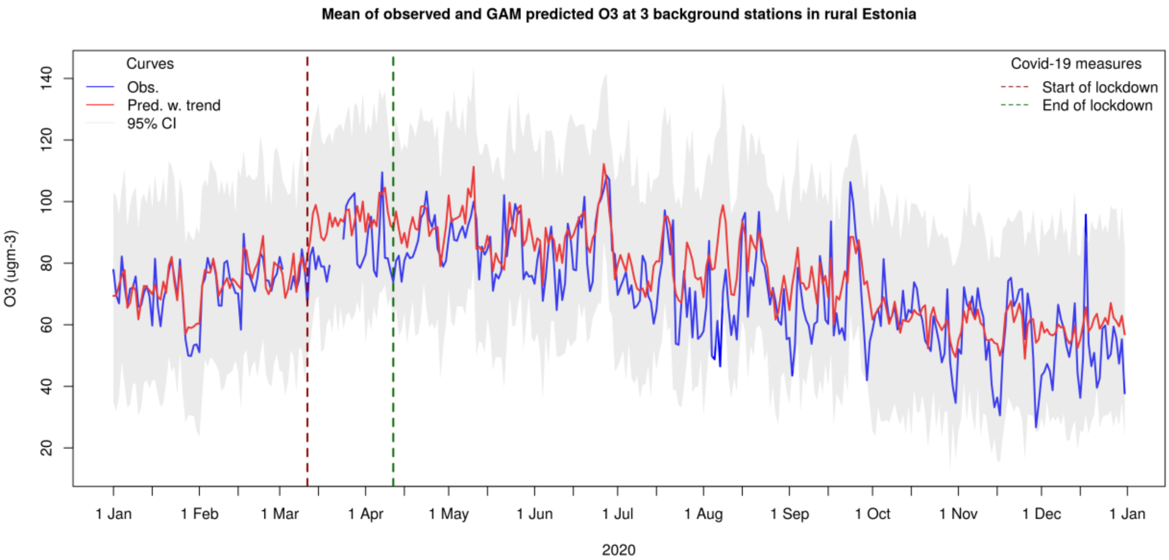
Mean of observed and GAM predicted O3 at 1 background stations in rural Cyprus
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
40
60
80
100
120
140
160
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

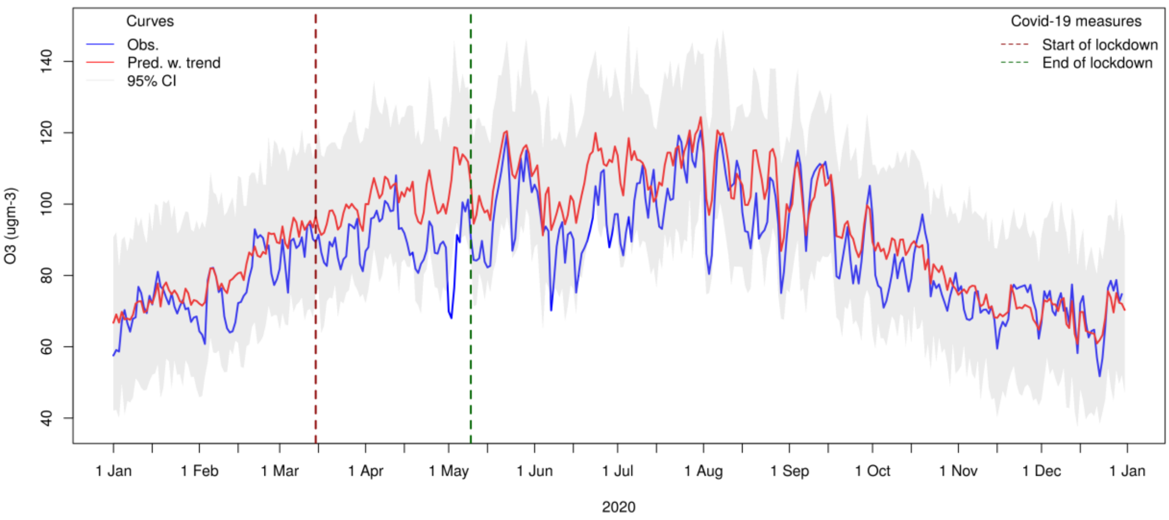
Mean of observed and GAM predicted O3 at 22 background stations in rural Czechia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 77 background stations in rural Germany
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

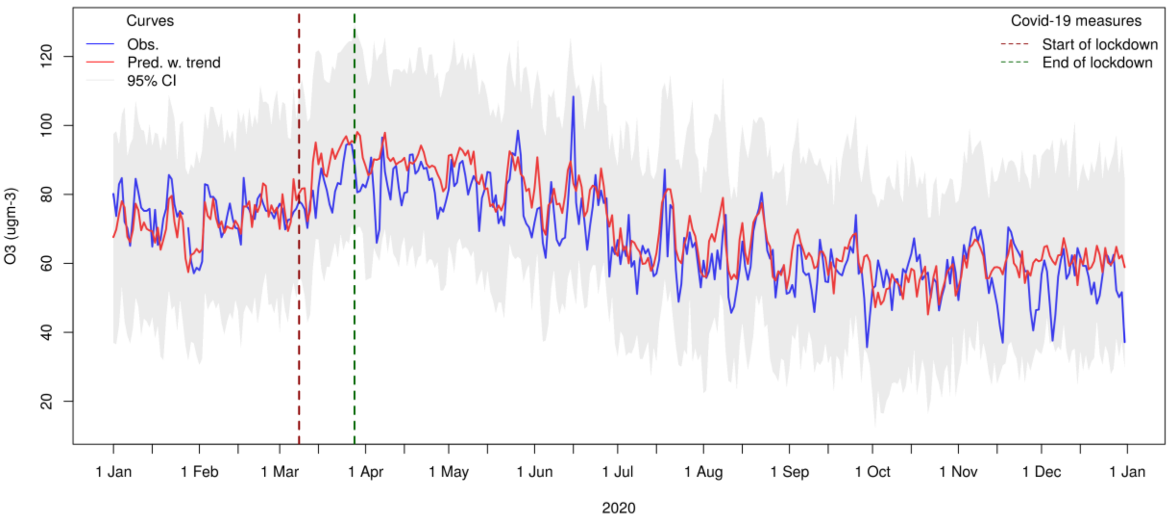

Mean of observed and GAM predicted O3 at 3 background stations in rural Denmark
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
20
40
60
80
100
120
140
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 3 background stations in rural Estonia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
20
40
60
80
100
120
140
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

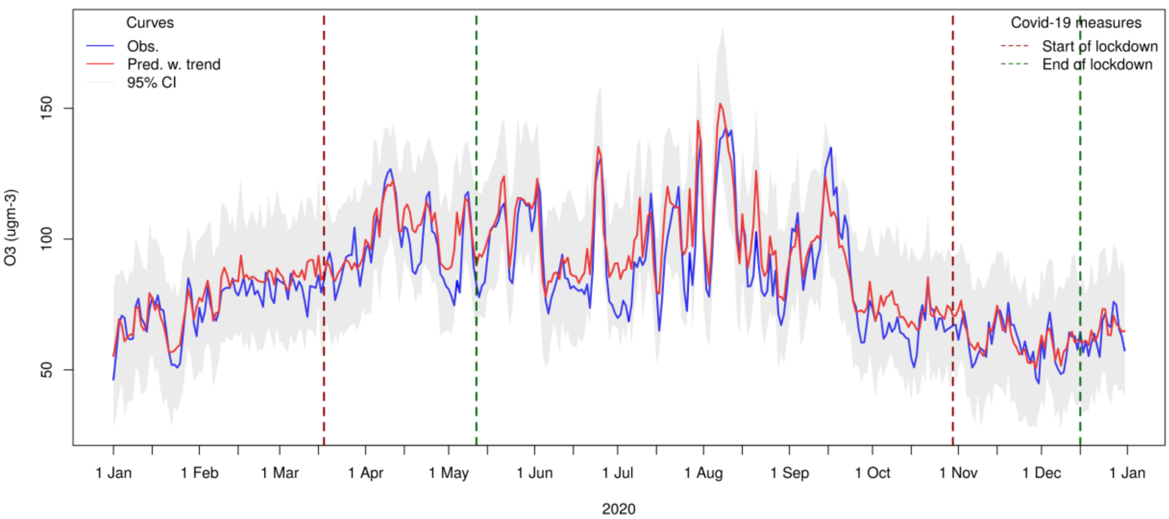
Mean of observed and GAM predicted O3 at 53 background stations in rural Spain

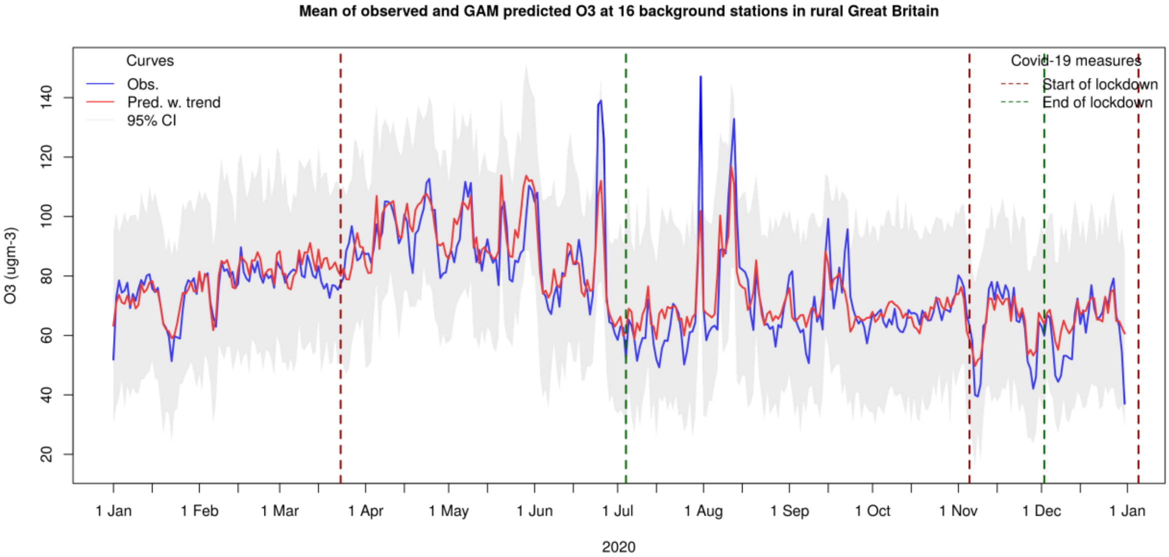


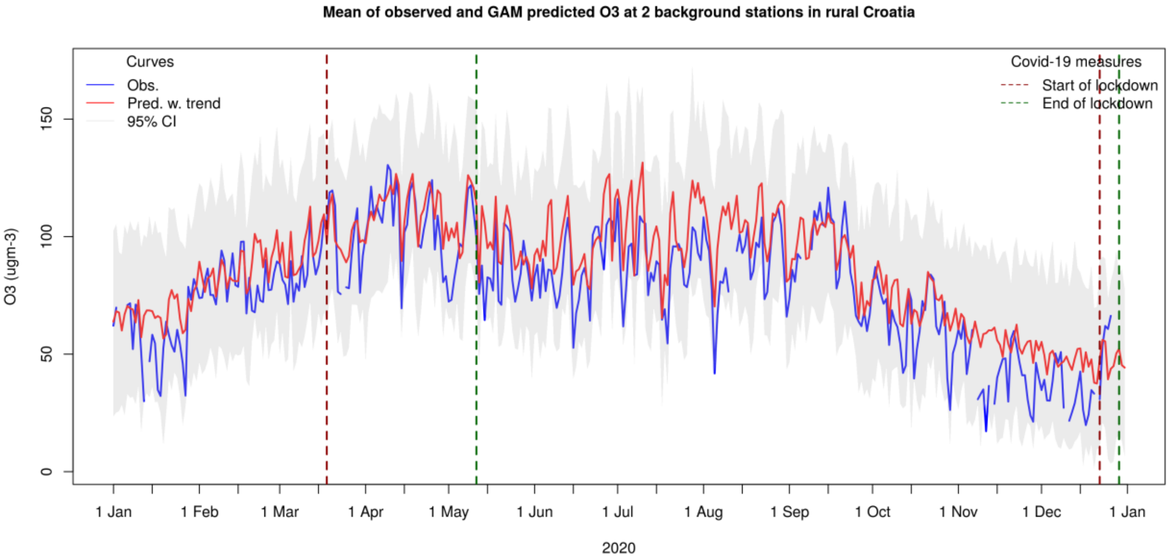

Mean of observed and GAM predicted O3 at 3 background stations in rural Finland

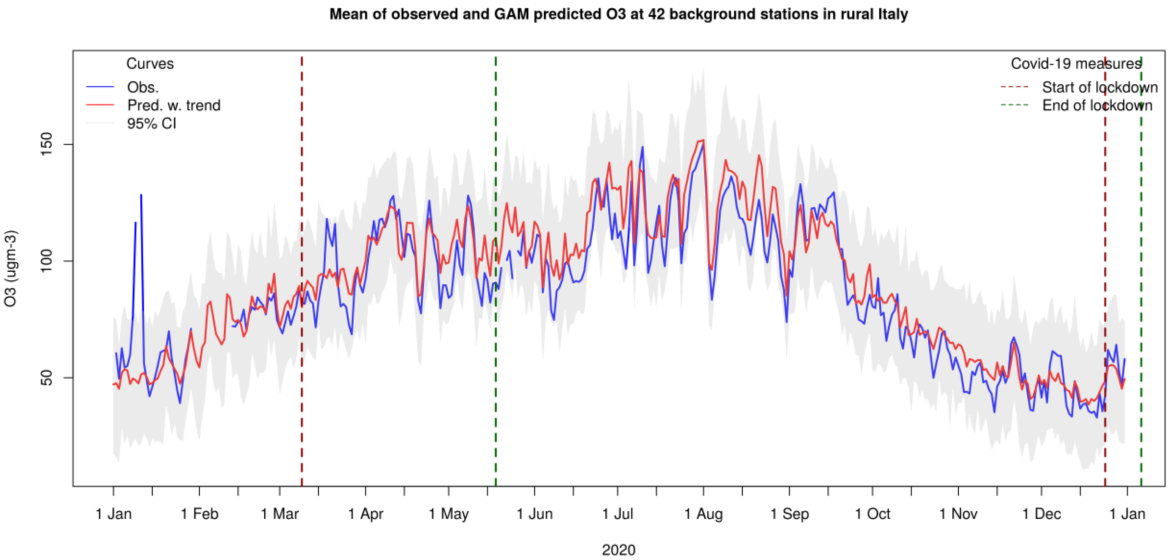


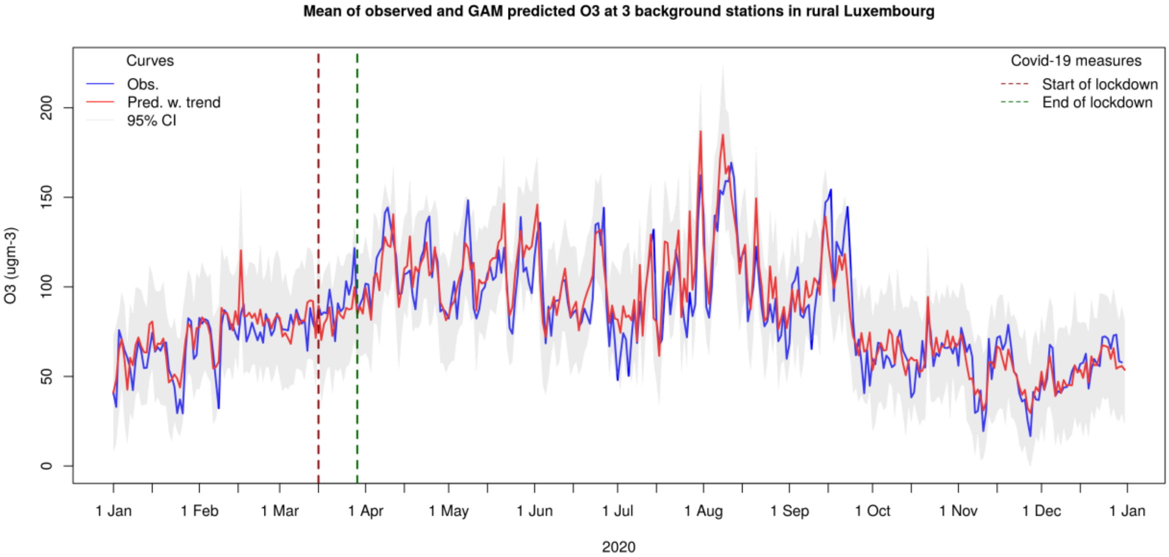

Mean of observed and GAM predicted O3 at 49 background stations in rural France

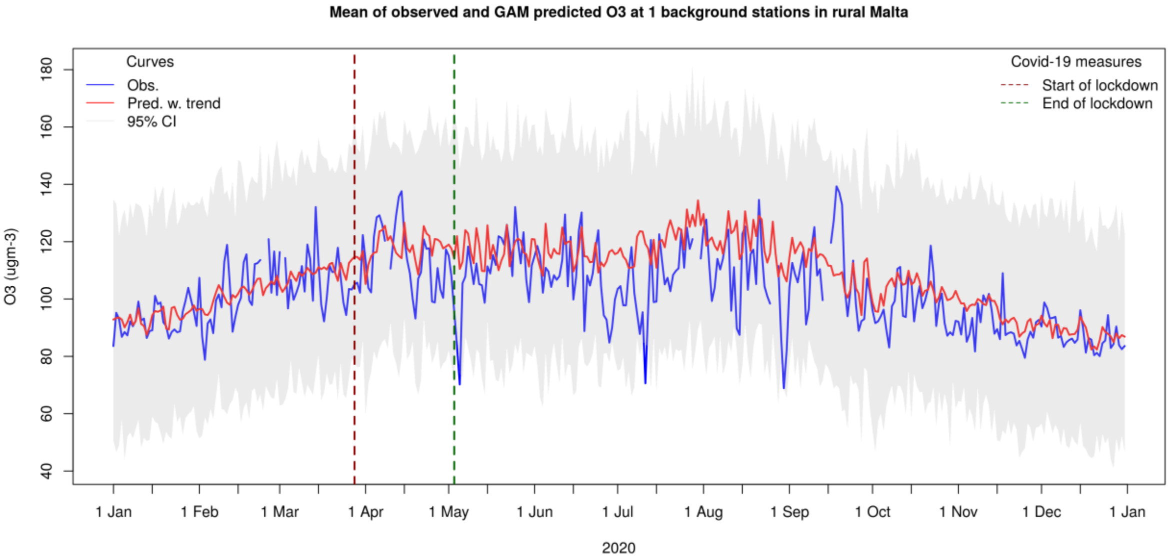


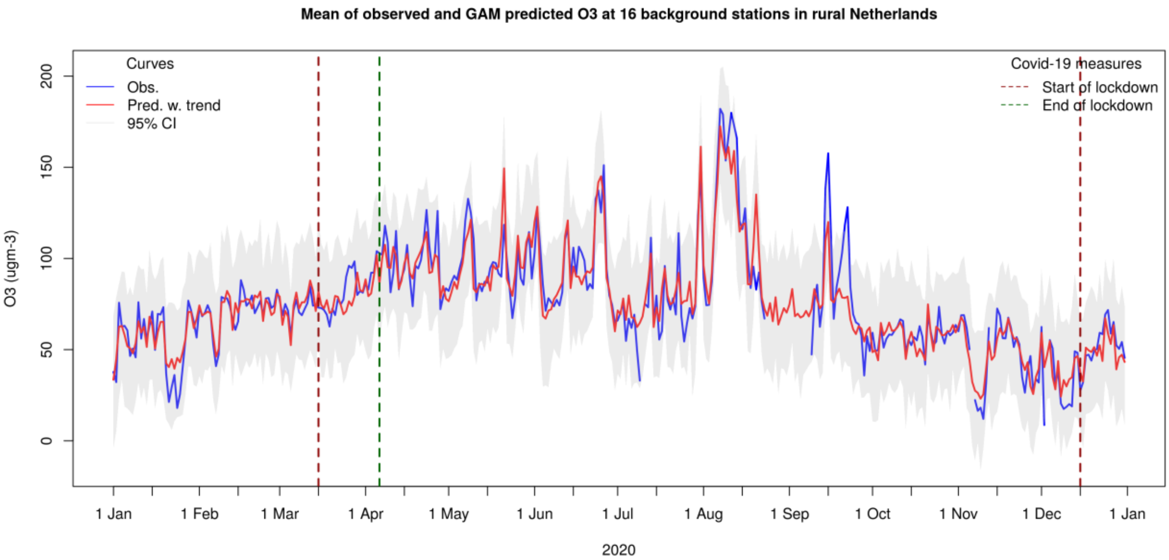

Mean of observed and GAM predicted O3 at 16 background stations in rural Great Britain
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
20
40
60
80
100
120
140
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

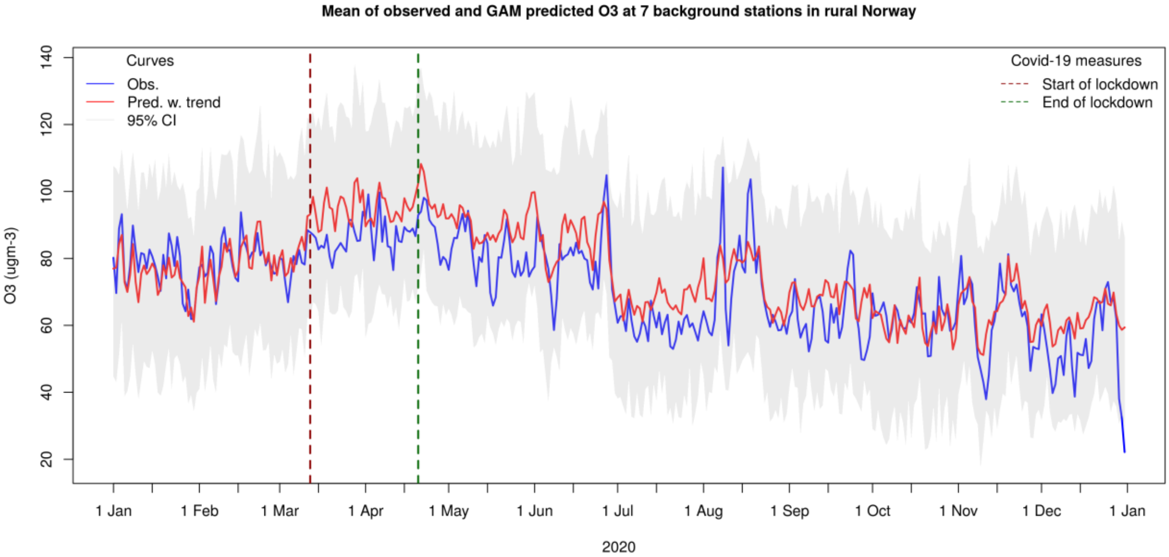

Mean of observed and GAM predicted O3 at 2 background stations in rural Croatia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

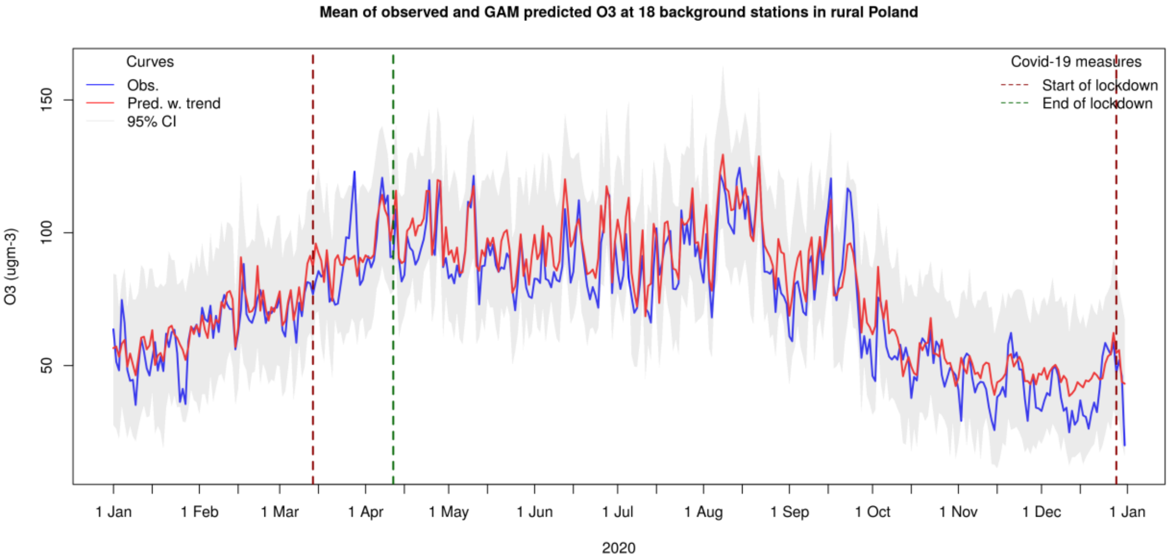

Mean of observed and GAM predicted O3 at 42 background stations in rural Italy
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

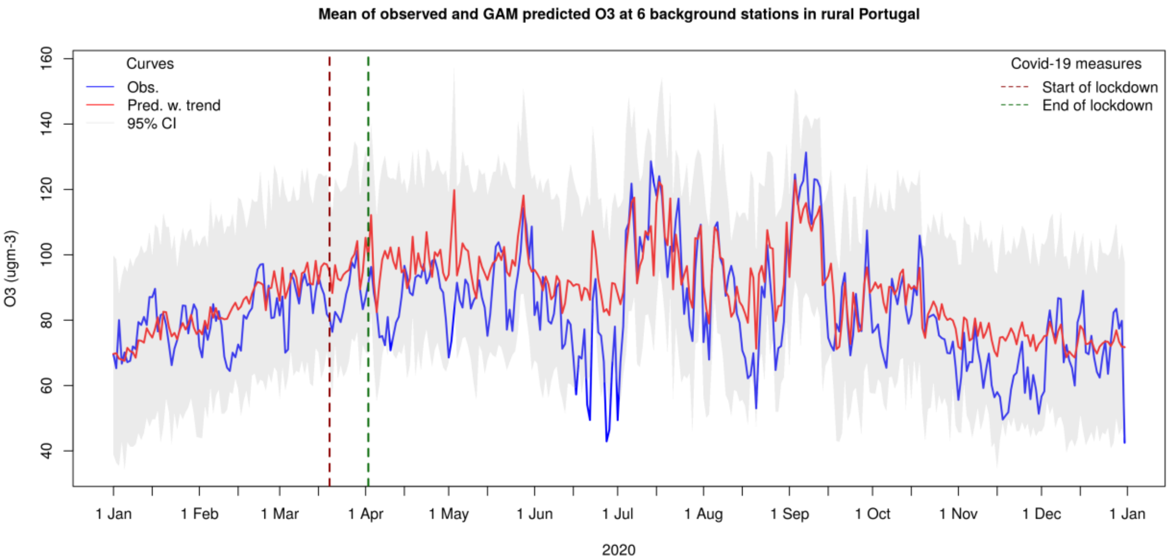

Mean of observed and GAM predicted O3 at 3 background stations in rural Luxembourg
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
200
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

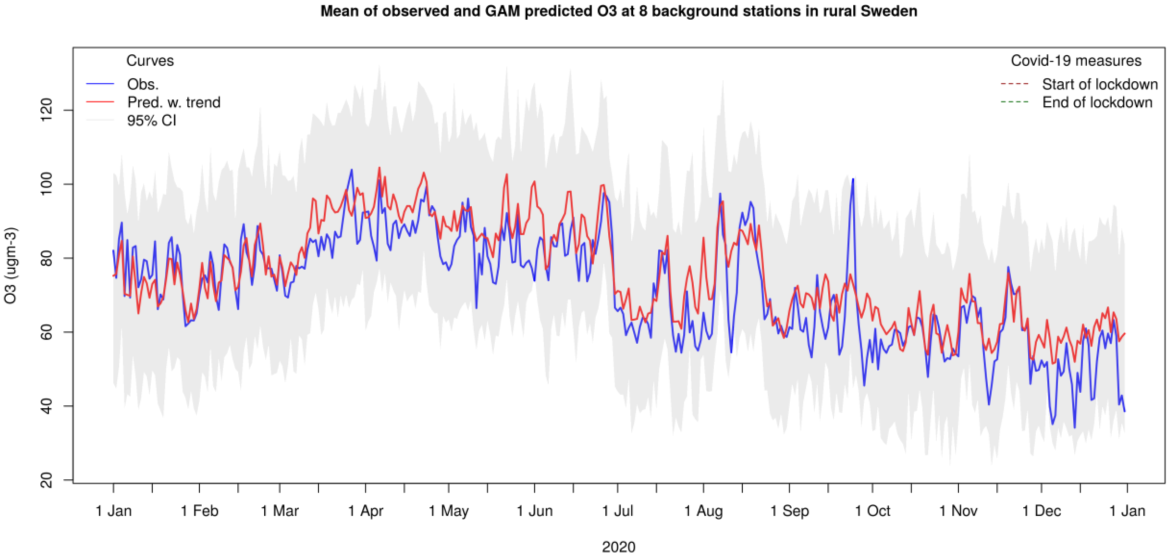

Mean of observed and GAM predicted O3 at 1 background stations in rural Malta
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
40
60
80
100
120
140
160
180
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

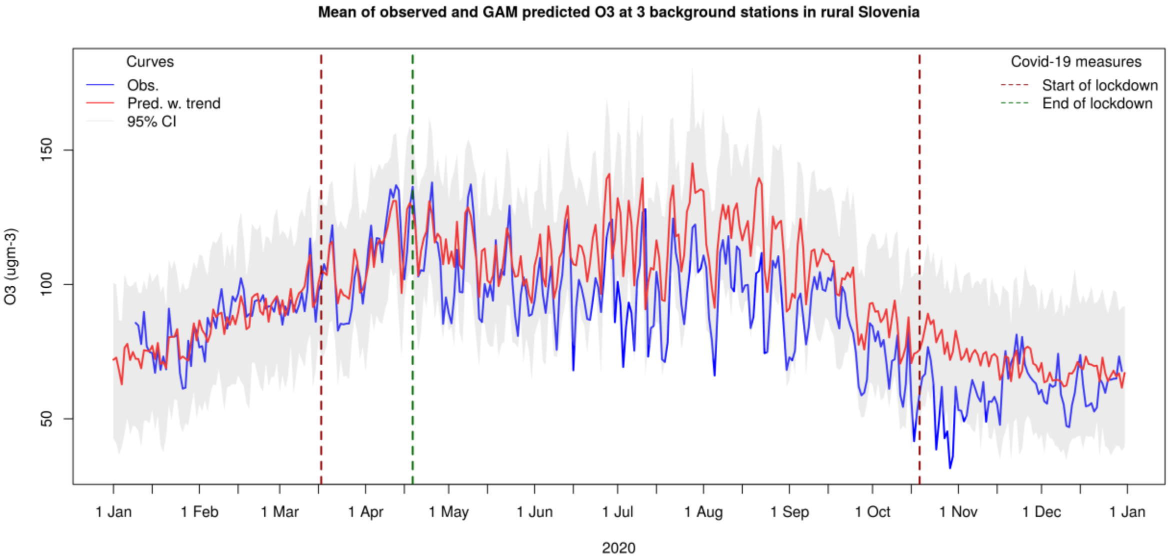

Mean of observed and GAM predicted O3 at 16 background stations in rural Netherlands
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
200
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 7 background stations in rural Norway
O3 (ugm-3)
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
20
40
60
80
100
120
140
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 18 background stations in rural Poland
O3 (ugm-3)
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 6 background stations in rural Portugal
O3 (ugm-3)
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
40
60
80
100
120
140
160
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 8 background stations in rural Sweden
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
20
40
60
80
100
120
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 3 background stations in rural Slovenia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

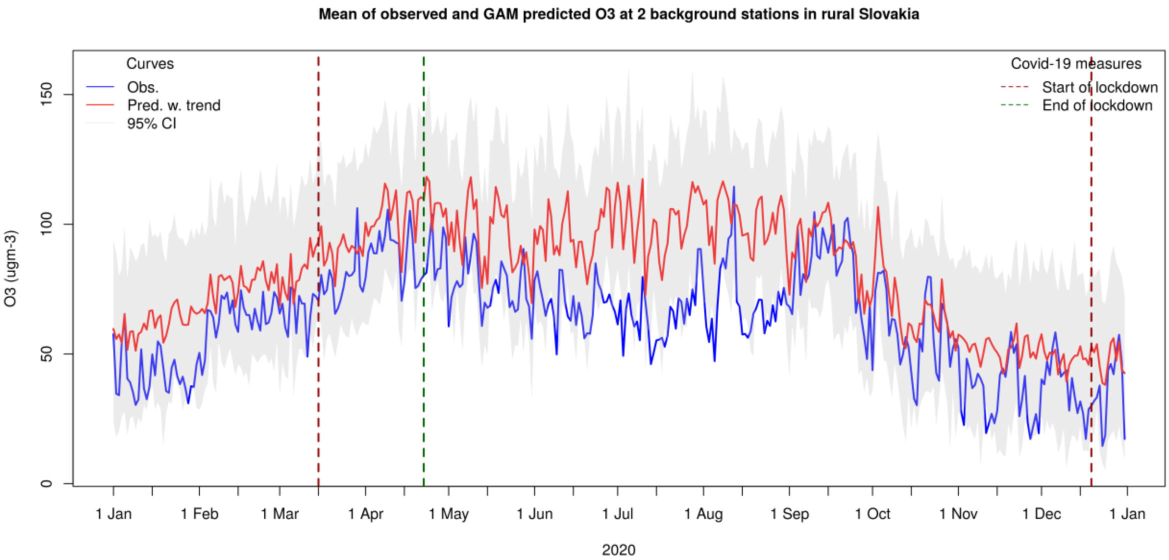
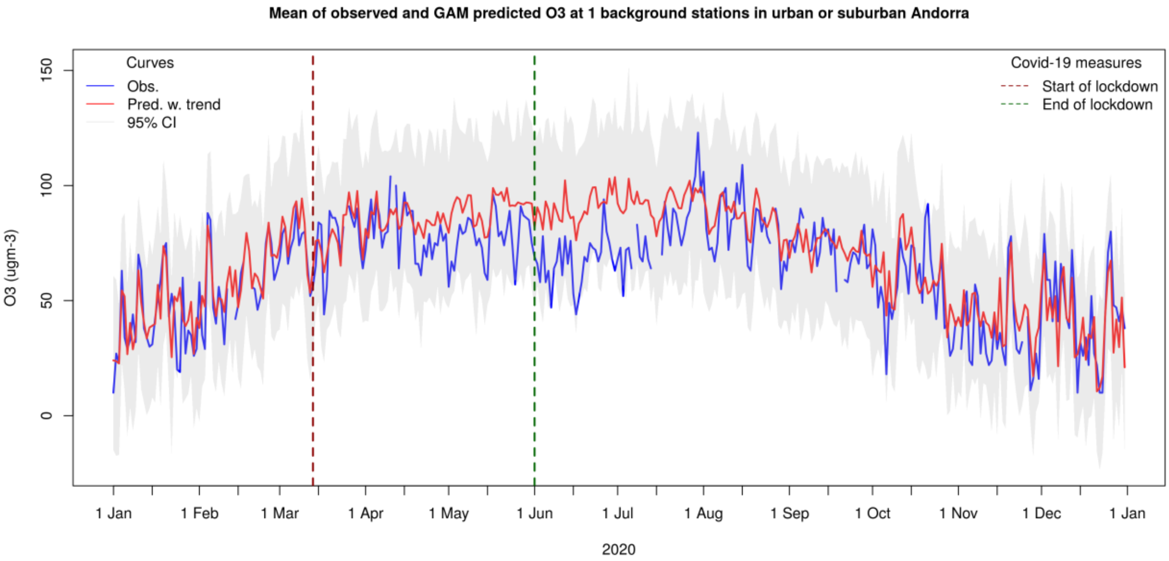
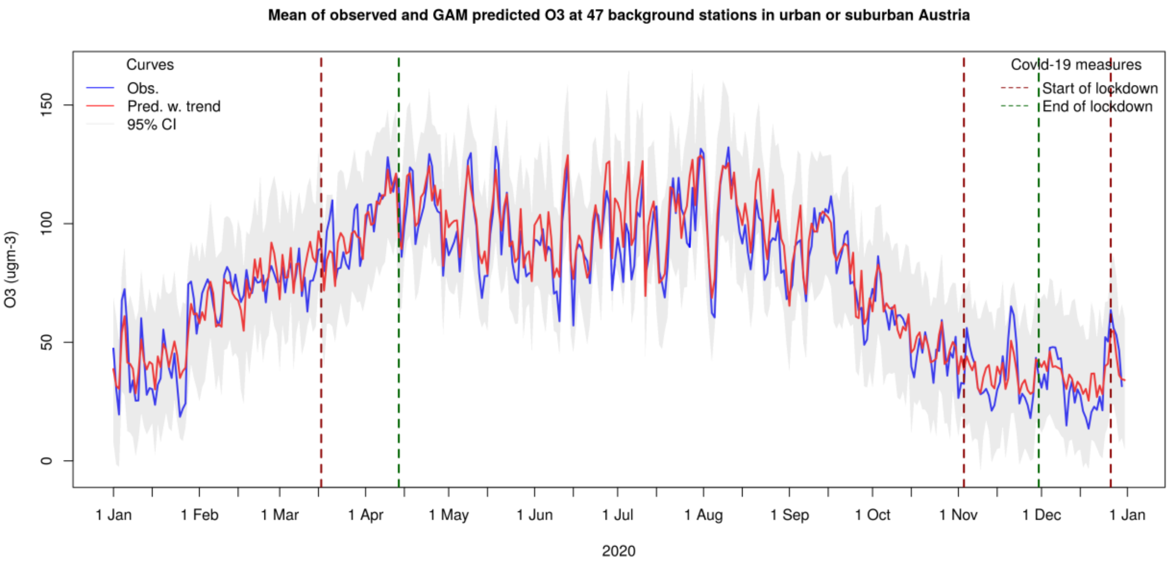
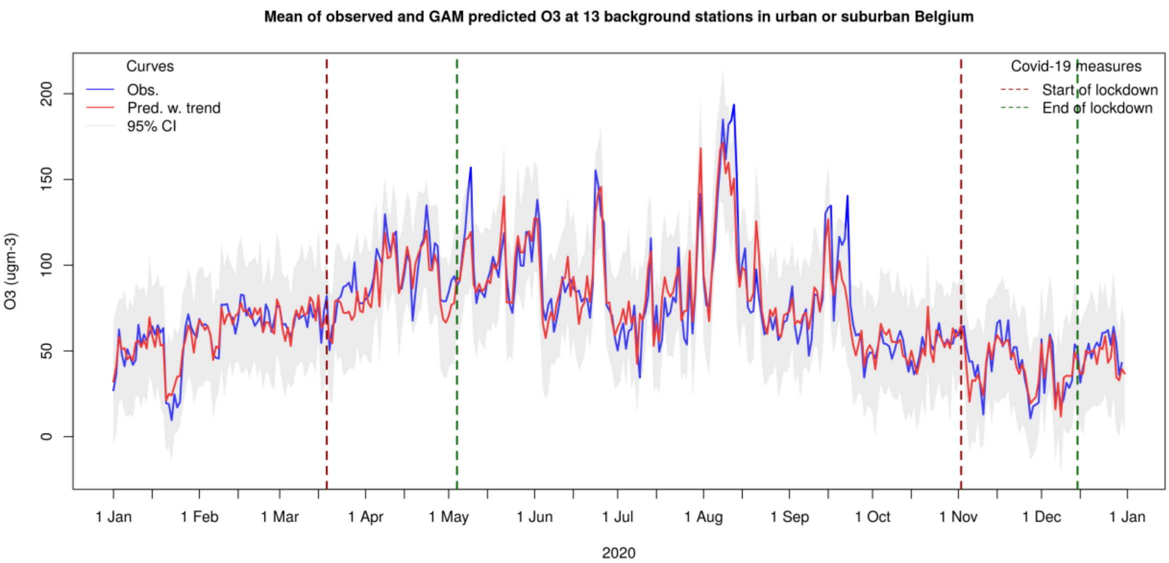

Mean of observed and GAM predicted O3 at 2 background stations in rural Slovakia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

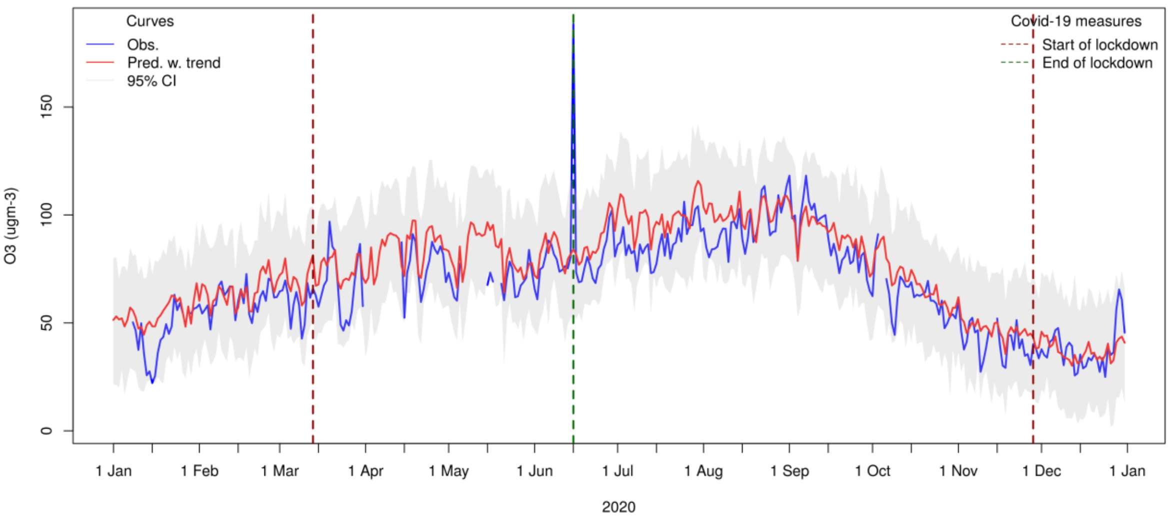
*Figure A.14 $O_3$ suburban*



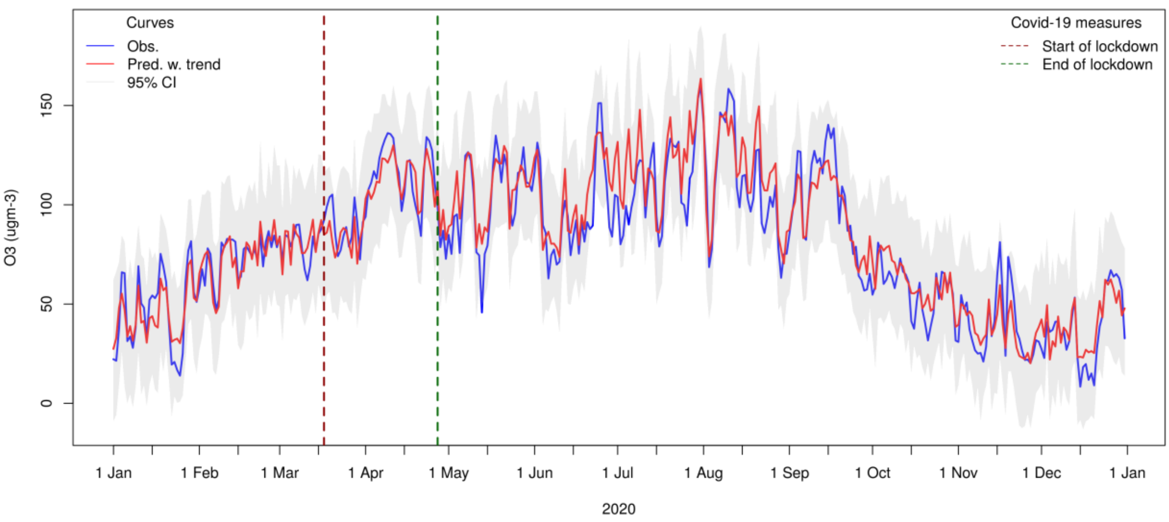



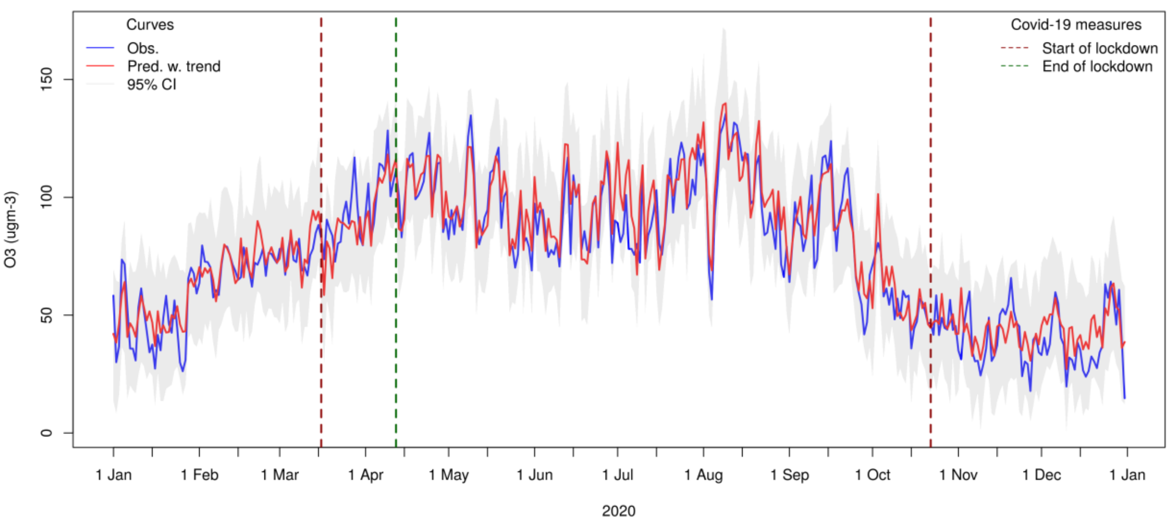
**Mean of observed and GAM predicted O3 at 12 background stations in urban or suburban Bulgaria**

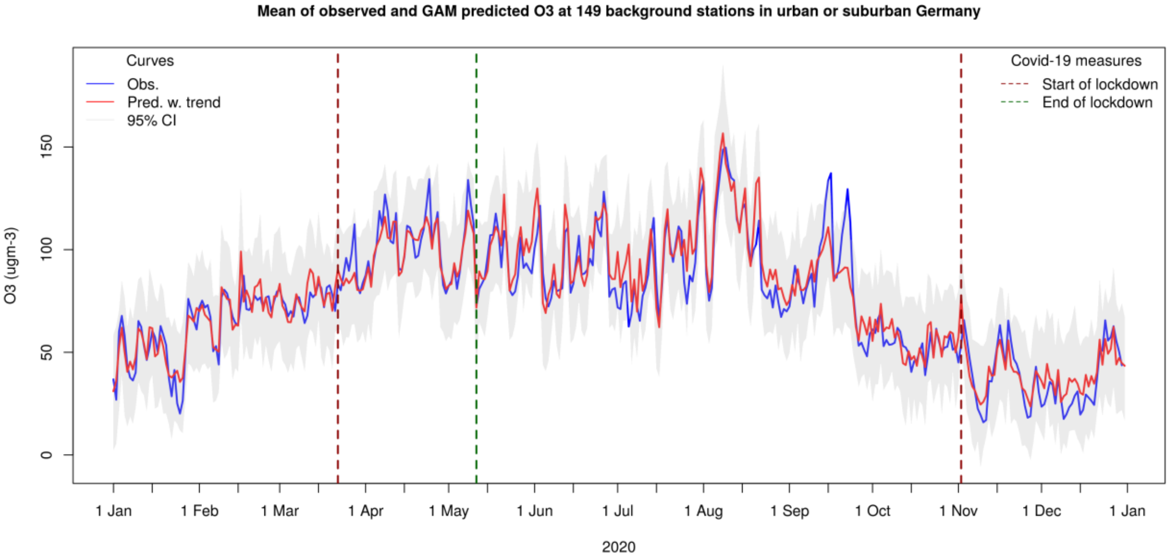


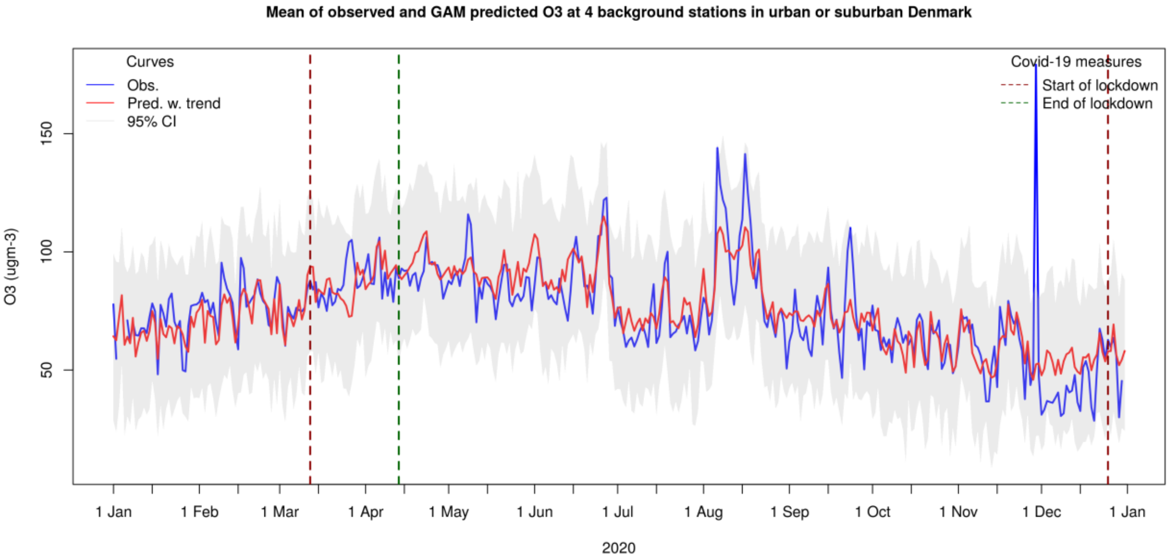

**Mean of observed and GAM predicted O3 at 10 background stations in urban or suburban Switzerland**

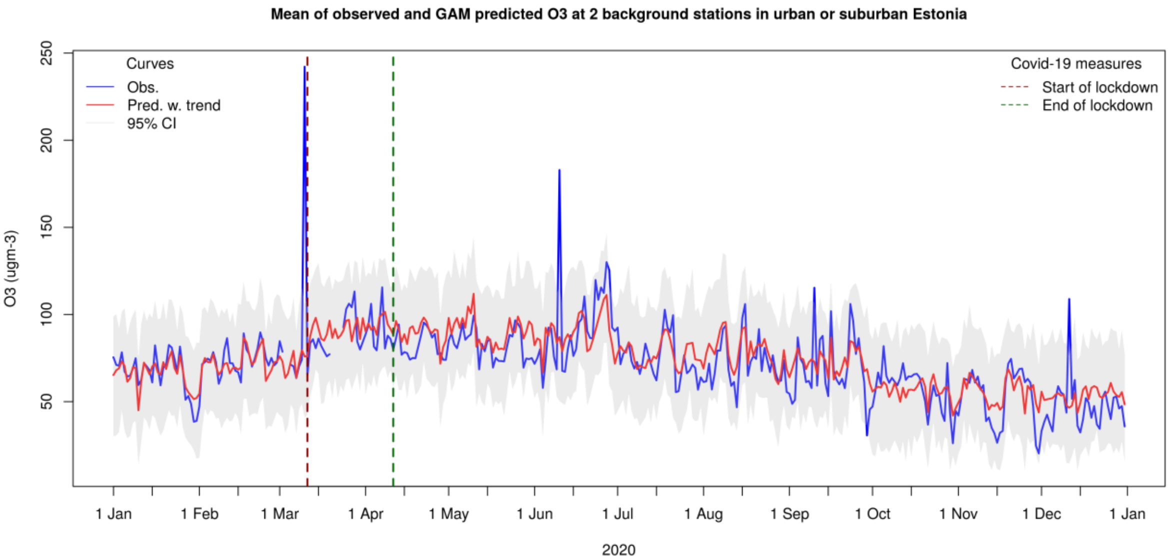



**Mean of observed and GAM predicted O3 at 27 background stations in urban or suburban Czechia**

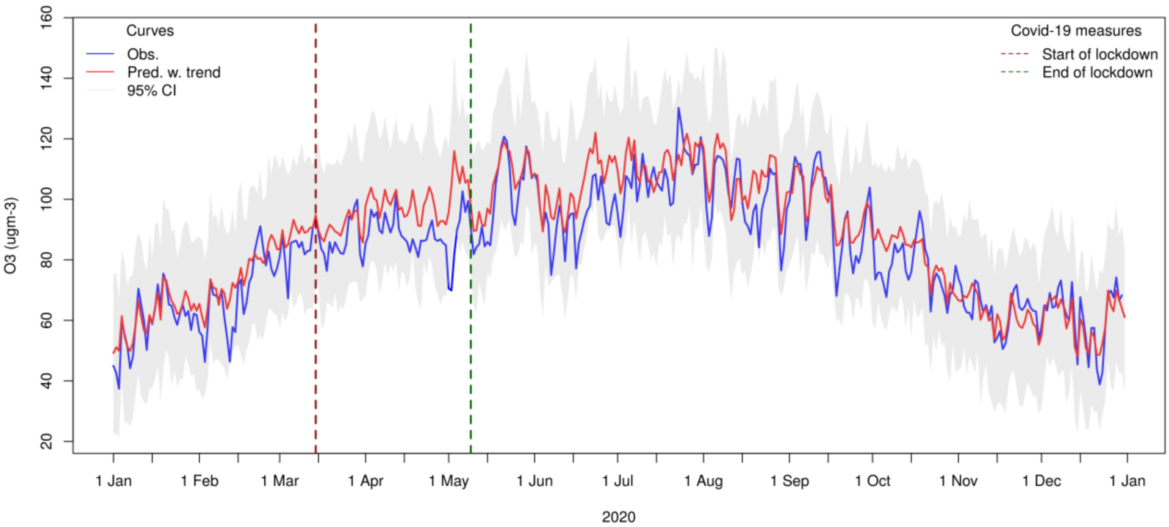



Mean of observed and GAM predicted O3 at 149 background stations in urban or suburban Germany
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

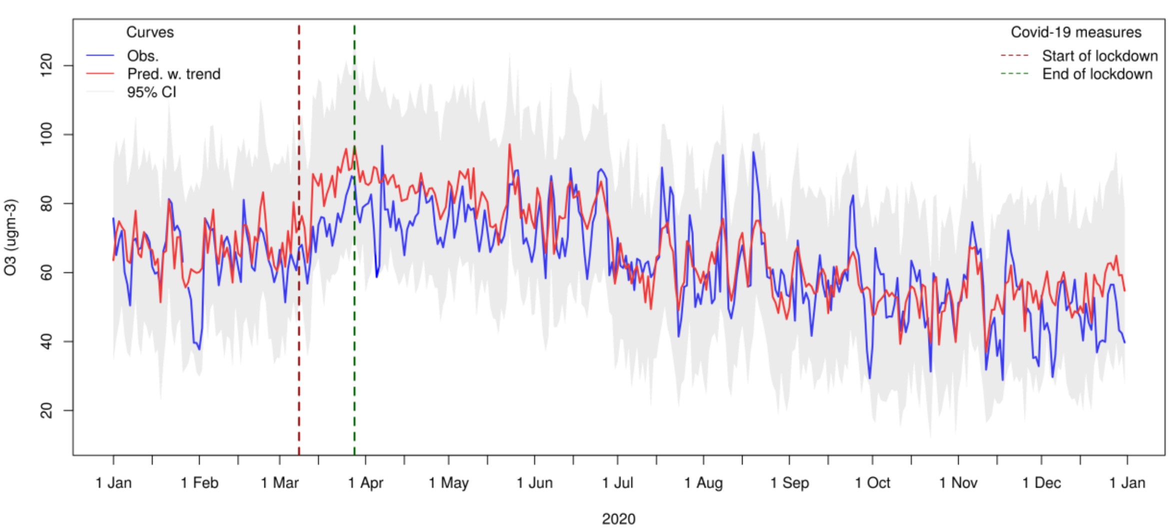

Mean of observed and GAM predicted O3 at 4 background stations in urban or suburban Denmark
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 2 background stations in urban or suburban Estonia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
50
100
150
200
250
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

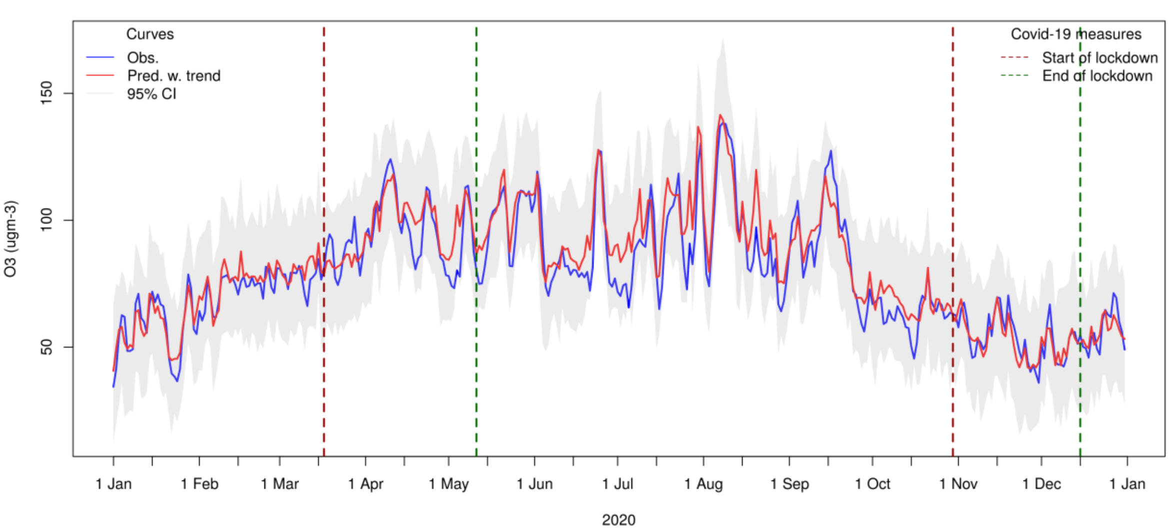
**Mean of observed and GAM predicted O3 at 91 background stations in urban or suburban Spain**



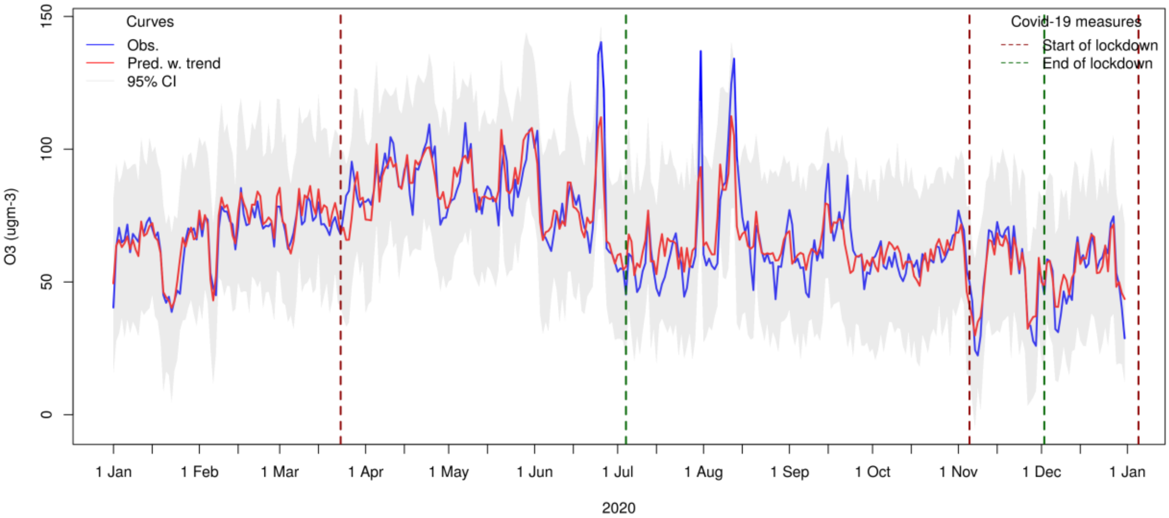

**Mean of observed and GAM predicted O3 at 2 background stations in urban or suburban Finland**



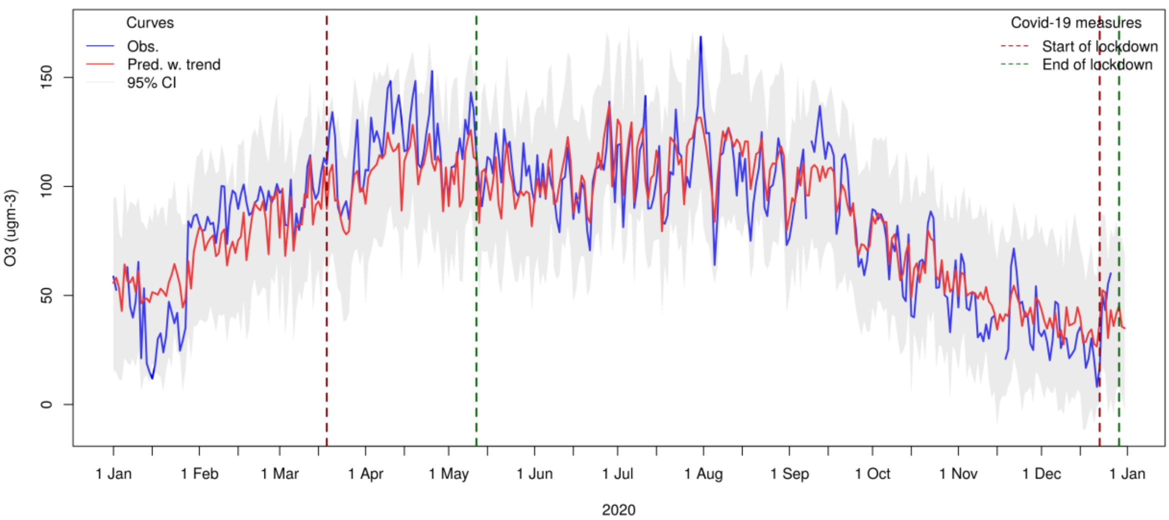

**Mean of observed and GAM predicted O3 at 193 background stations in urban or suburban France**



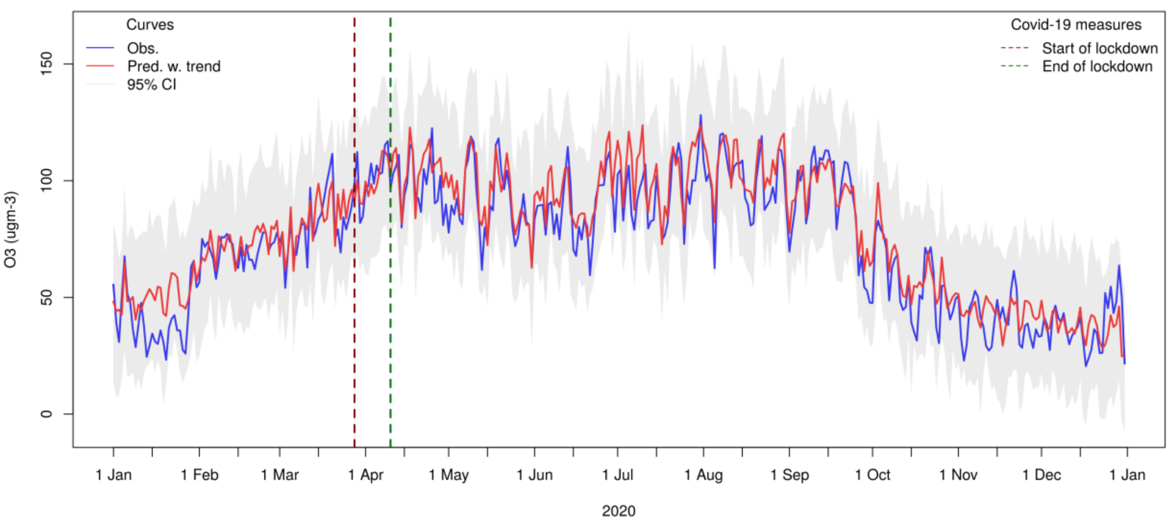
Mean of observed and GAM predicted O3 at 33 background stations in urban or suburban Great Britain

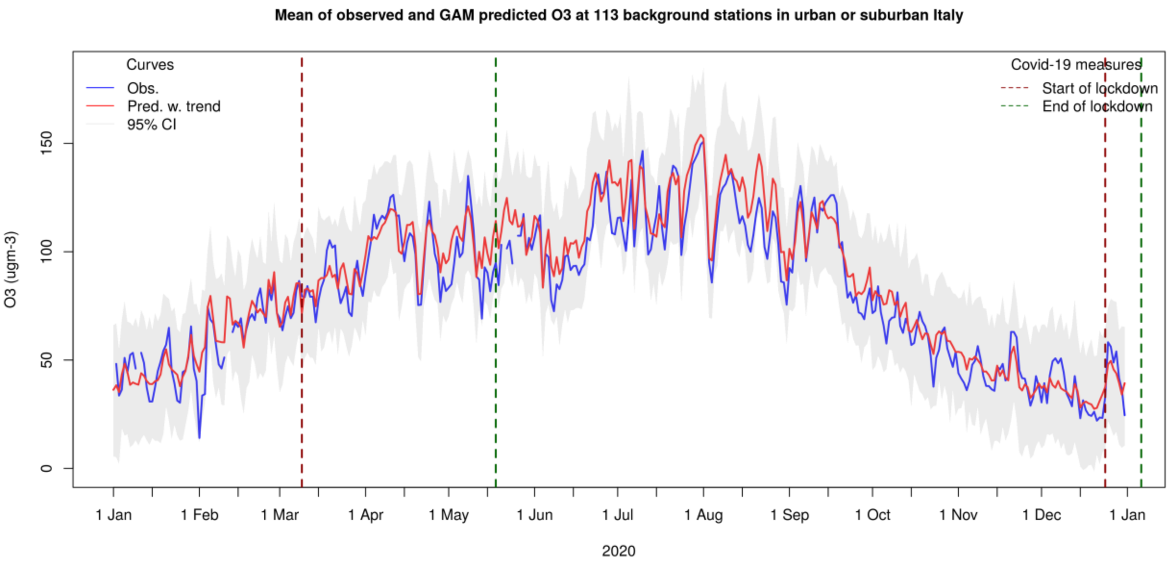



Mean of observed and GAM predicted O3 at 2 background stations in urban or suburban Croatia

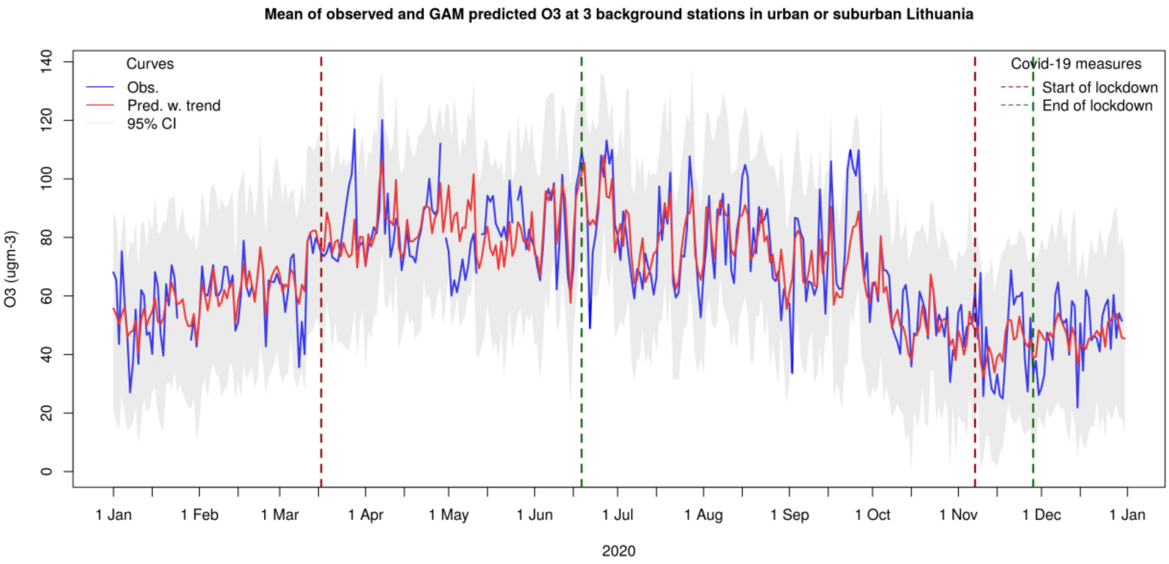



Mean of observed and GAM predicted O3 at 12 background stations in urban or suburban Hungary

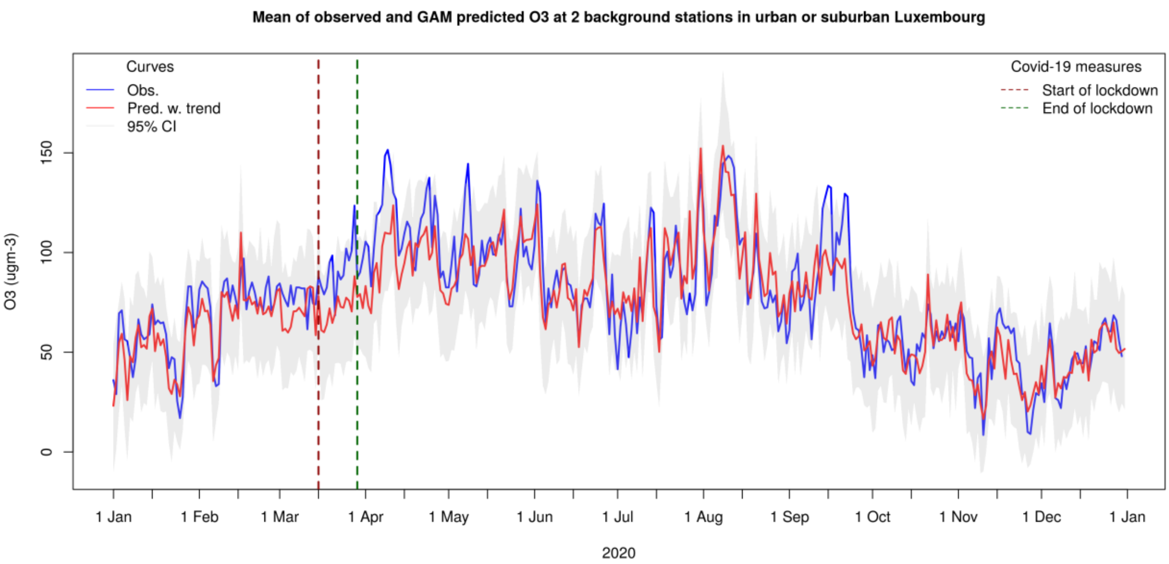




Mean of observed and GAM predicted O3 at 113 background stations in urban or suburban Italy
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

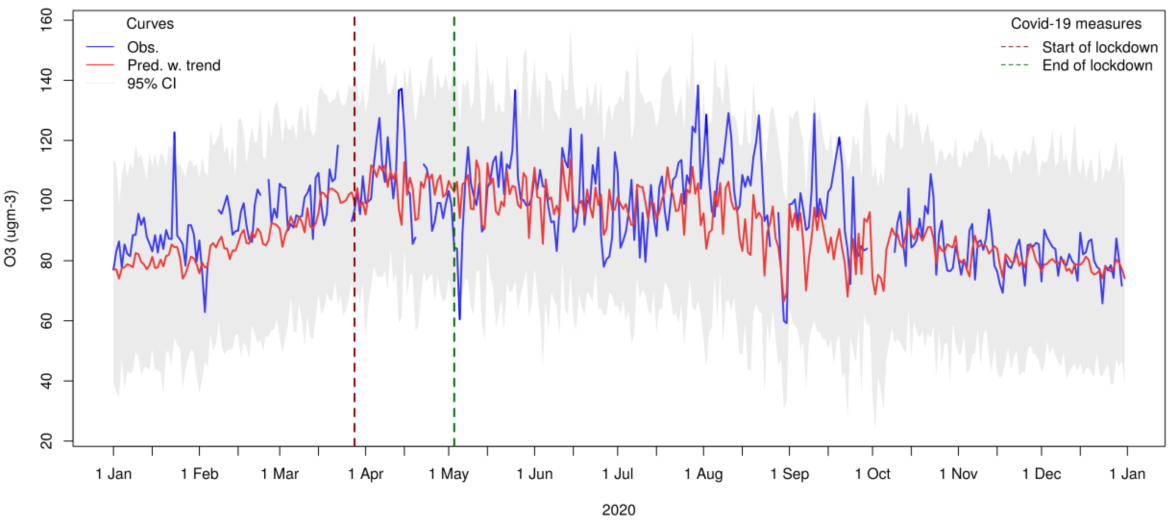



Mean of observed and GAM predicted O3 at 3 background stations in urban or suburban Lithuania
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
20
40
60
80
100
120
140
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

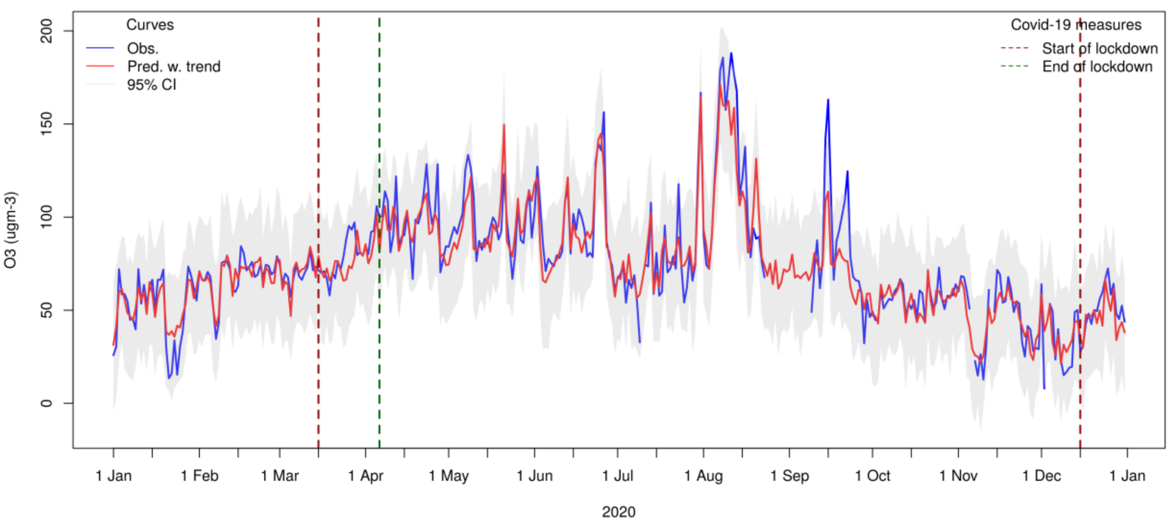



Mean of observed and GAM predicted O3 at 2 background stations in urban or suburban Luxembourg
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

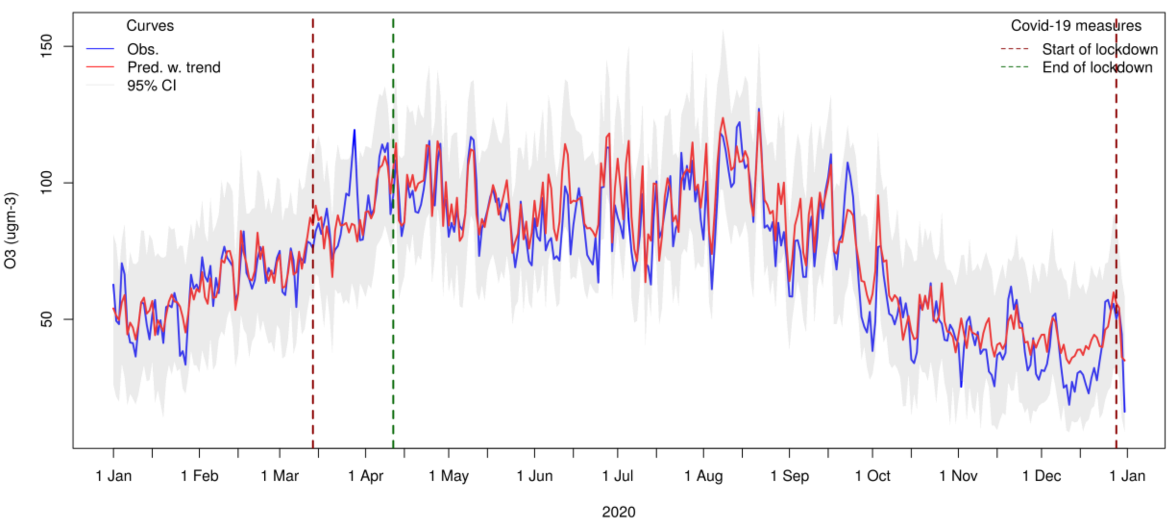
**Mean of observed and GAM predicted O3 at 1 background stations in urban or suburban Malta**



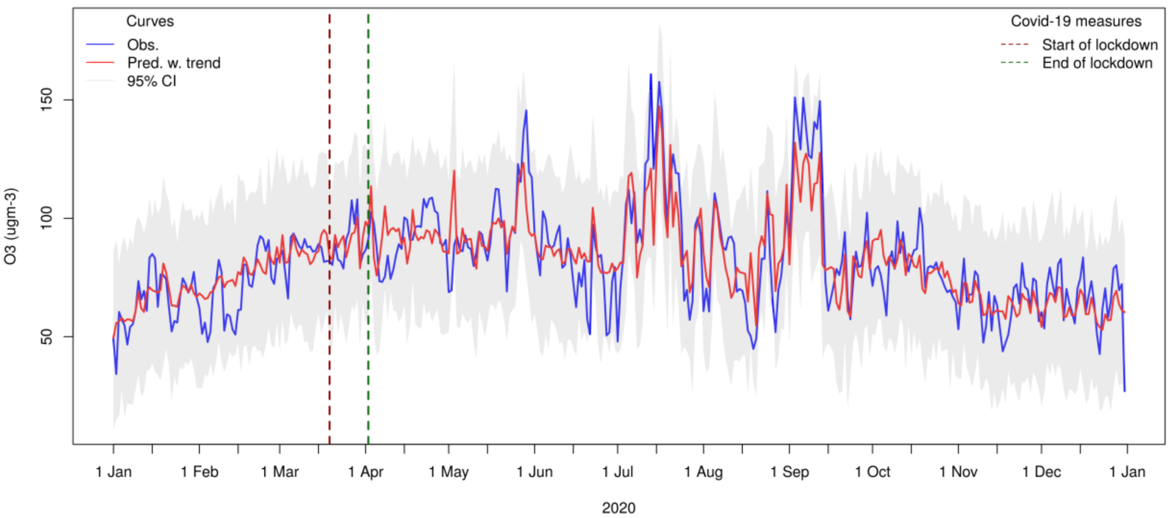

**Mean of observed and GAM predicted O3 at 9 background stations in urban or suburban Netherlands**



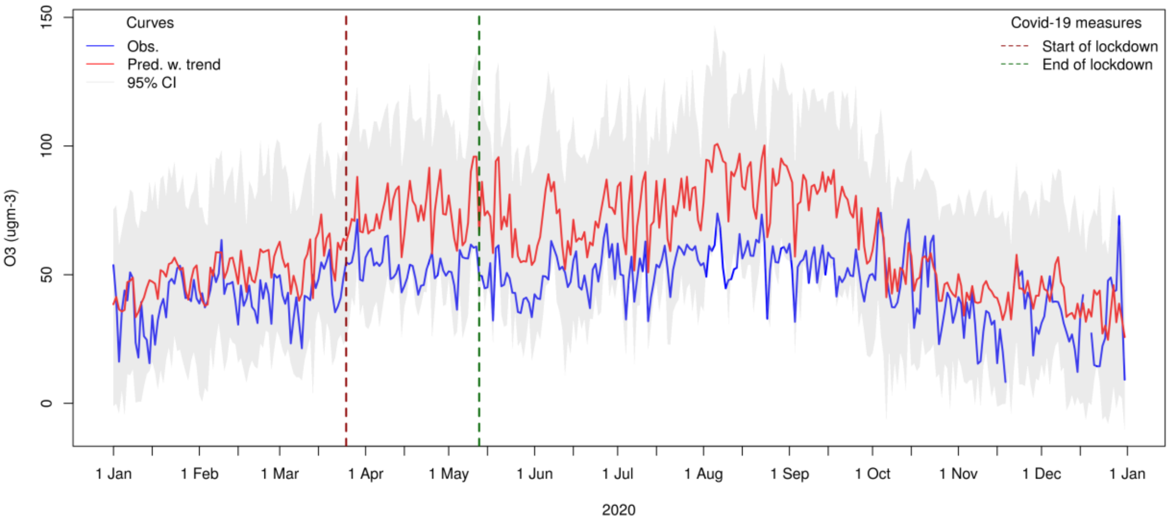

**Mean of observed and GAM predicted O3 at 42 background stations in urban or suburban Poland**



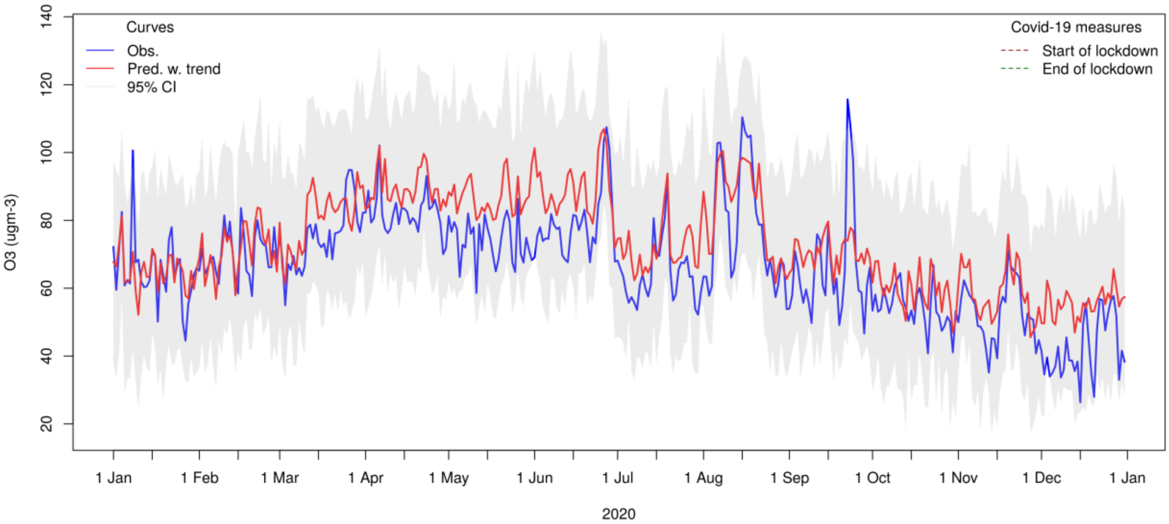
**Mean of observed and GAM predicted O3 at 12 background stations in urban or suburban Portugal**

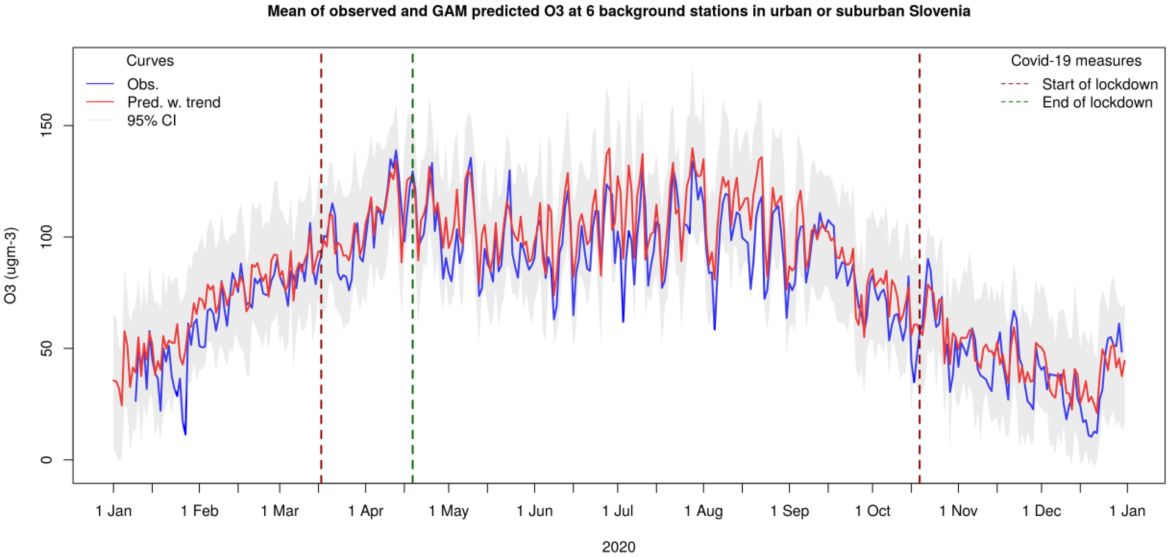



**Mean of observed and GAM predicted O3 at 1 background stations in urban or suburban Romania**




**Mean of observed and GAM predicted O3 at 10 background stations in urban or suburban Sweden**




Mean of observed and GAM predicted O3 at 6 background stations in urban or suburban Slovenia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

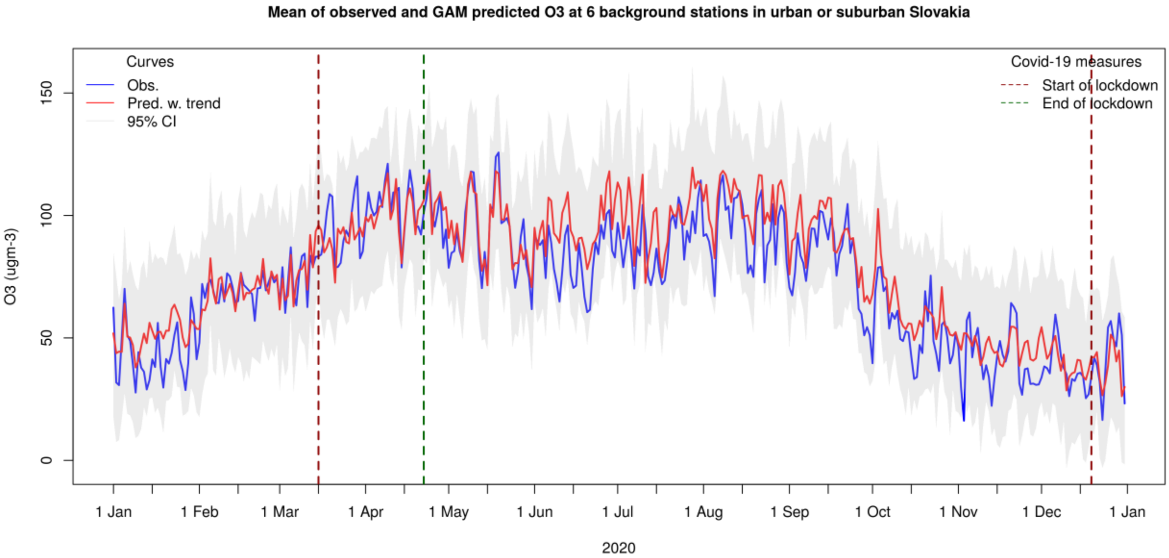
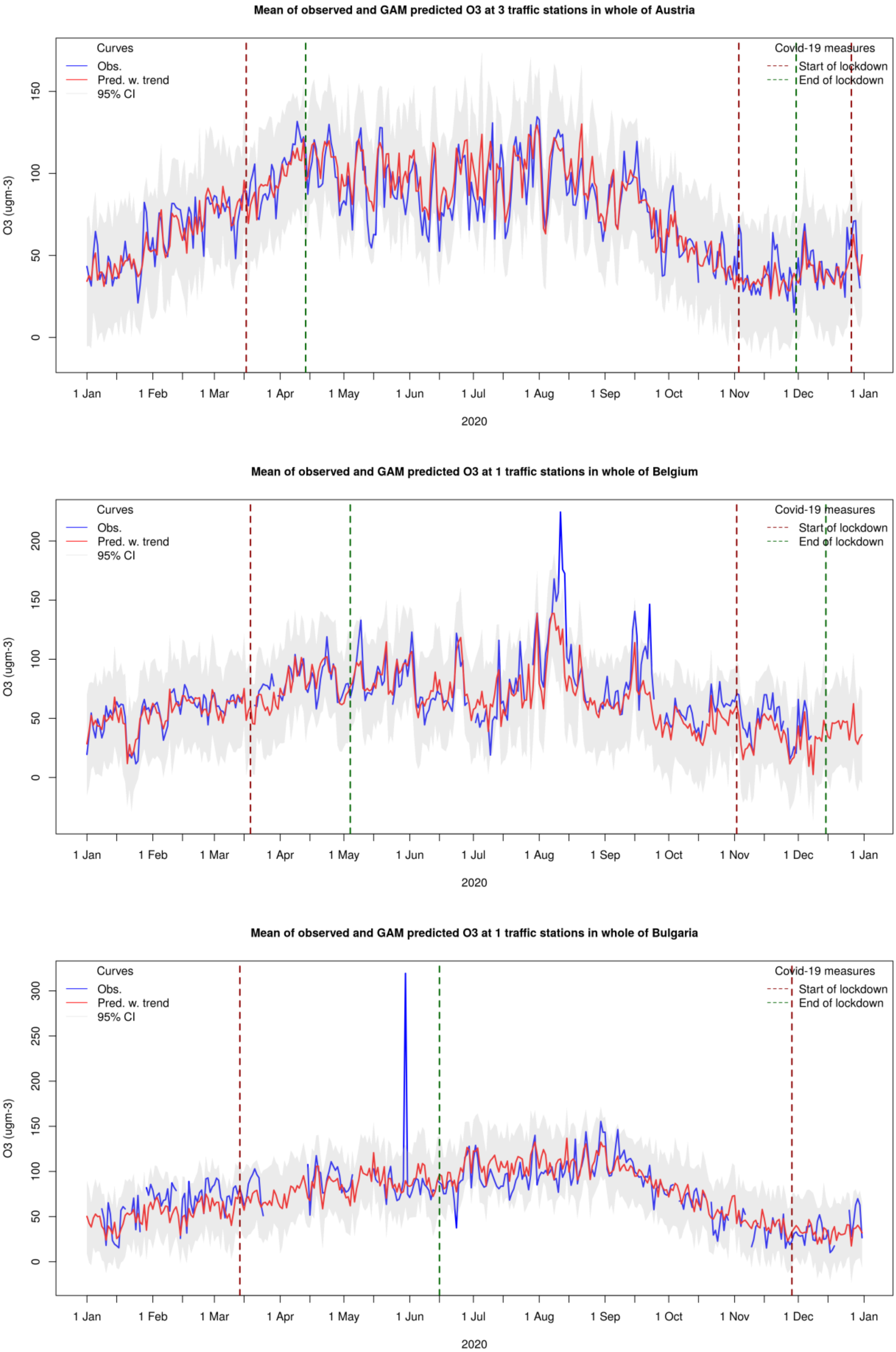
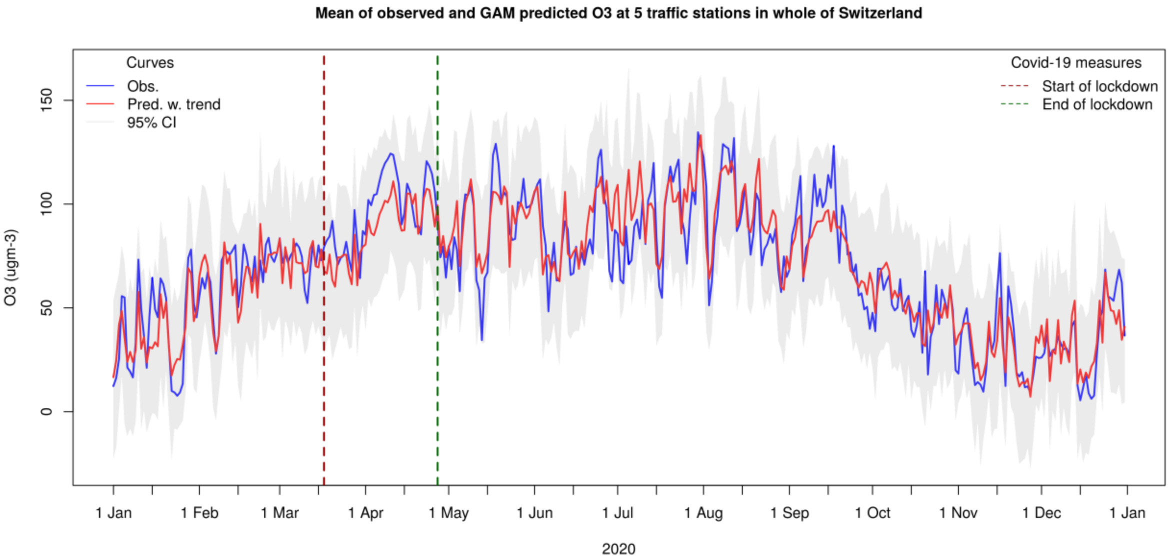
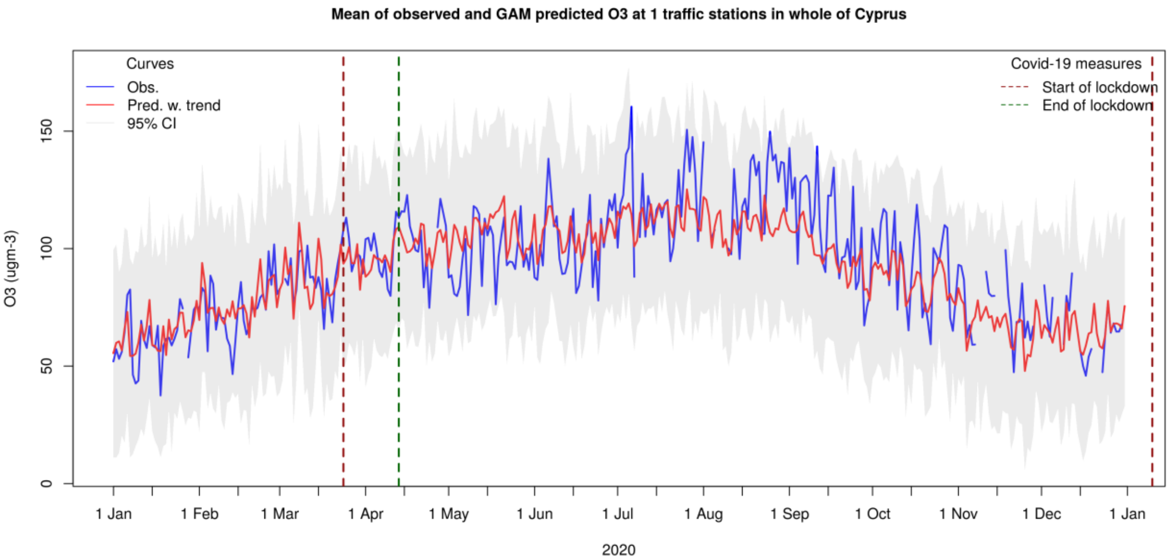
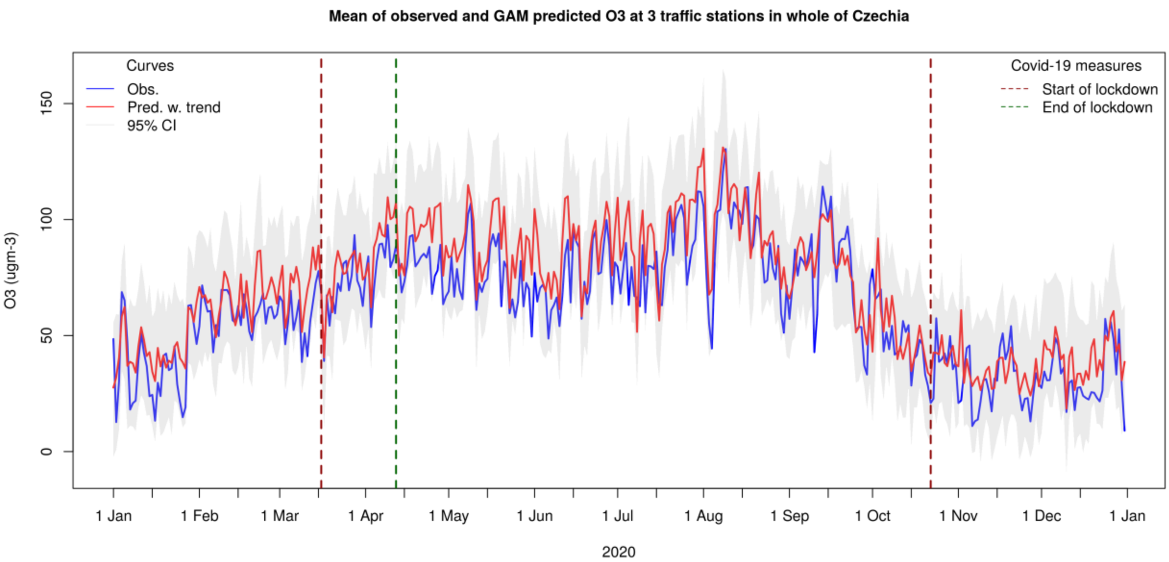

Mean of observed and GAM predicted O3 at 6 background stations in urban or suburban Slovakia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

*Figure A.15   $O_3$ traffic*

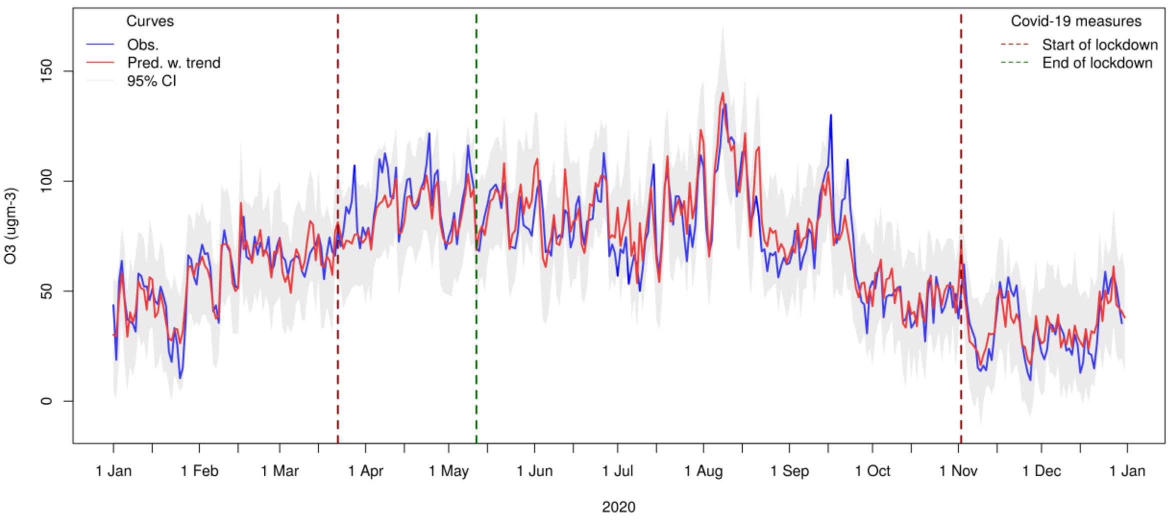



Mean of observed and GAM predicted O3 at 5 traffic stations in whole of Switzerland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

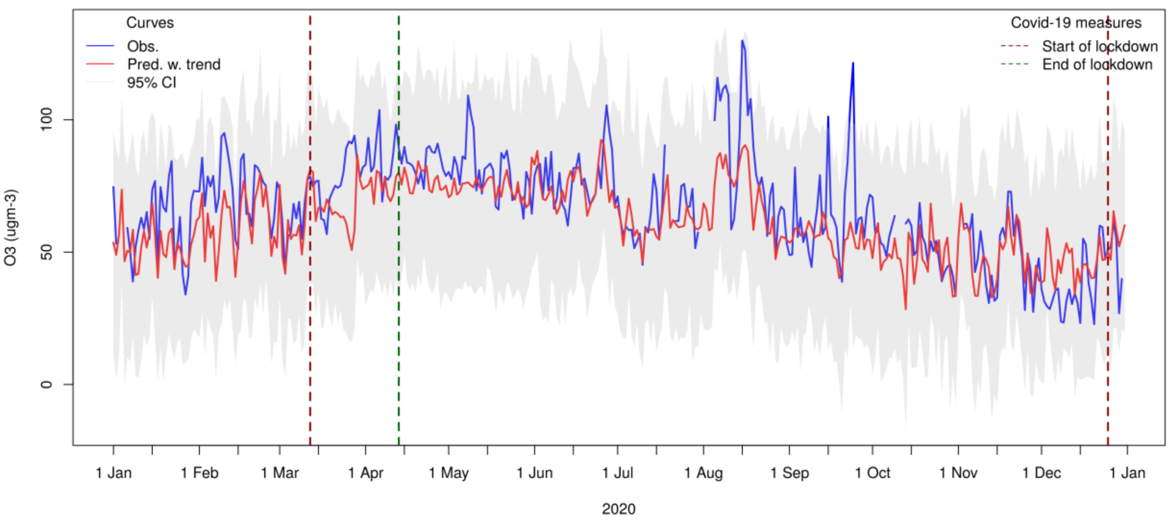

Mean of observed and GAM predicted O3 at 1 traffic stations in whole of Cyprus
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 3 traffic stations in whole of Czechia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

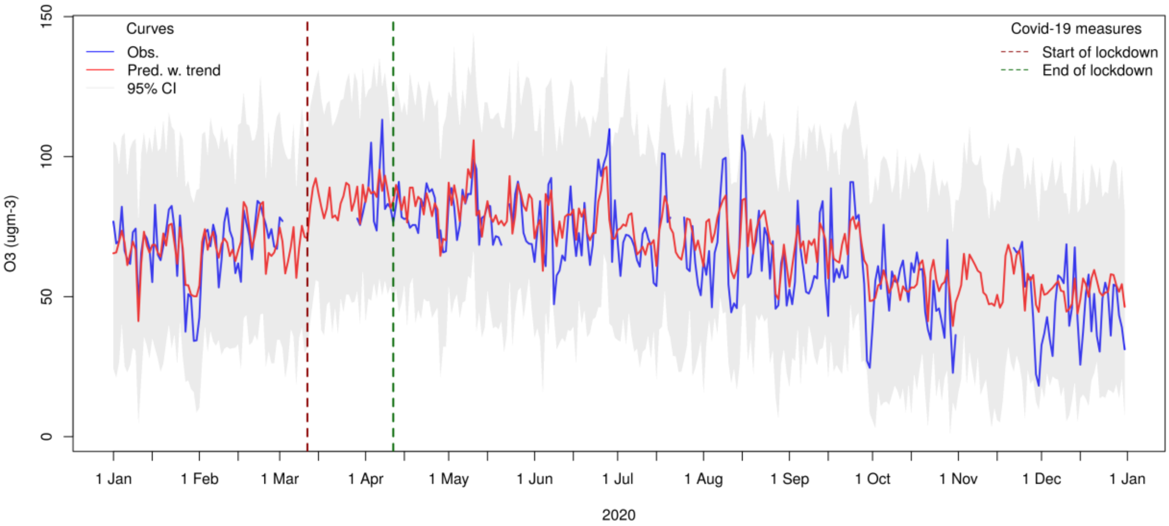
Mean of observed and GAM predicted O3 at 4 traffic stations in whole of Germany

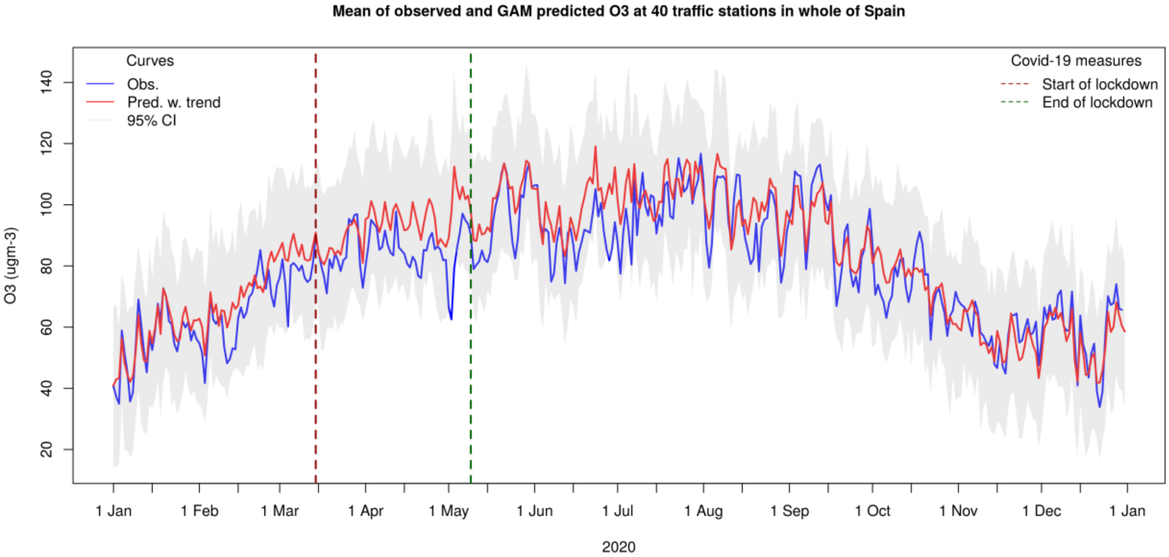



Mean of observed and GAM predicted O3 at 1 traffic stations in whole of Denmark

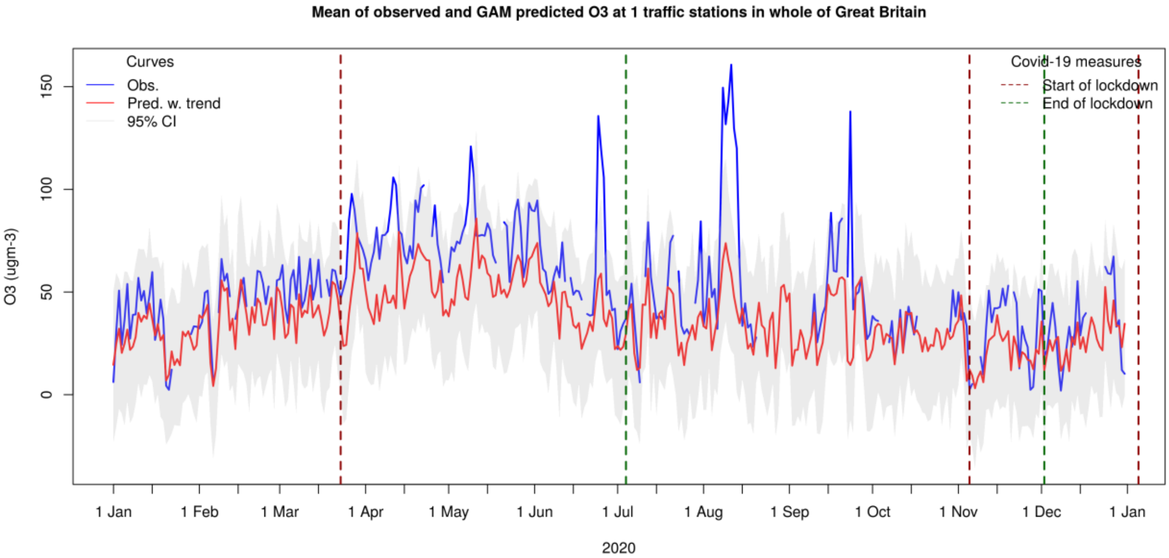



Mean of observed and GAM predicted O3 at 1 traffic stations in whole of Estonia

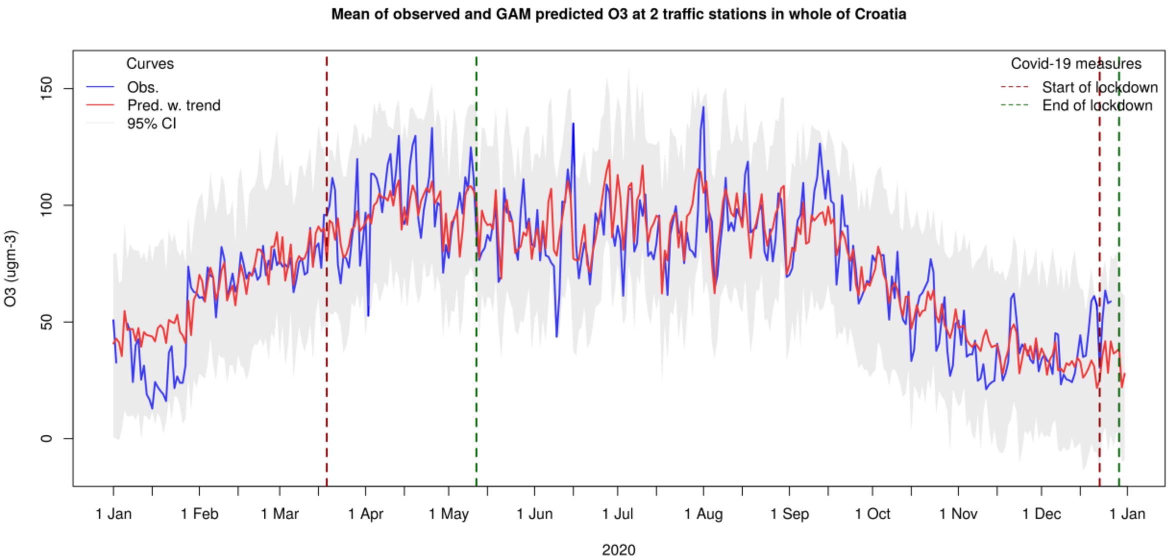




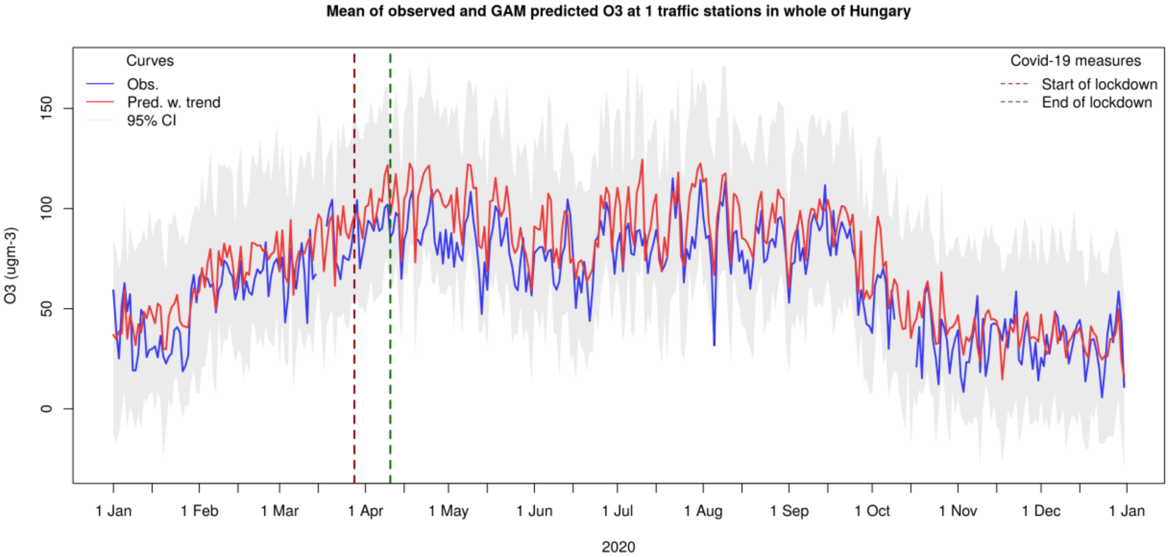
Mean of observed and GAM predicted O3 at 40 traffic stations in whole of Spain
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
20
40
60
80
100
120
140
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

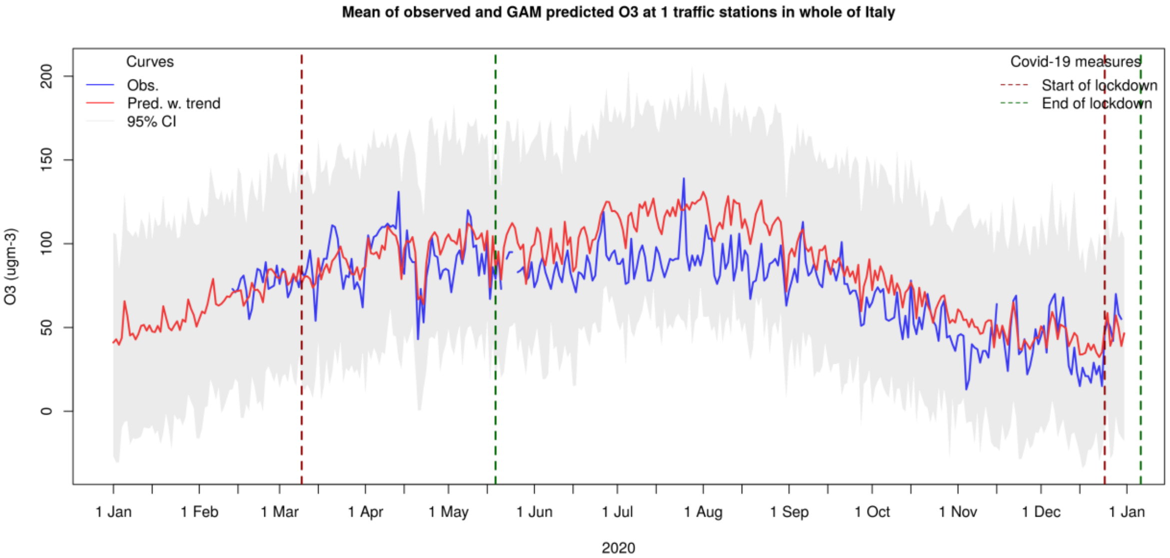



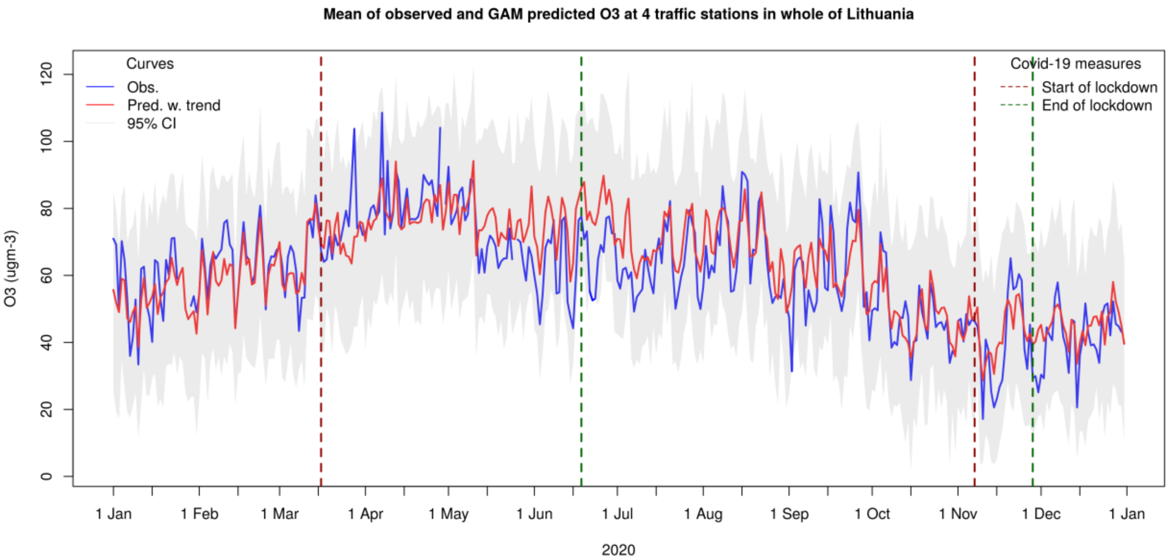
Mean of observed and GAM predicted O3 at 1 traffic stations in whole of Great Britain
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

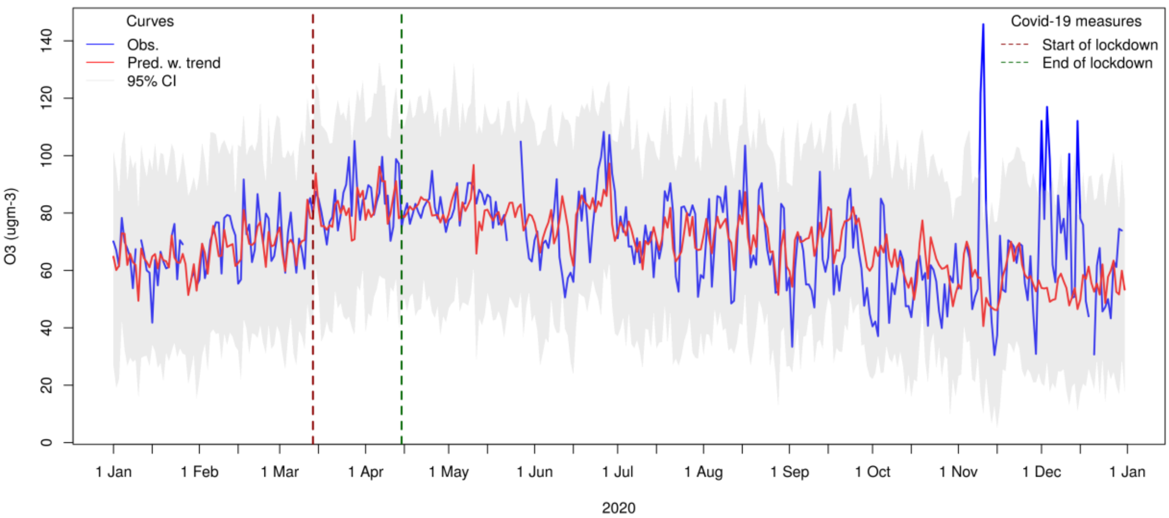
Mean of observed and GAM predicted O3 at 2 traffic stations in whole of Croatia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted O3 at 1 traffic stations in whole of Hungary
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
2020

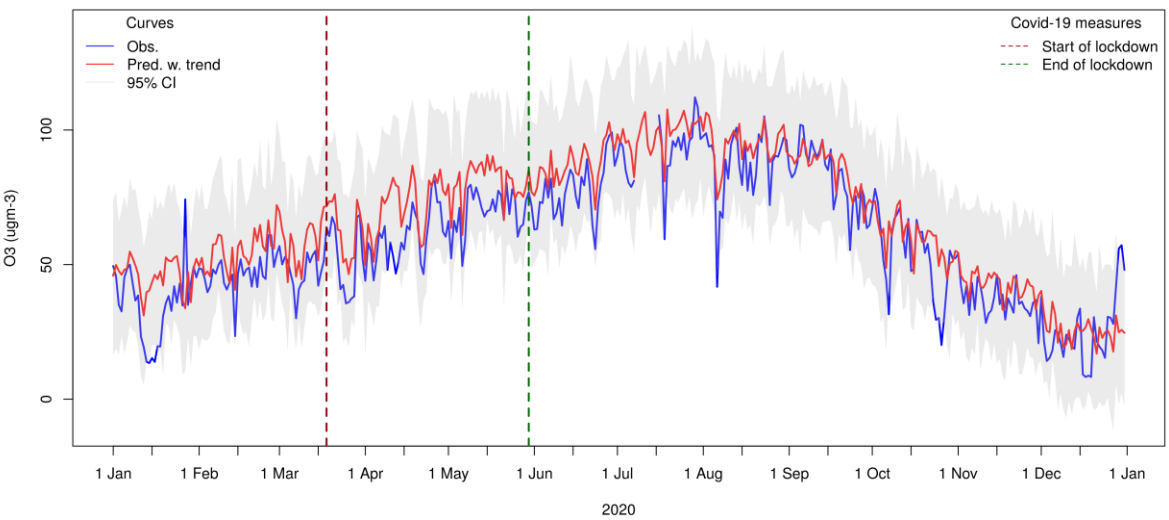

Mean of observed and GAM predicted O3 at 1 traffic stations in whole of Italy
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
2020


Mean of observed and GAM predicted O3 at 4 traffic stations in whole of Lithuania
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
2020

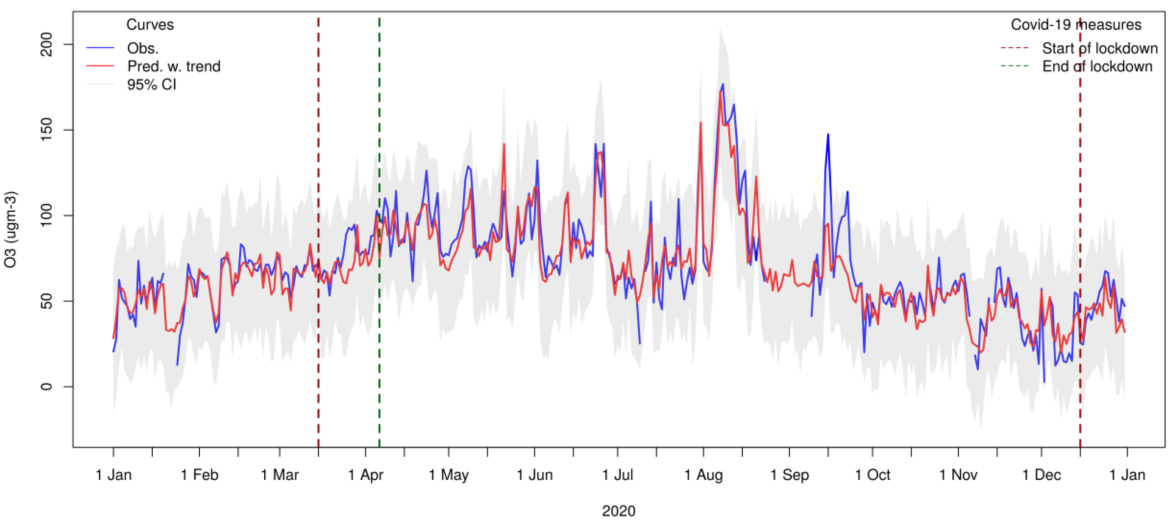
**Mean of observed and GAM predicted O3 at 1 traffic stations in whole of Latvia**

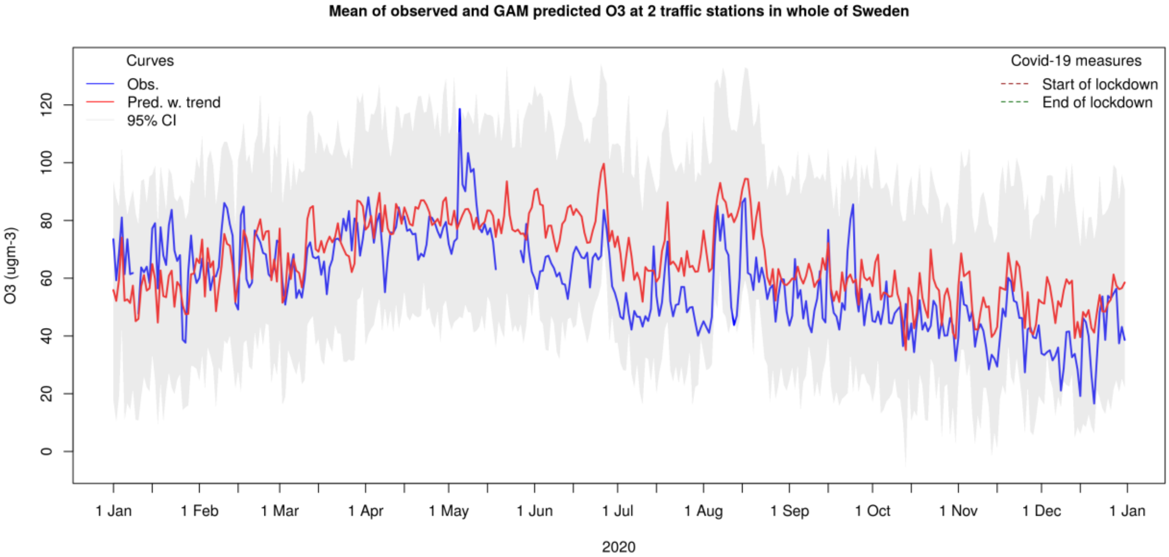



**Mean of observed and GAM predicted O3 at 3 traffic stations in whole of North Macedonia**




**Mean of observed and GAM predicted O3 at 3 traffic stations in whole of Netherlands**




Mean of observed and GAM predicted O3 at 2 traffic stations in whole of Sweden
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
20
40
60
80
100
120
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

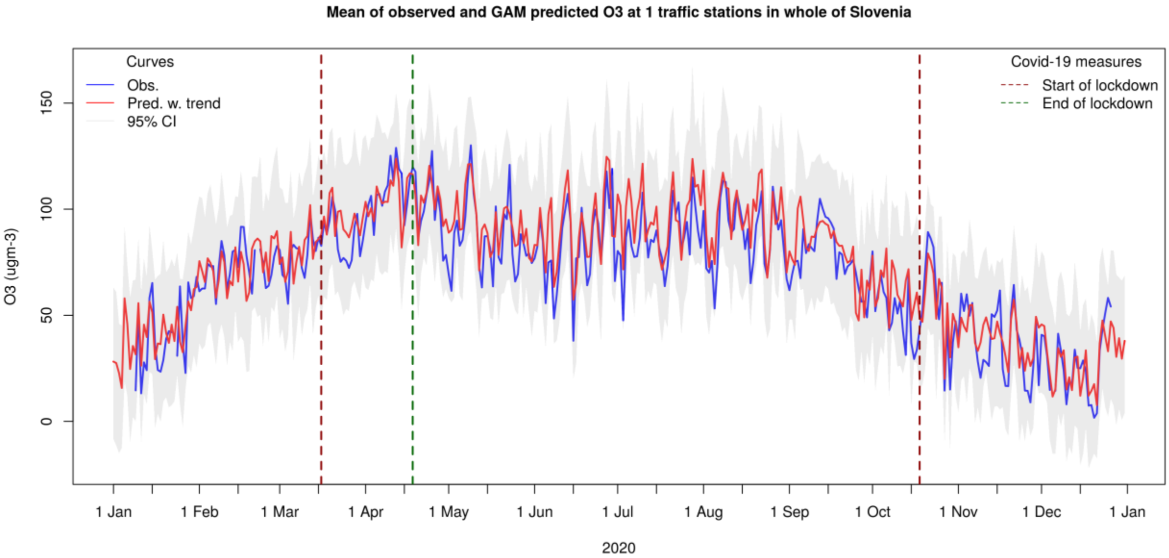
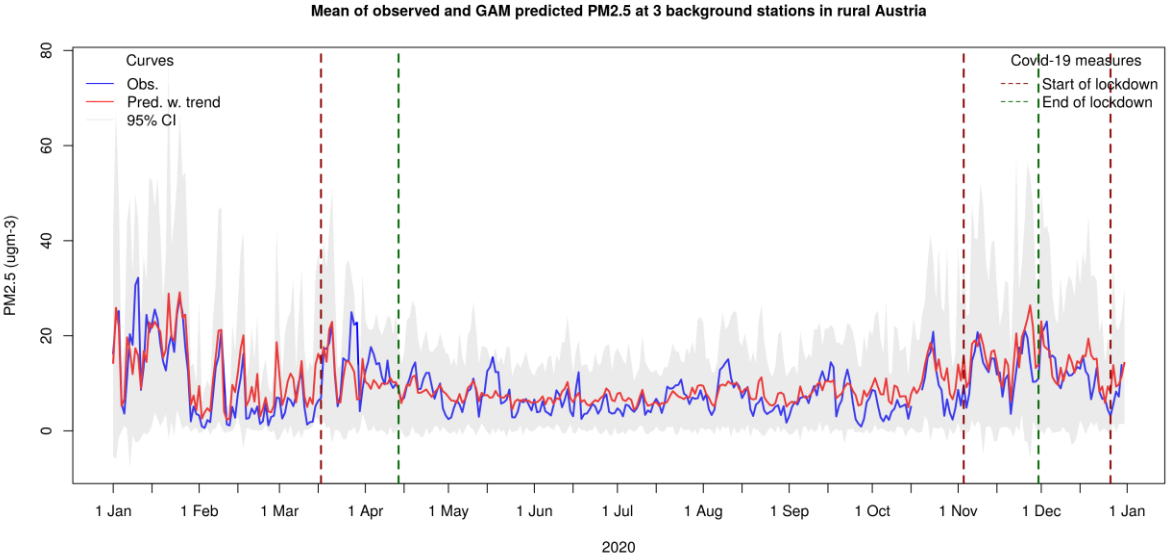
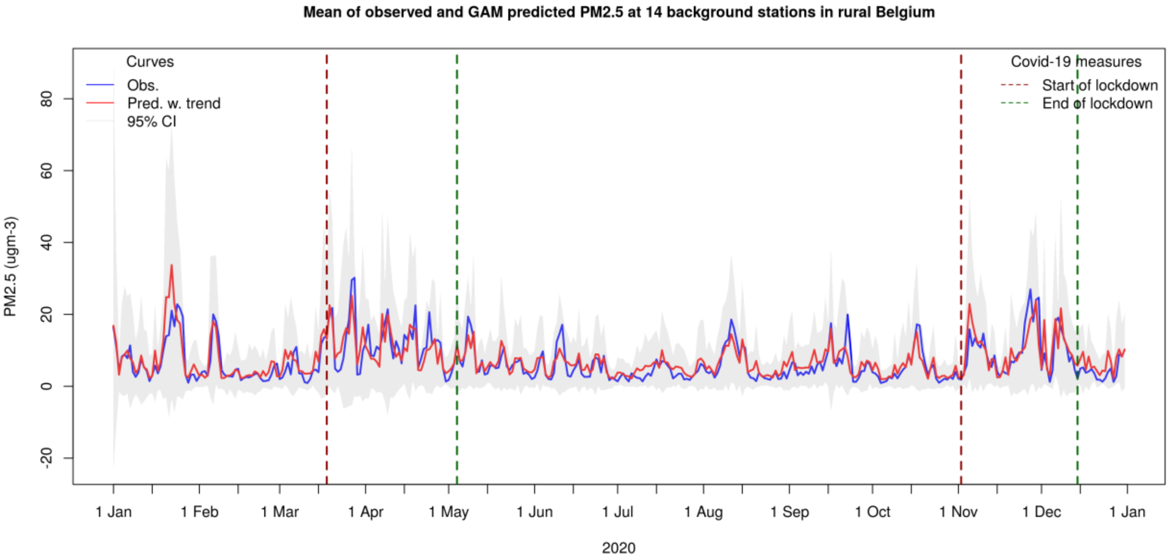
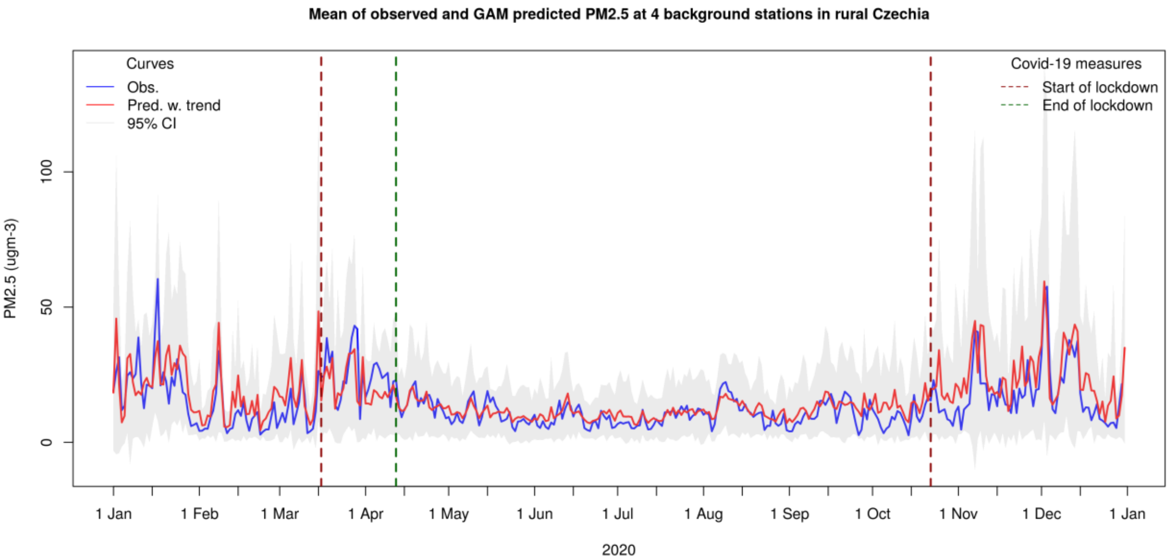
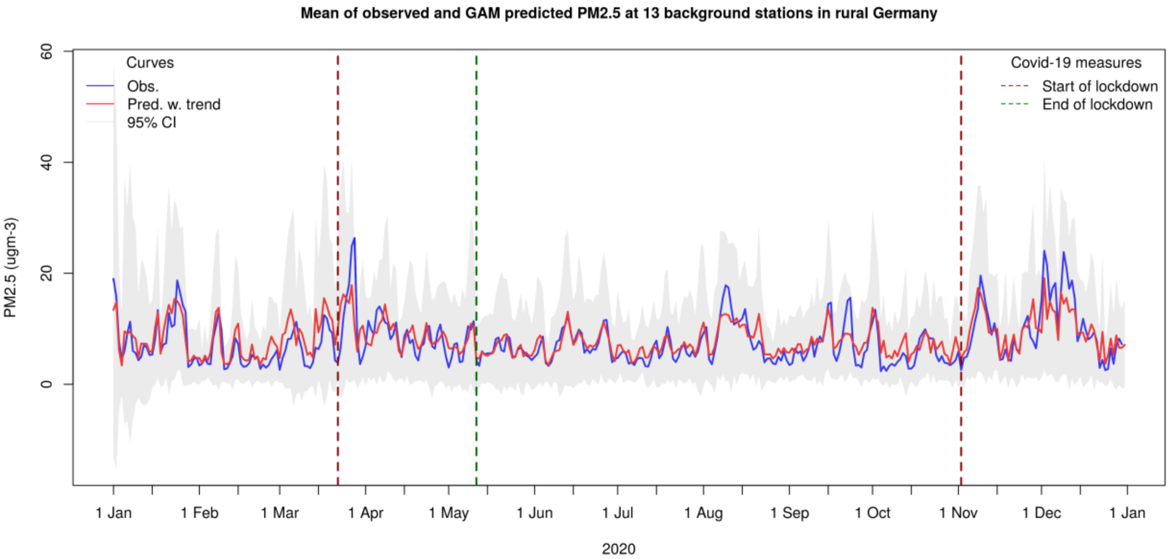

Mean of observed and GAM predicted O3 at 1 traffic stations in whole of Slovenia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
O3 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

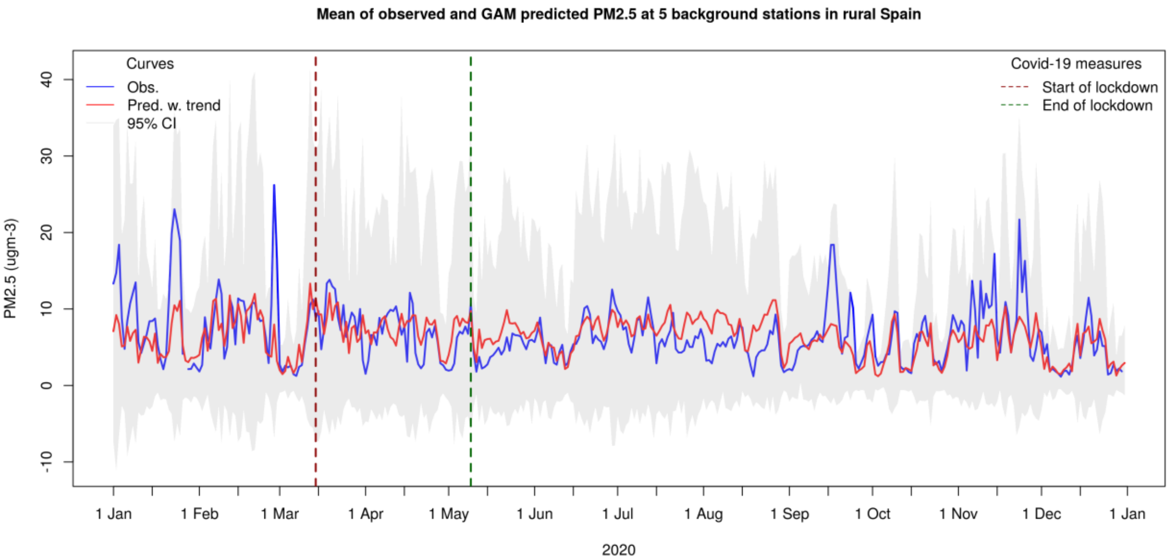
*Figure A.16 PM$_{2.5}$ rural*

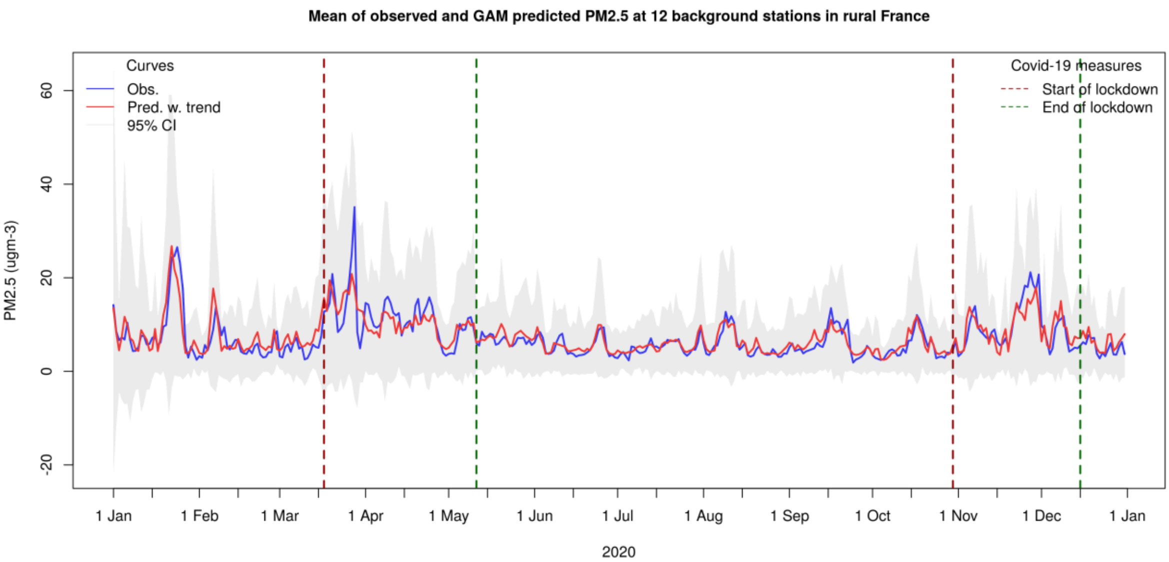


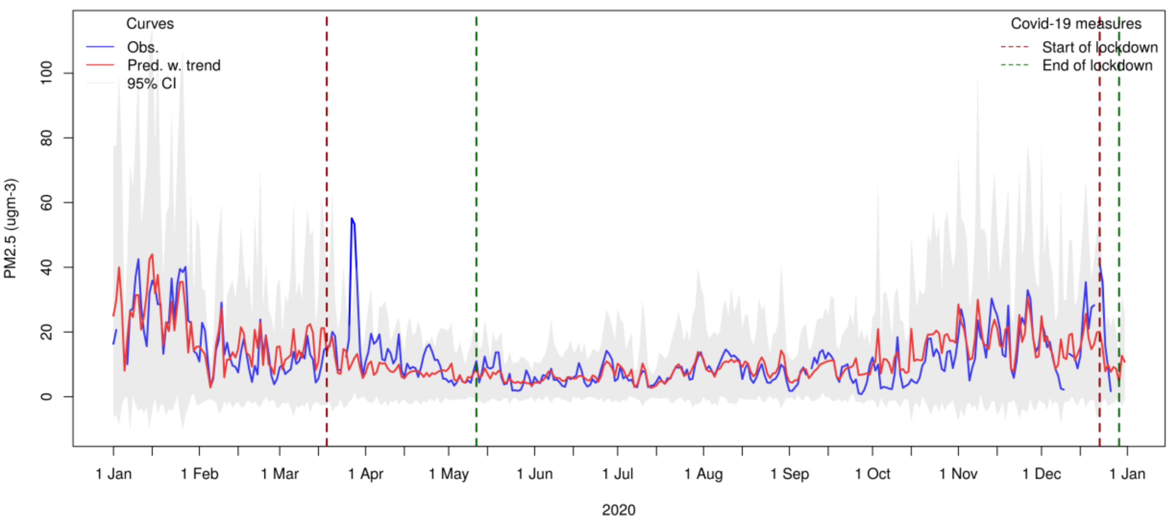




Mean of observed and GAM predicted PM2.5 at 13 background stations in rural Germany
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

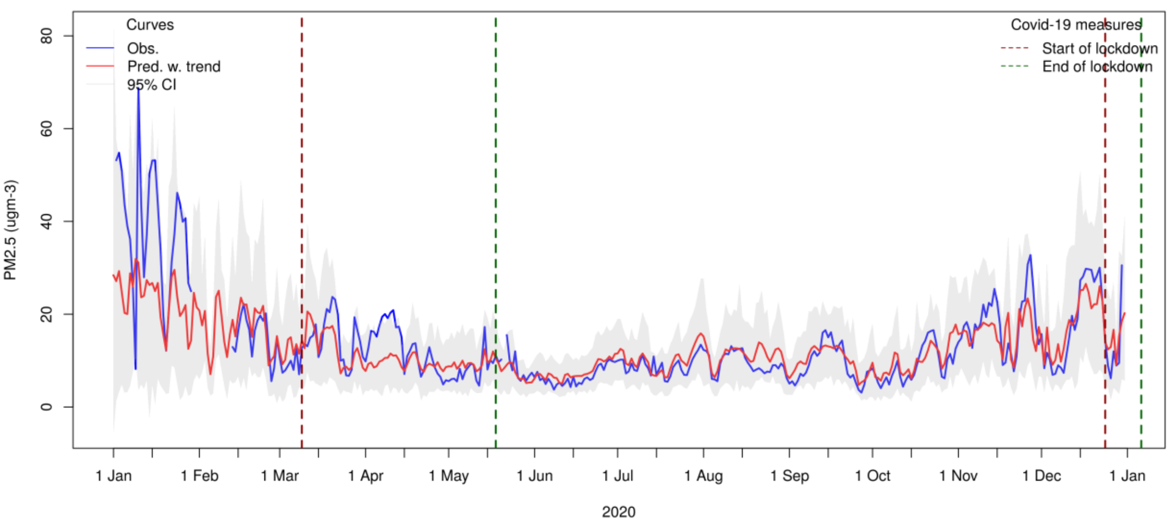

Mean of observed and GAM predicted PM2.5 at 5 background stations in rural Spain
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted PM2.5 at 12 background stations in rural France
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

**Mean of observed and GAM predicted PM2.5 at 2 background stations in rural Croatia**




**Mean of observed and GAM predicted PM2.5 at 7 background stations in rural Italy**




**Mean of observed and GAM predicted PM2.5 at 1 background stations in rural Luxembourg**

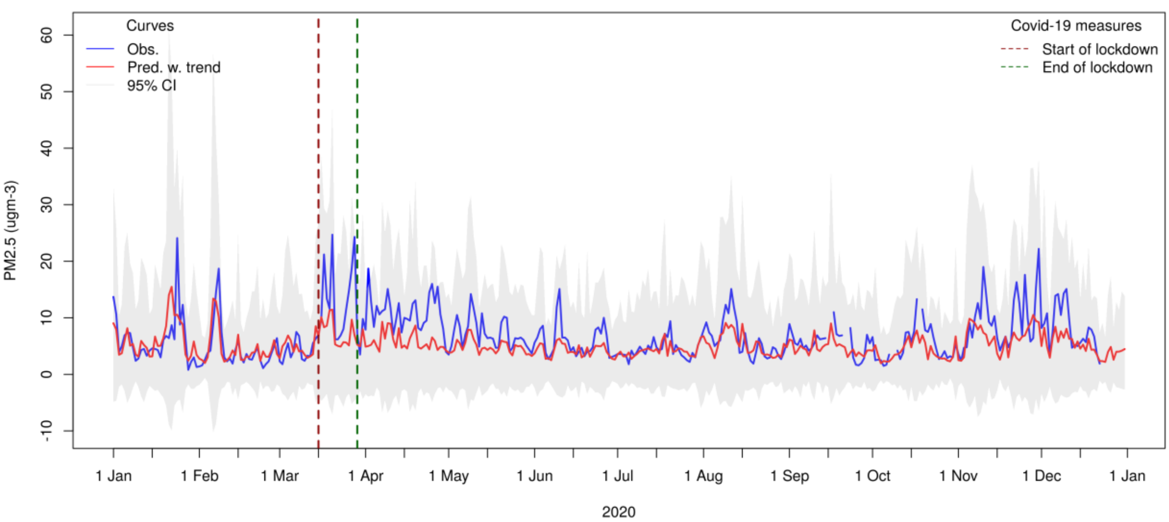
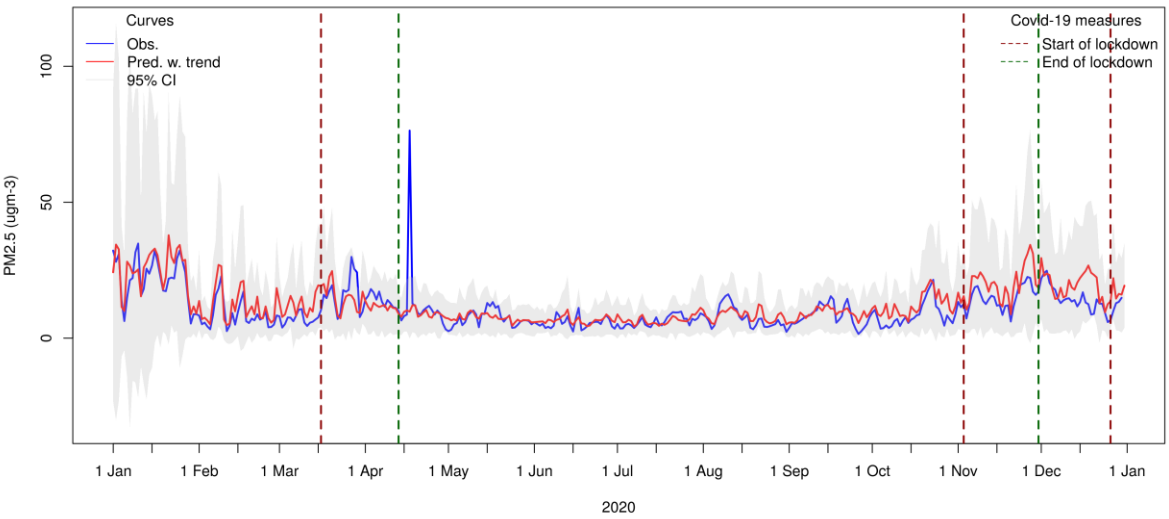
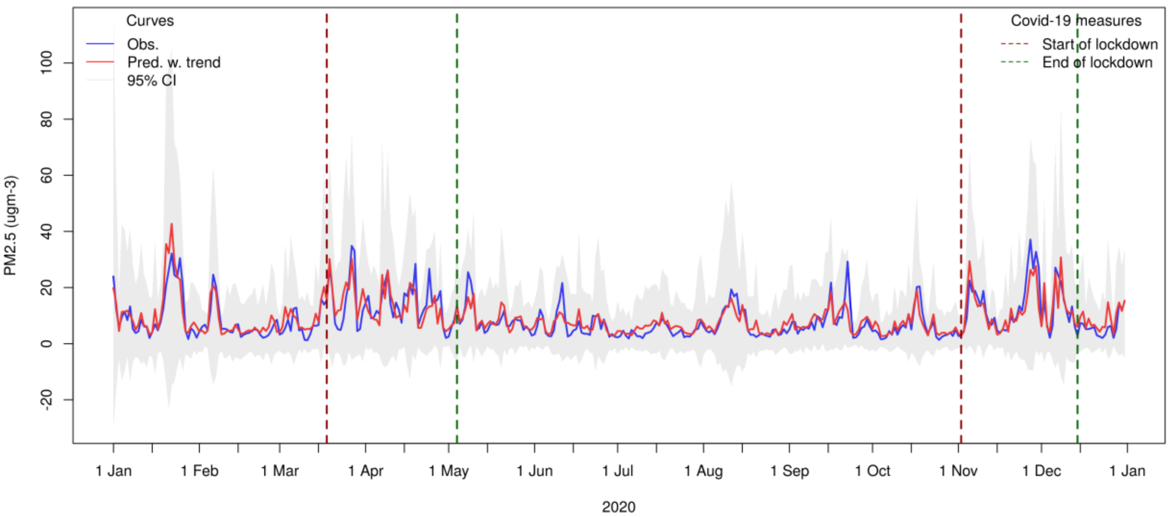


*Figure A.17 PM2.5 suburban*

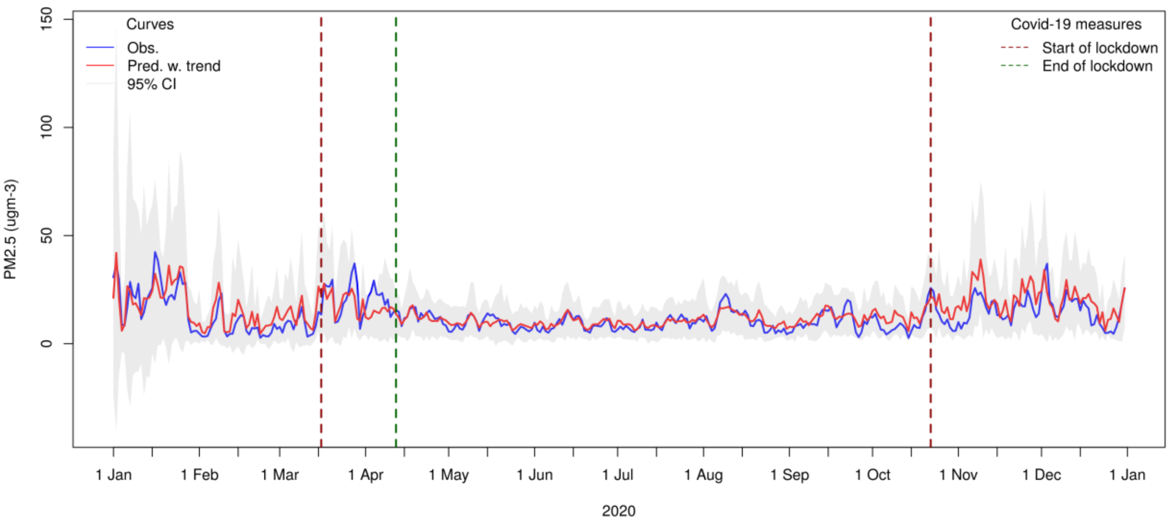
Mean of observed and GAM predicted PM2.5 at 15 background stations in urban or suburban Austria



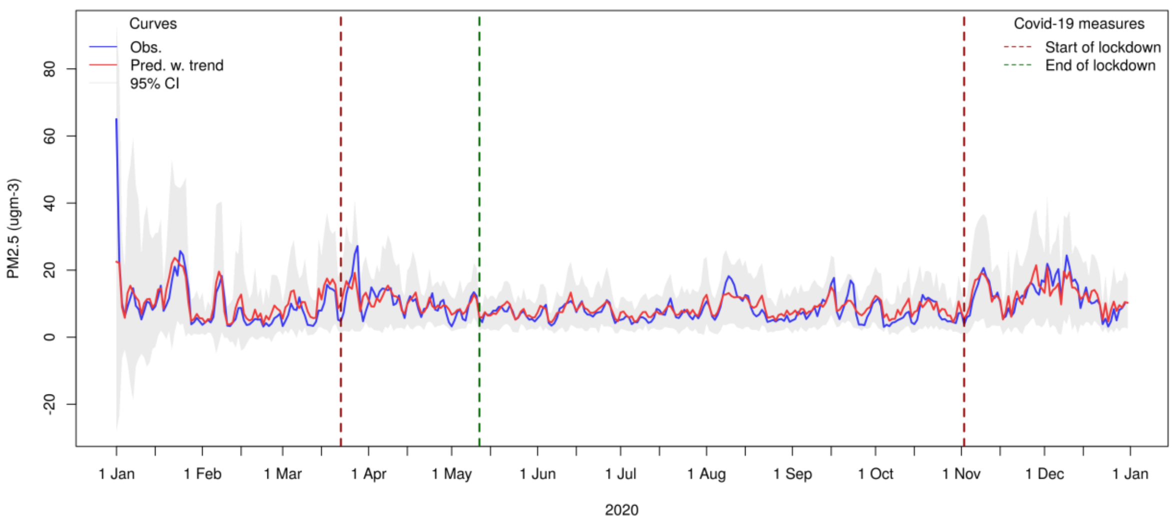

Mean of observed and GAM predicted PM2.5 at 20 background stations in urban or suburban Belgium



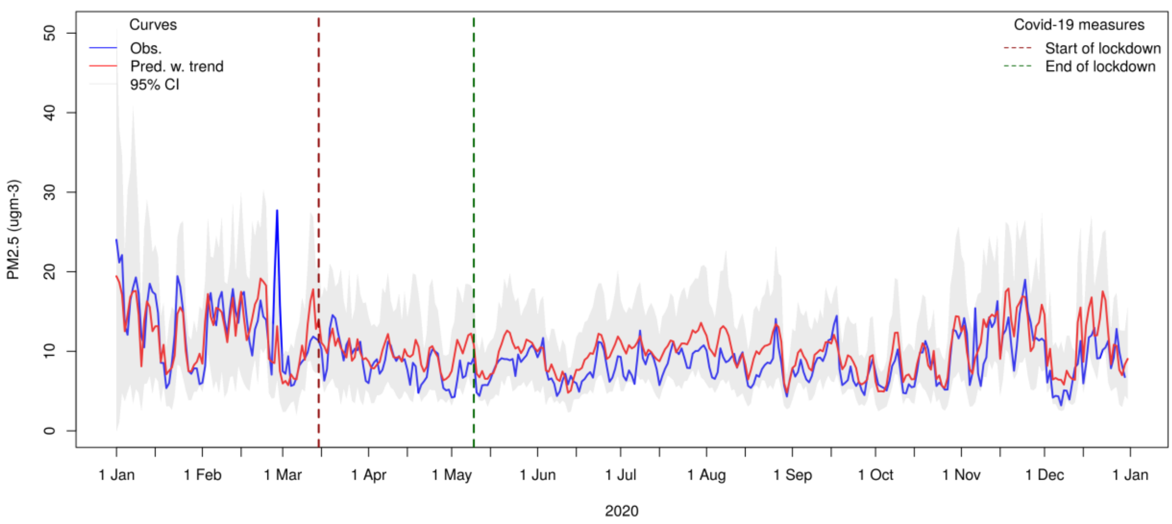

Mean of observed and GAM predicted PM2.5 at 18 background stations in urban or suburban Czechia



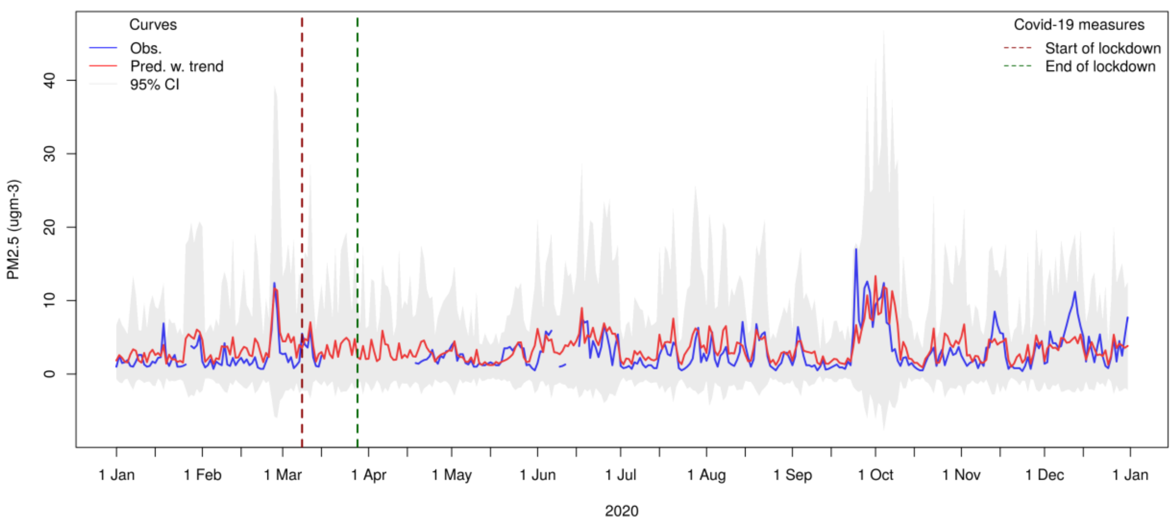
**Mean of observed and GAM predicted PM2.5 at 60 background stations in urban or suburban Germany**



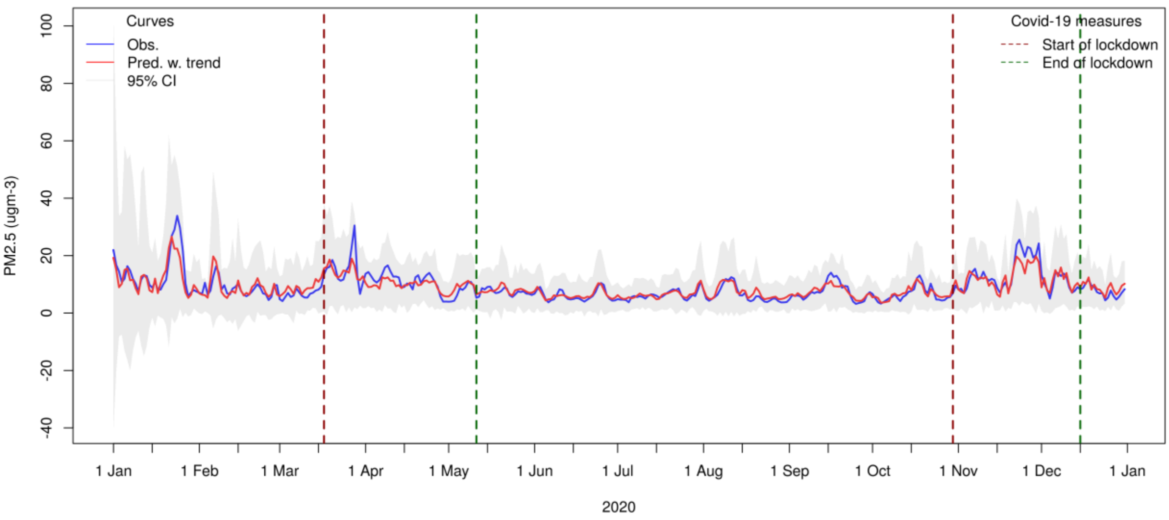

**Mean of observed and GAM predicted PM2.5 at 14 background stations in urban or suburban Spain**



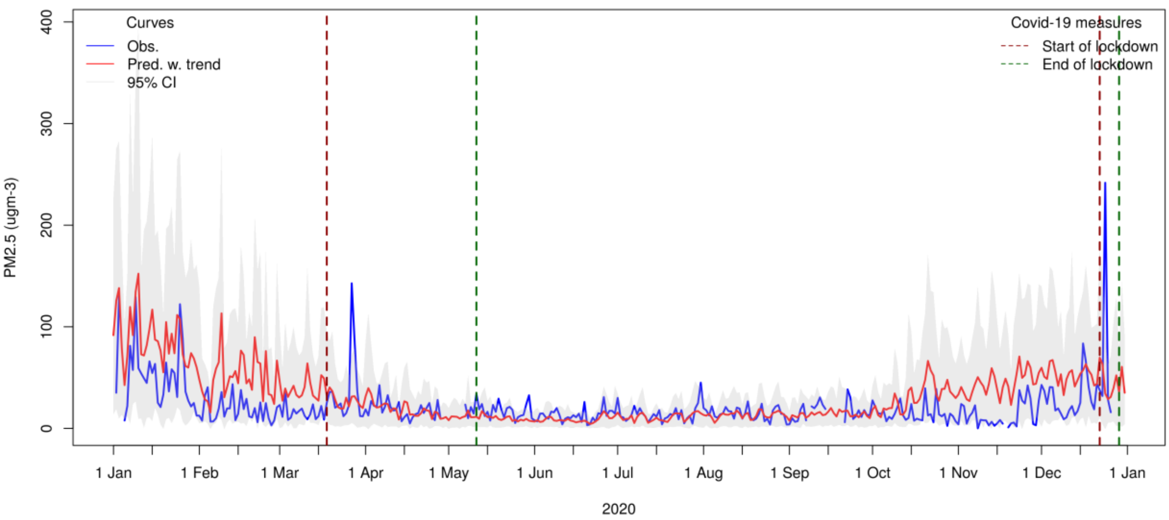

**Mean of observed and GAM predicted PM2.5 at 1 background stations in urban or suburban Finland**



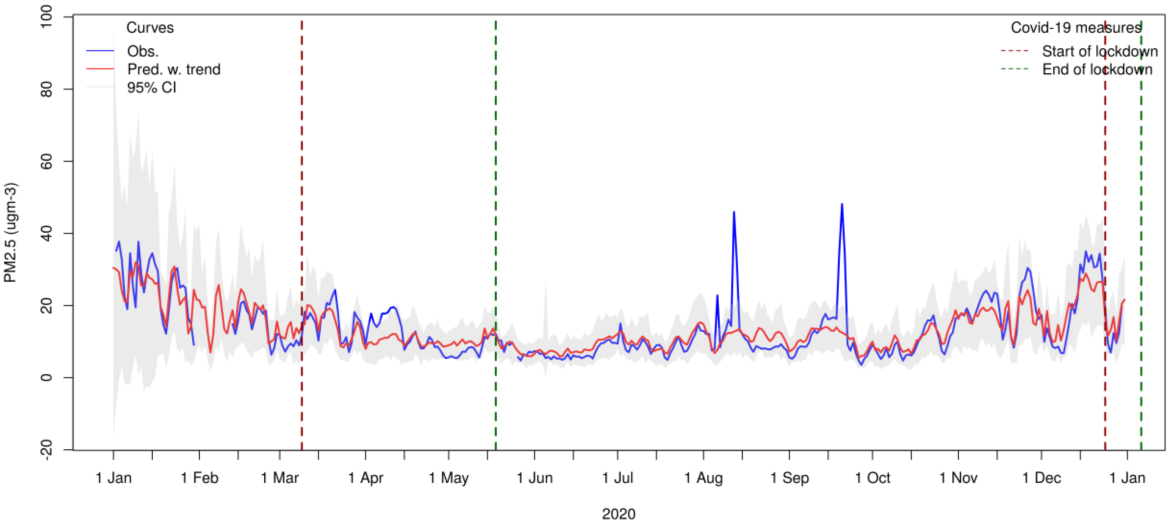
**Mean of observed and GAM predicted PM2.5 at 49 background stations in urban or suburban France**



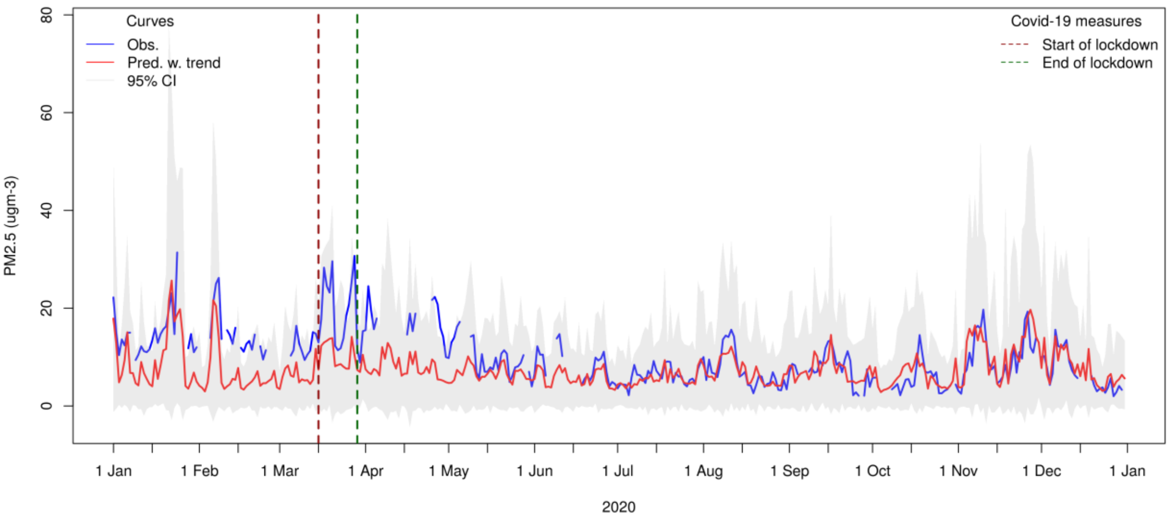

**Mean of observed and GAM predicted PM2.5 at 1 background stations in urban or suburban Croatia**



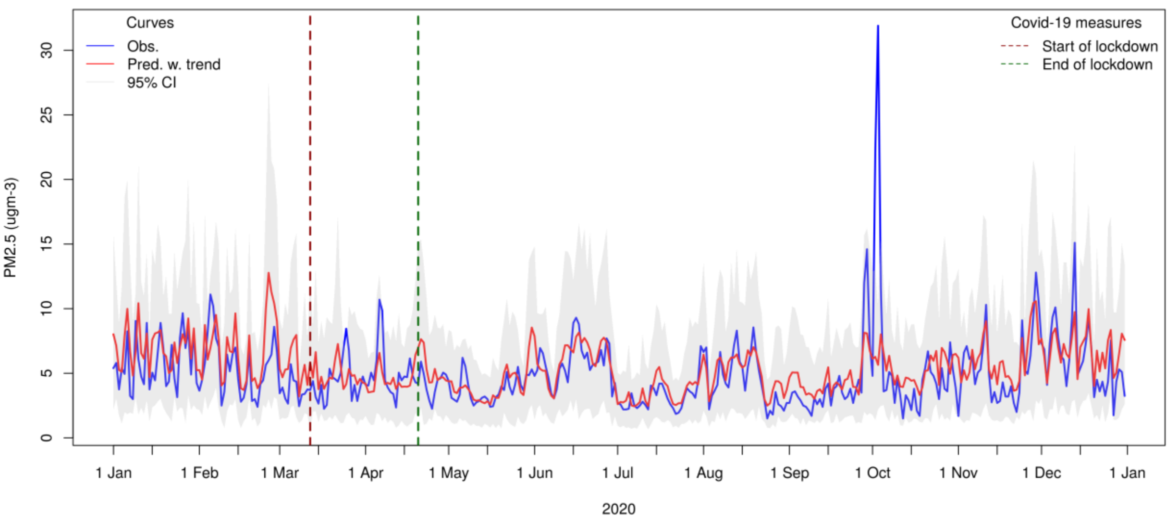

**Mean of observed and GAM predicted PM2.5 at 32 background stations in urban or suburban Italy**



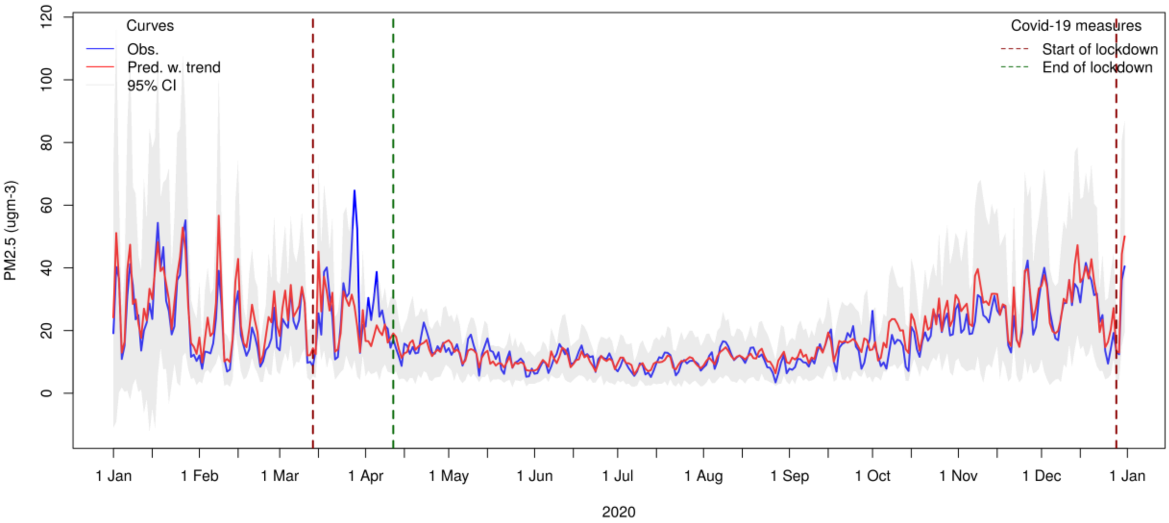
**Mean of observed and GAM predicted PM2.5 at 1 background stations in urban or suburban Luxembourg**

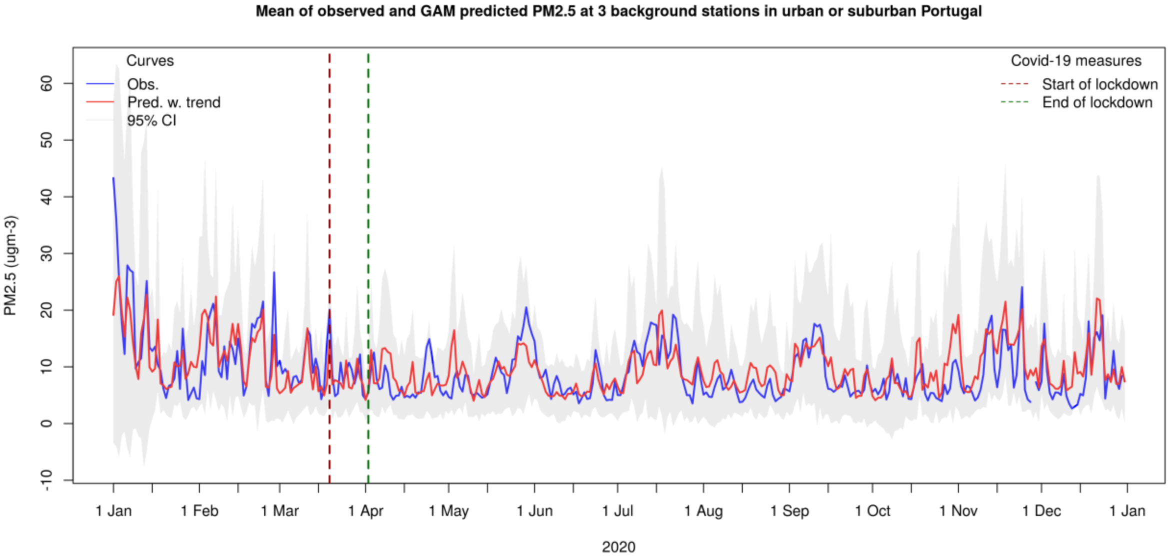



**Mean of observed and GAM predicted PM2.5 at 2 background stations in urban or suburban Norway**

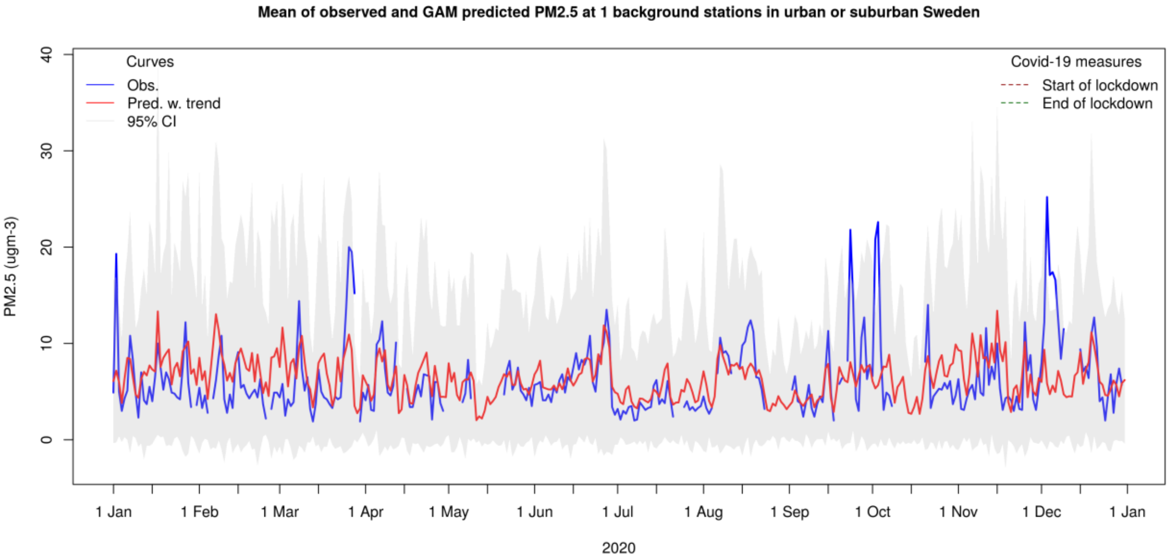



**Mean of observed and GAM predicted PM2.5 at 13 background stations in urban or suburban Poland**



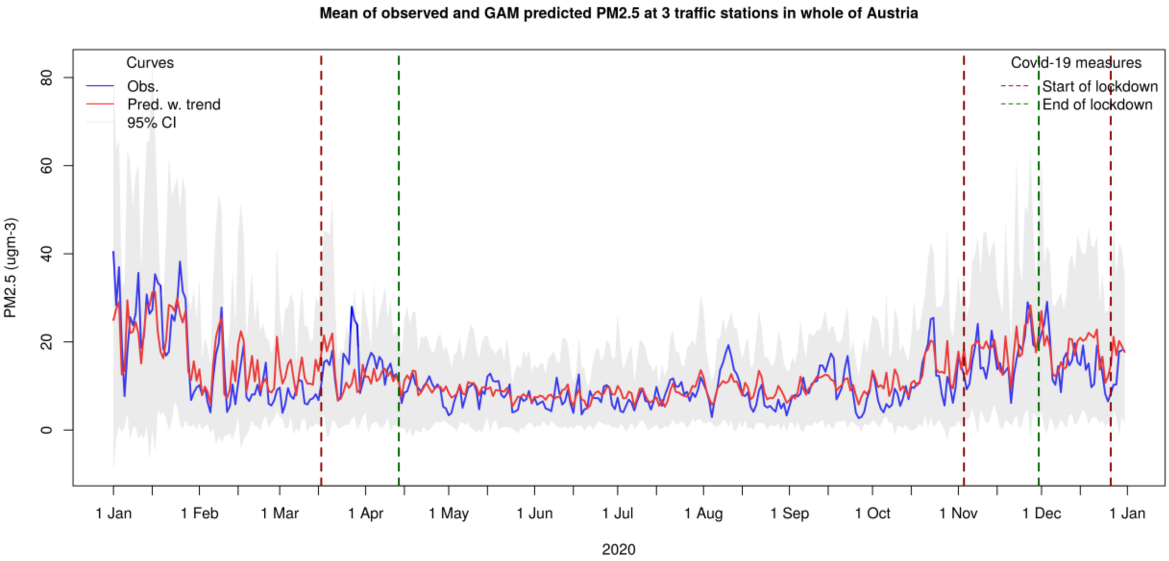


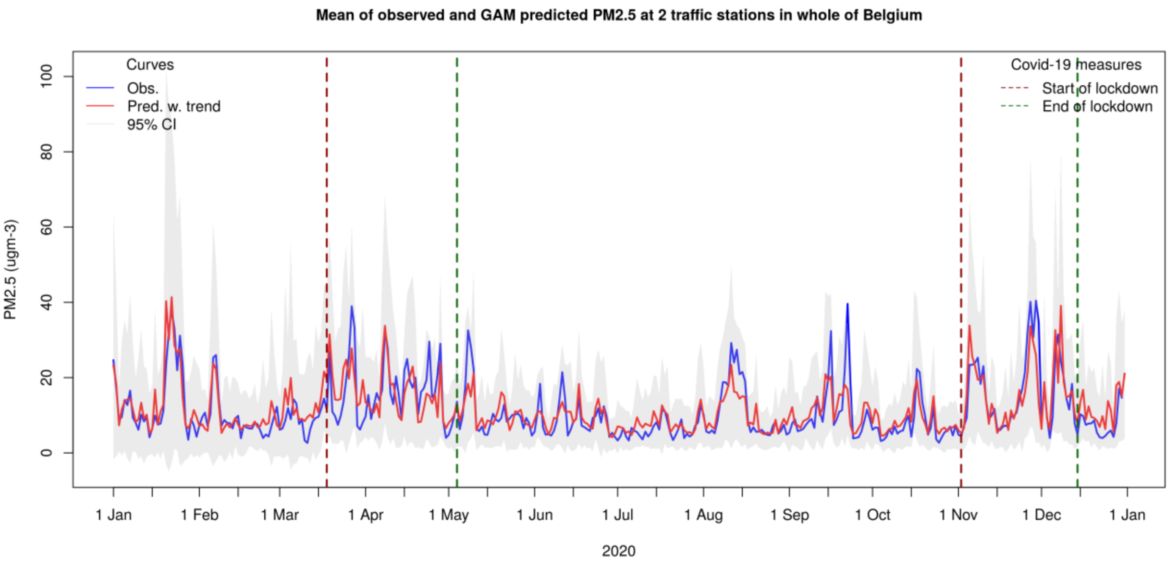
Mean of observed and GAM predicted PM2.5 at 3 background stations in urban or suburban Portugal
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
-10
0
10
20
30
40
50
60
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

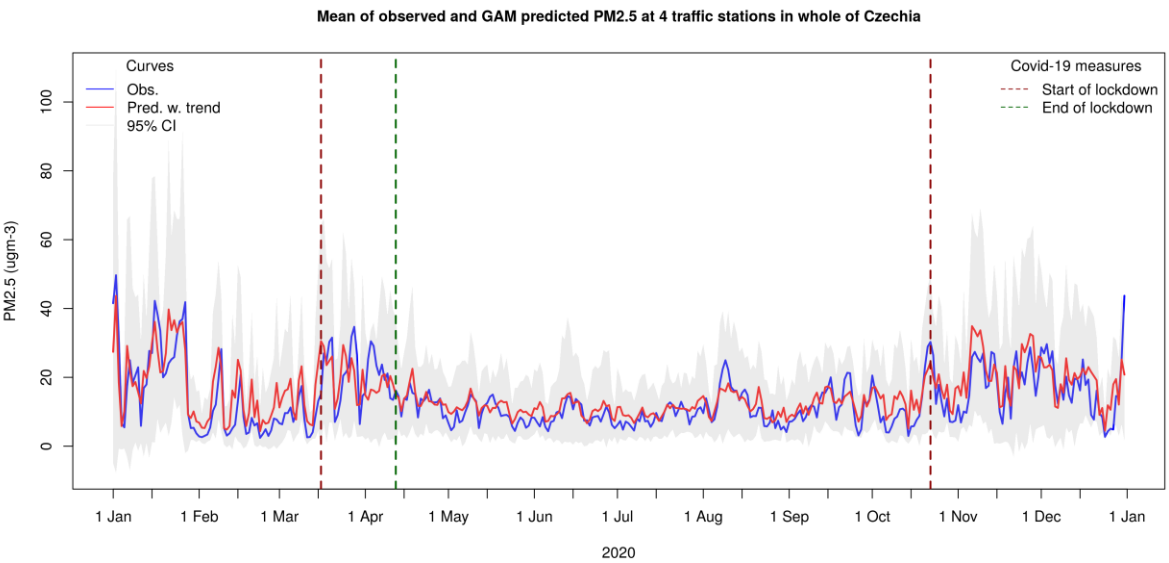



Mean of observed and GAM predicted PM2.5 at 1 background stations in urban or suburban Sweden
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
0
10
20
30
40
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

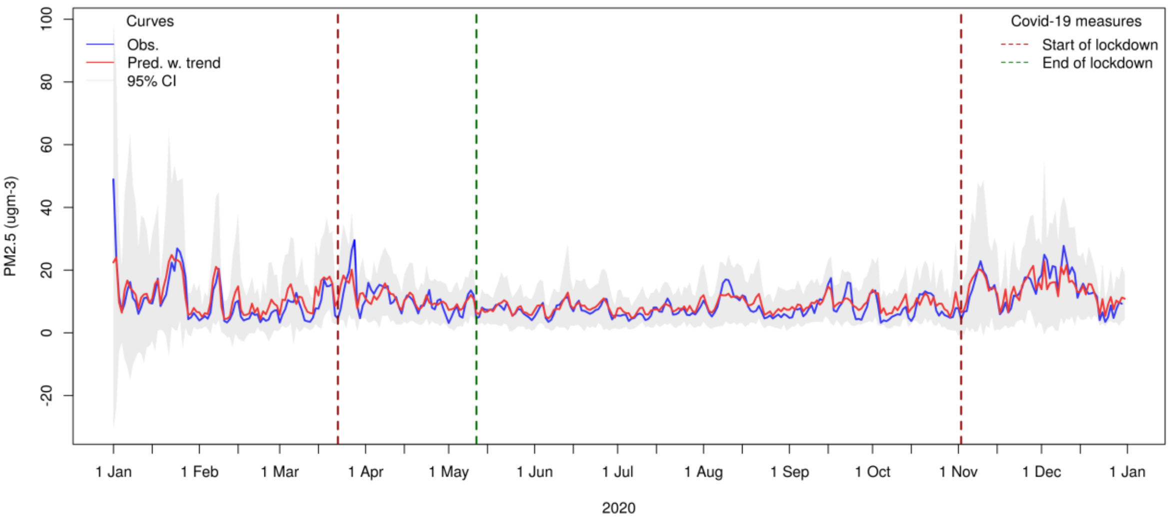
*Figure A.18 PM$_{2.5}$ traffic*



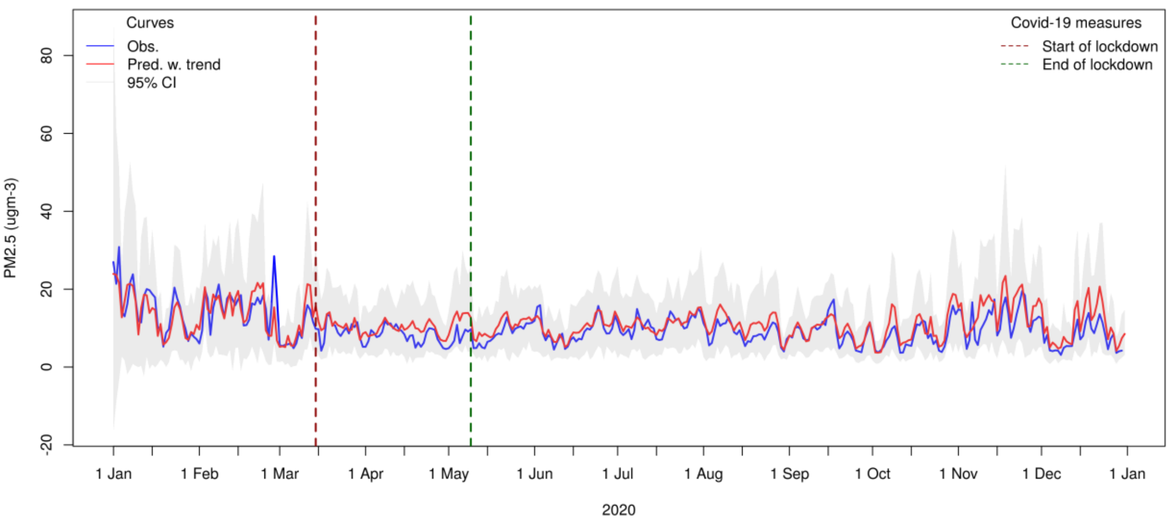



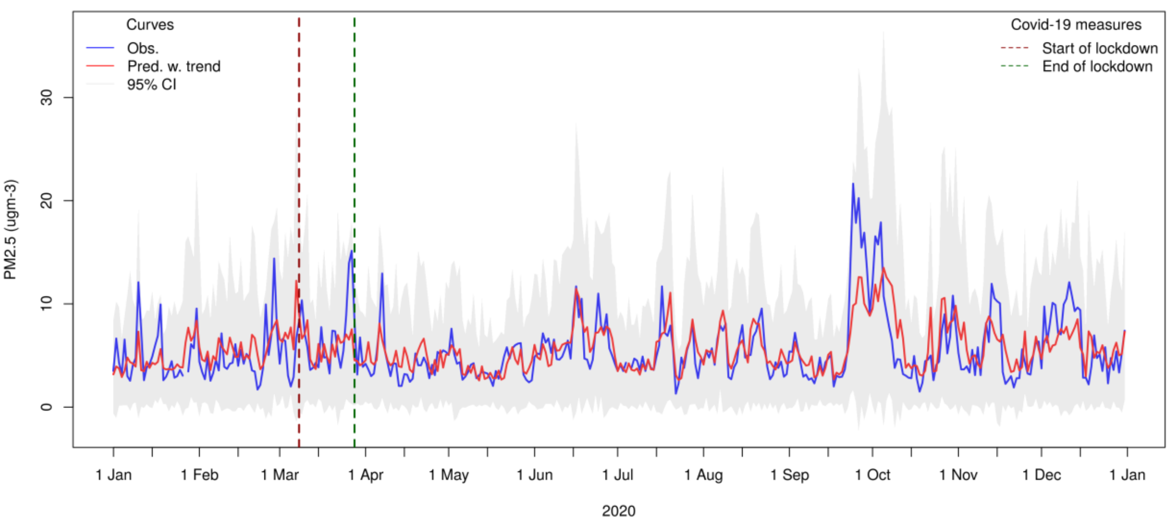
**Mean of observed and GAM predicted PM2.5 at 46 traffic stations in whole of Germany**

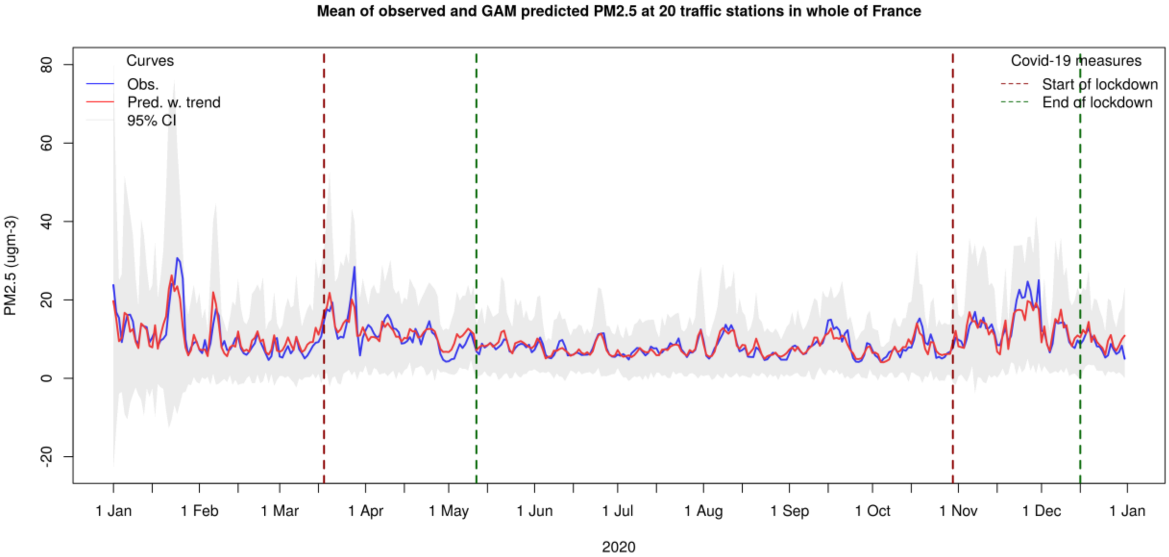



**Mean of observed and GAM predicted PM2.5 at 14 traffic stations in whole of Spain**

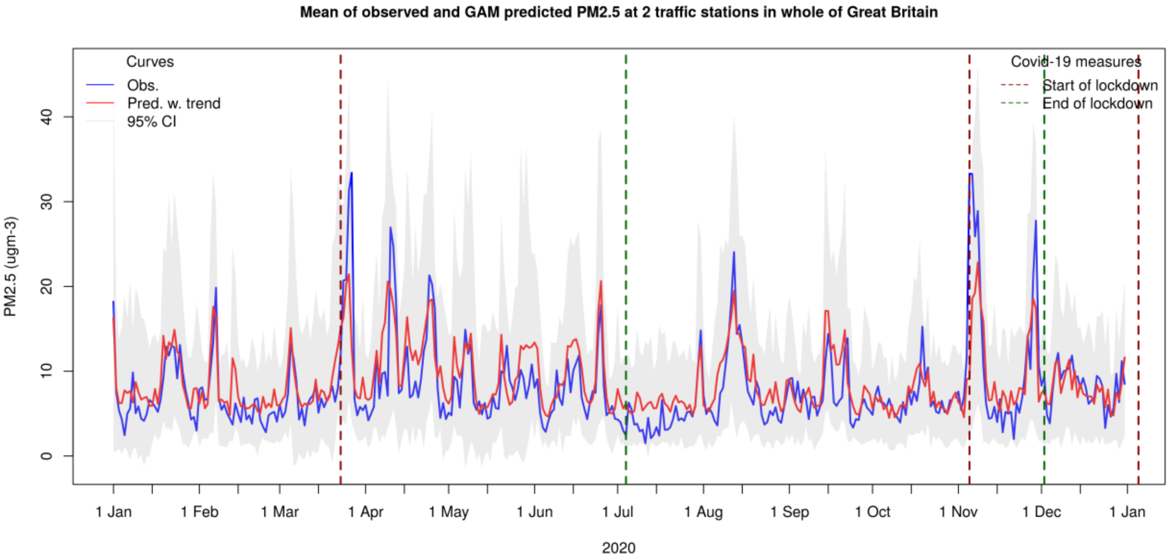



**Mean of observed and GAM predicted PM2.5 at 2 traffic stations in whole of Finland**

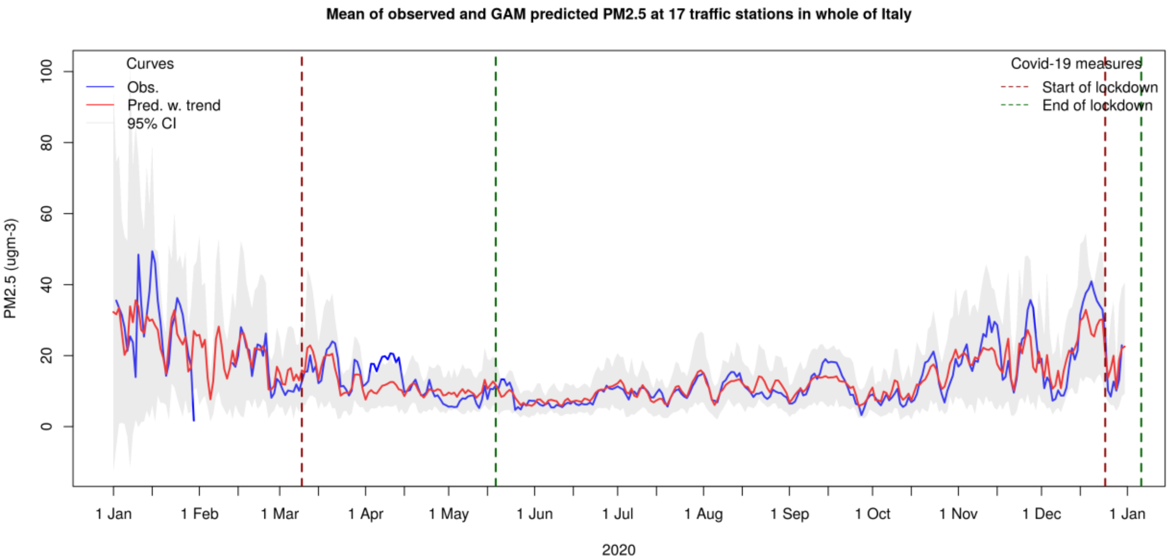




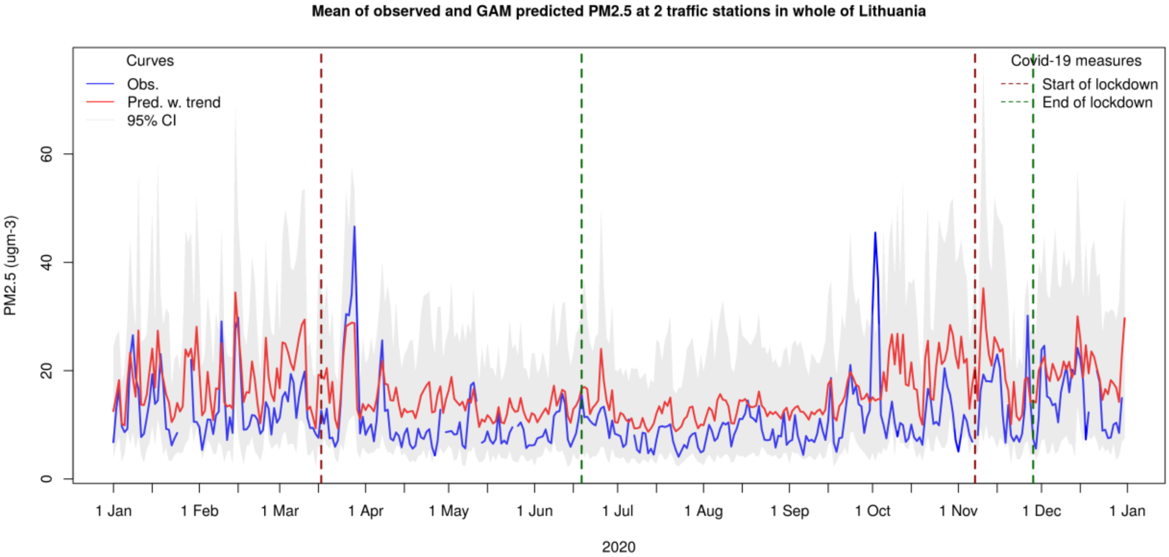
Mean of observed and GAM predicted PM2.5 at 20 traffic stations in whole of France
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
-20
0
20
40
60
80
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

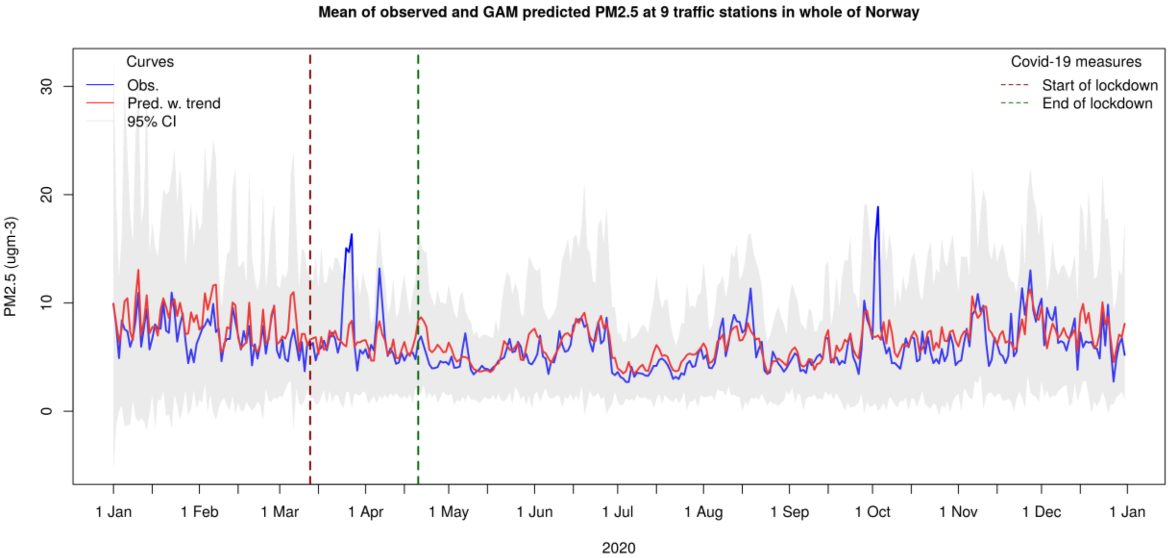



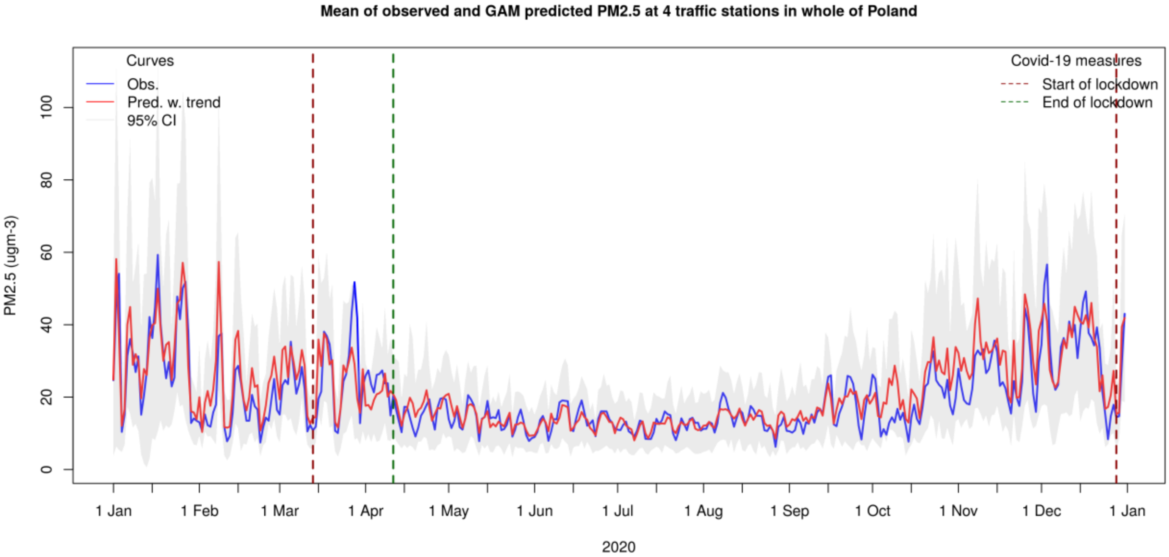
Mean of observed and GAM predicted PM2.5 at 2 traffic stations in whole of Great Britain
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
0
10
20
30
40
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

Mean of observed and GAM predicted PM2.5 at 17 traffic stations in whole of Italy
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
0
20
40
60
80
100
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted PM2.5 at 2 traffic stations in whole of Lithuania
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
0
20
40
60
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted PM2.5 at 9 traffic stations in whole of Norway
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
0
10
20
30
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted PM2.5 at 4 traffic stations in whole of Poland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
0
20
40
60
80
100
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

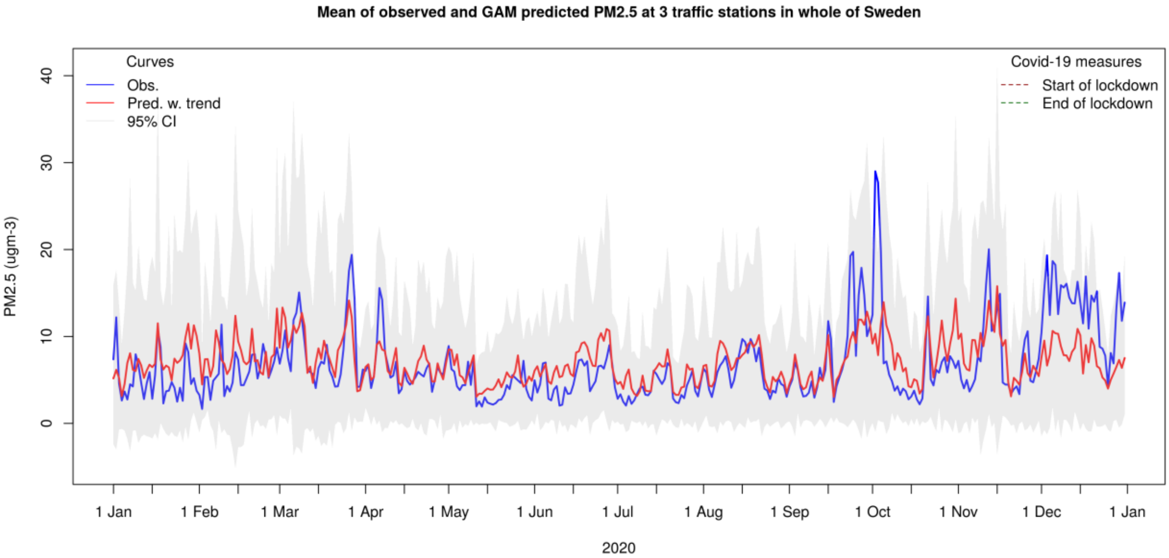
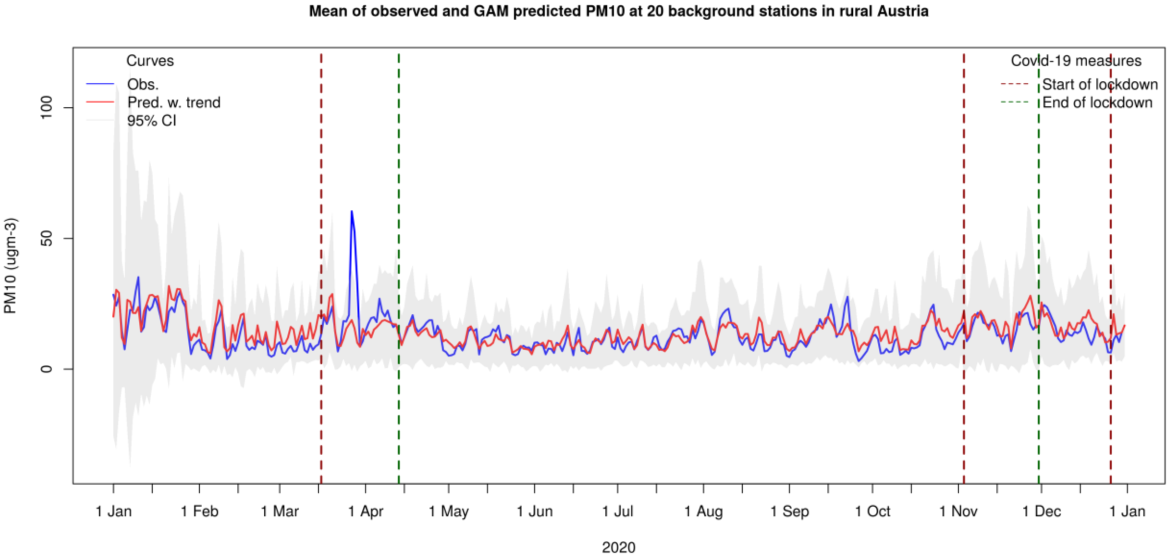
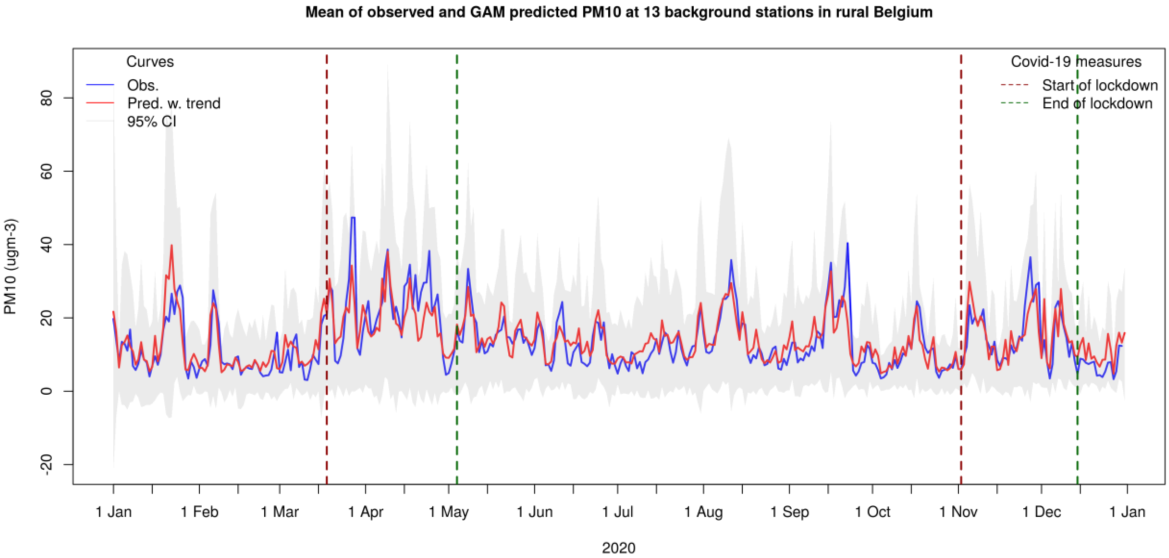
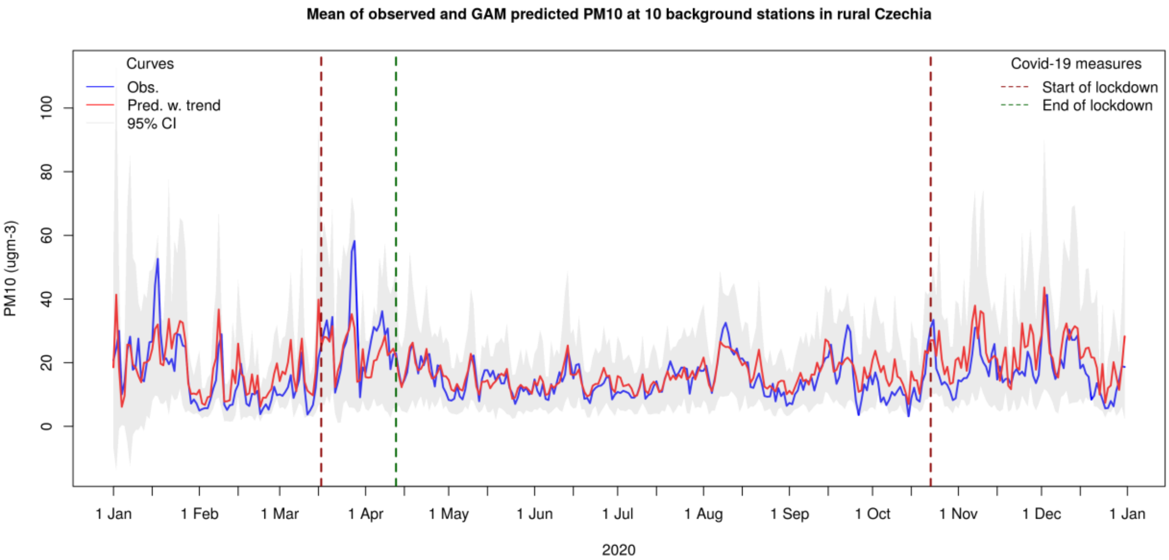
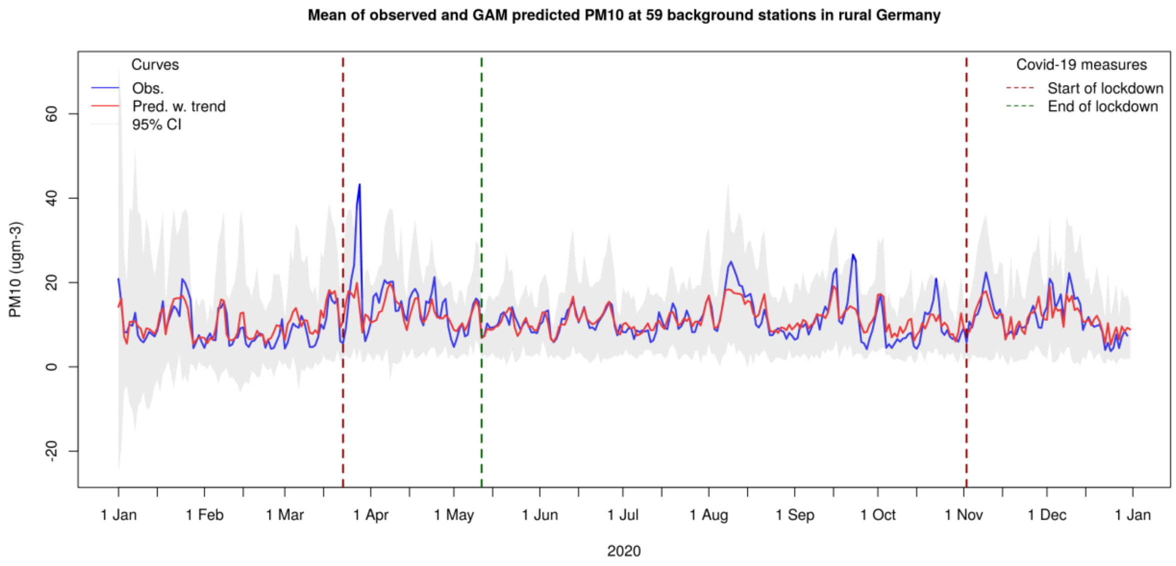

Mean of observed and GAM predicted PM2.5 at 3 traffic stations in whole of Sweden
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM2.5 (ugm-3)
0
10
20
30
40
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

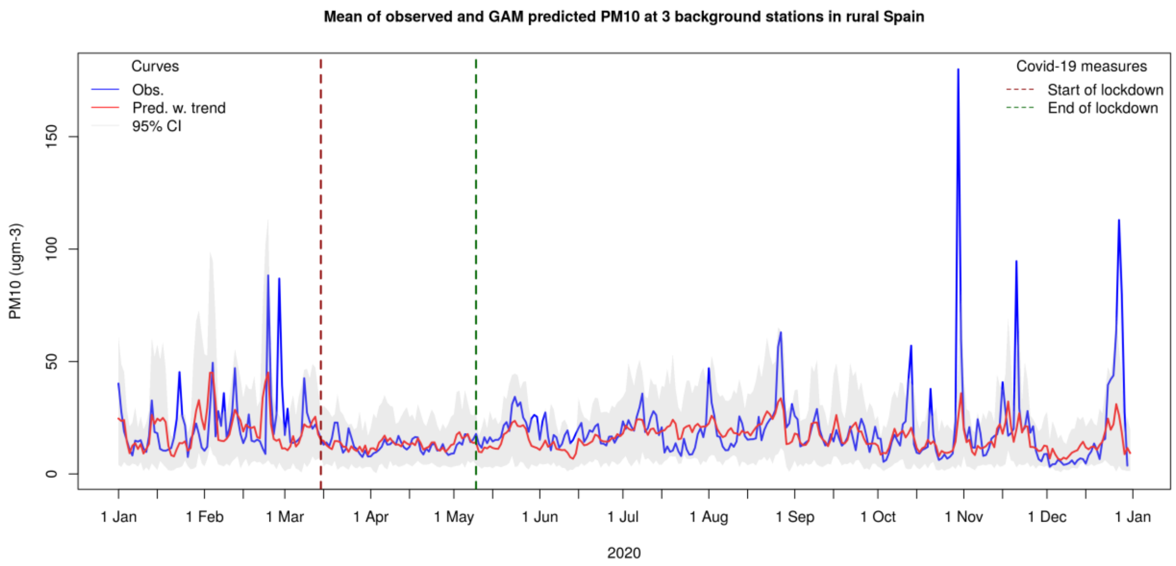
*Figure A.19   $PM_{10}$ rural*

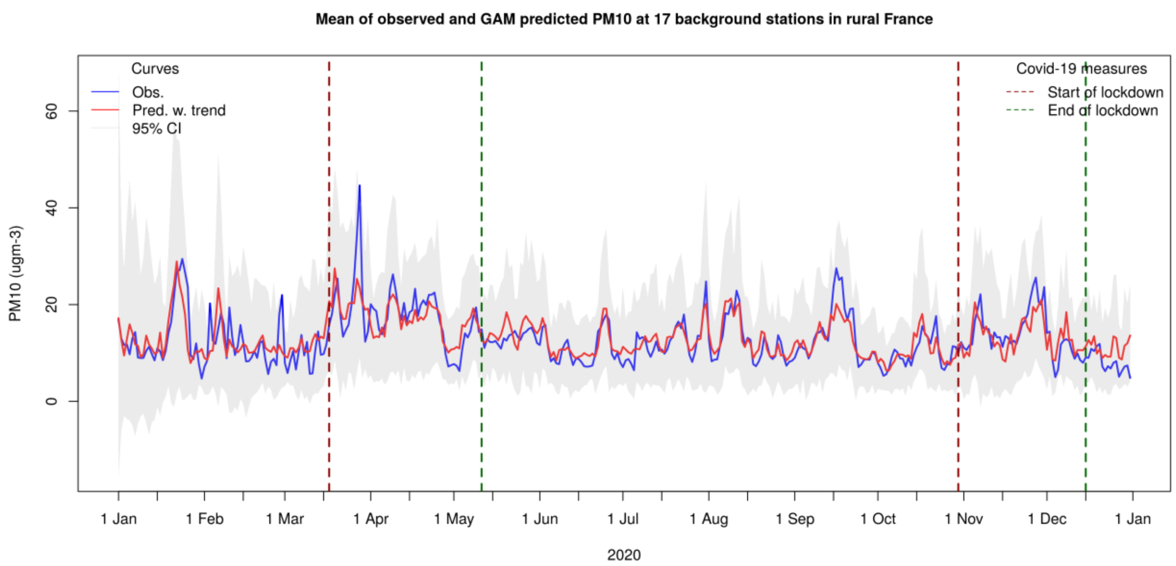


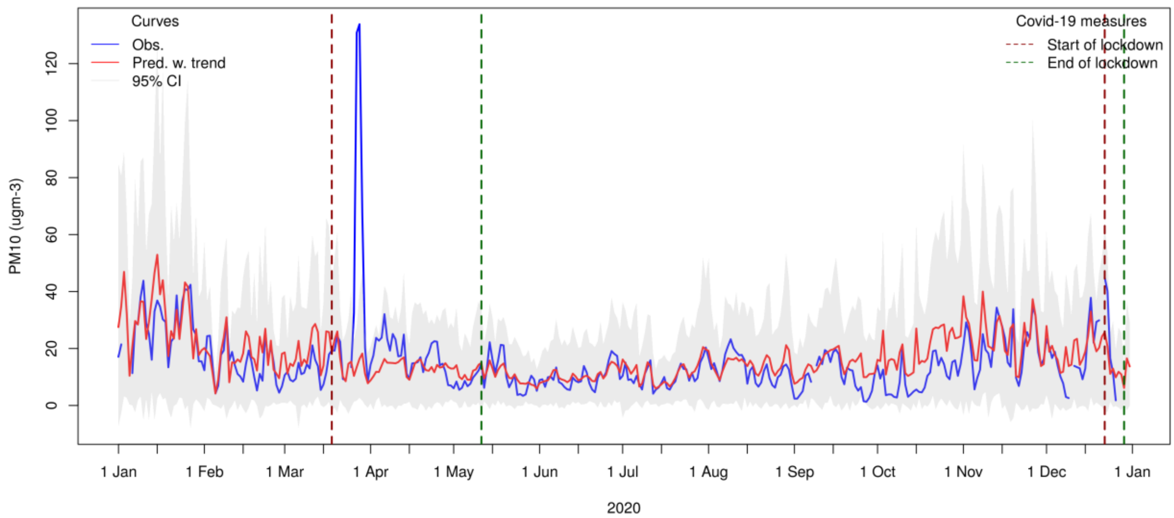




Mean of observed and GAM predicted PM10 at 59 background stations in rural Germany
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
-20
0
20
40
60
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

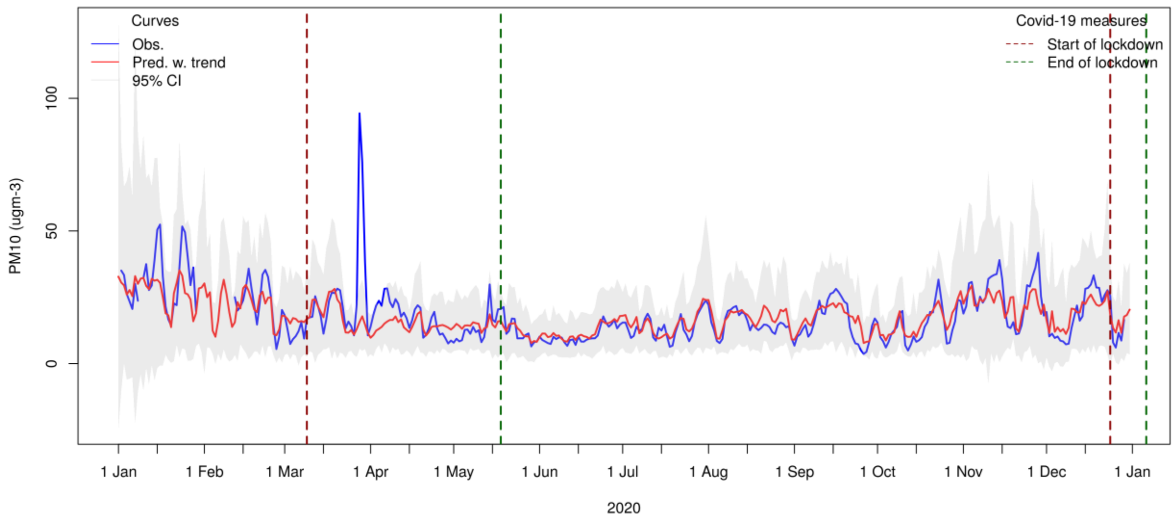

Mean of observed and GAM predicted PM10 at 3 background stations in rural Spain
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
50
100
150
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

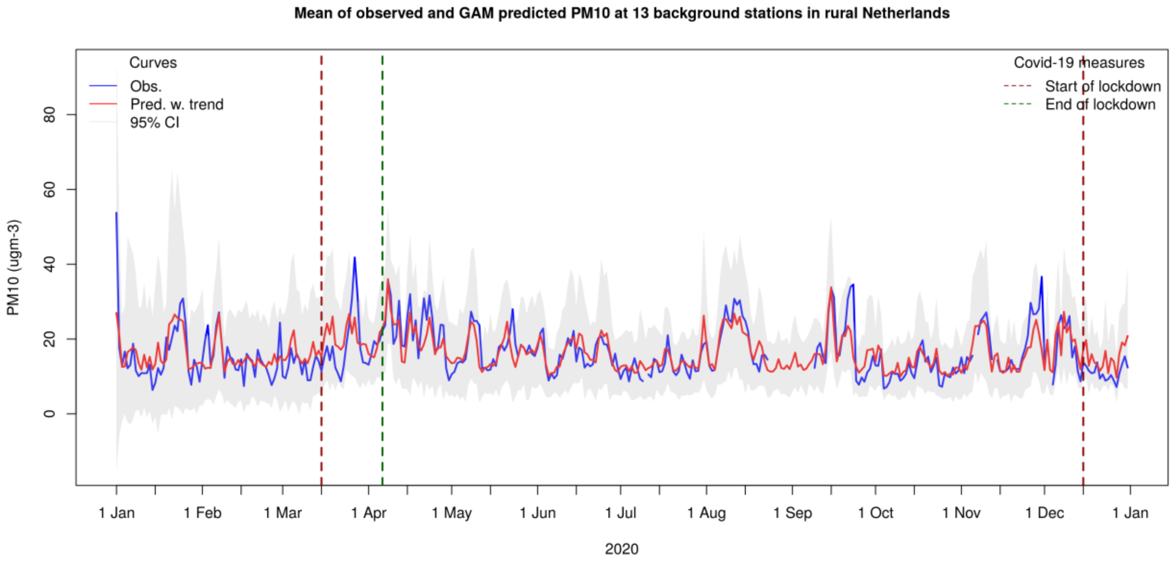

Mean of observed and GAM predicted PM10 at 17 background stations in rural France
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
20
40
60
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

**Mean of observed and GAM predicted PM10 at 2 background stations in rural Croatia**




**Mean of observed and GAM predicted PM10 at 17 background stations in rural Italy**




Mean of observed and GAM predicted PM10 at 13 background stations in rural Netherlands
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
20
40
60
80
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

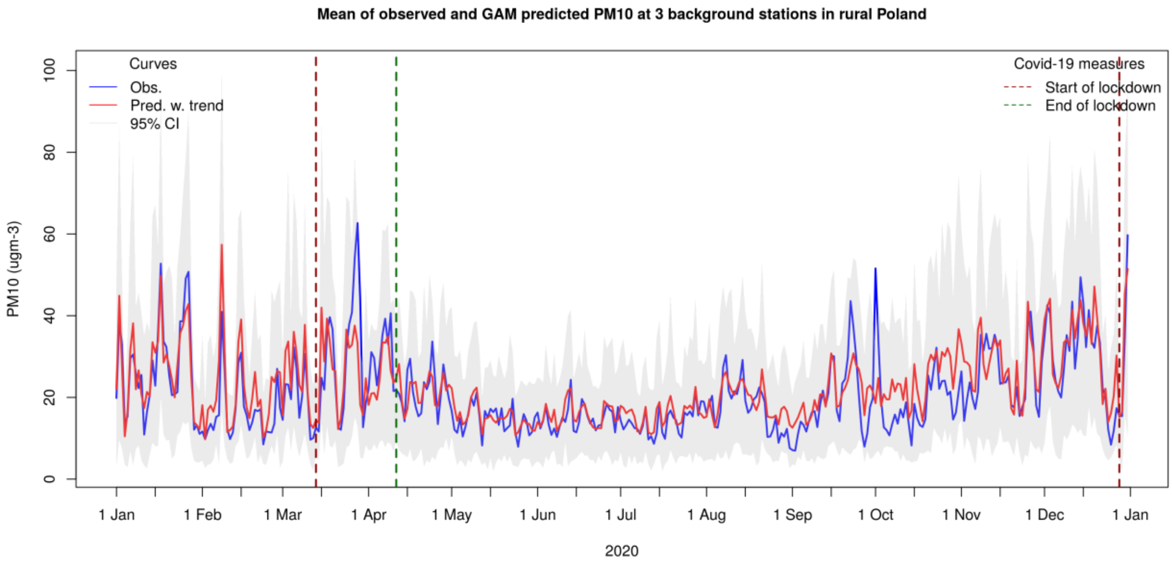
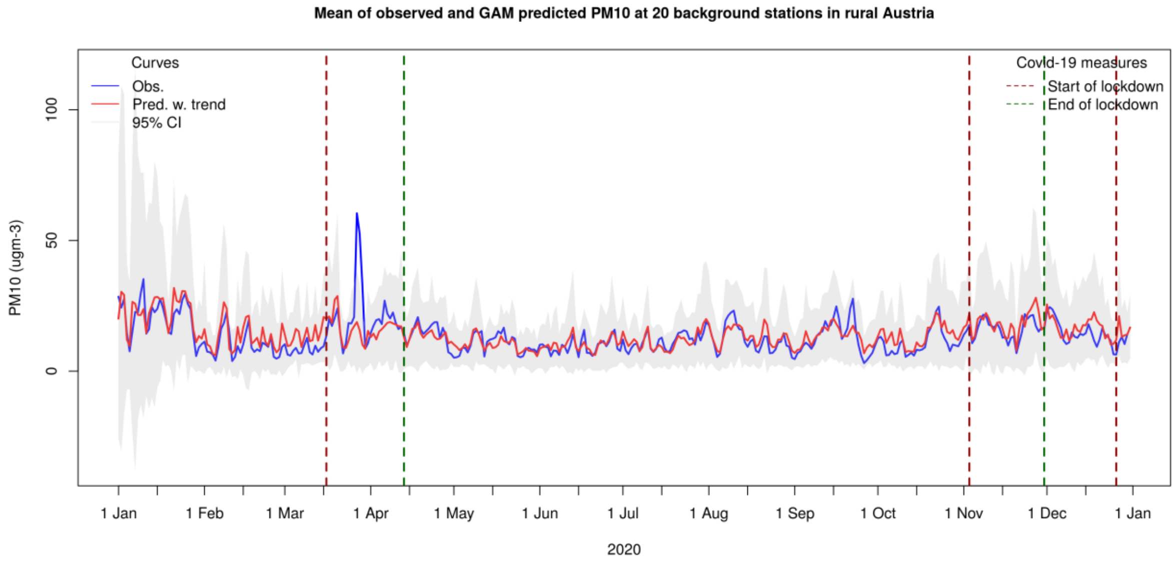
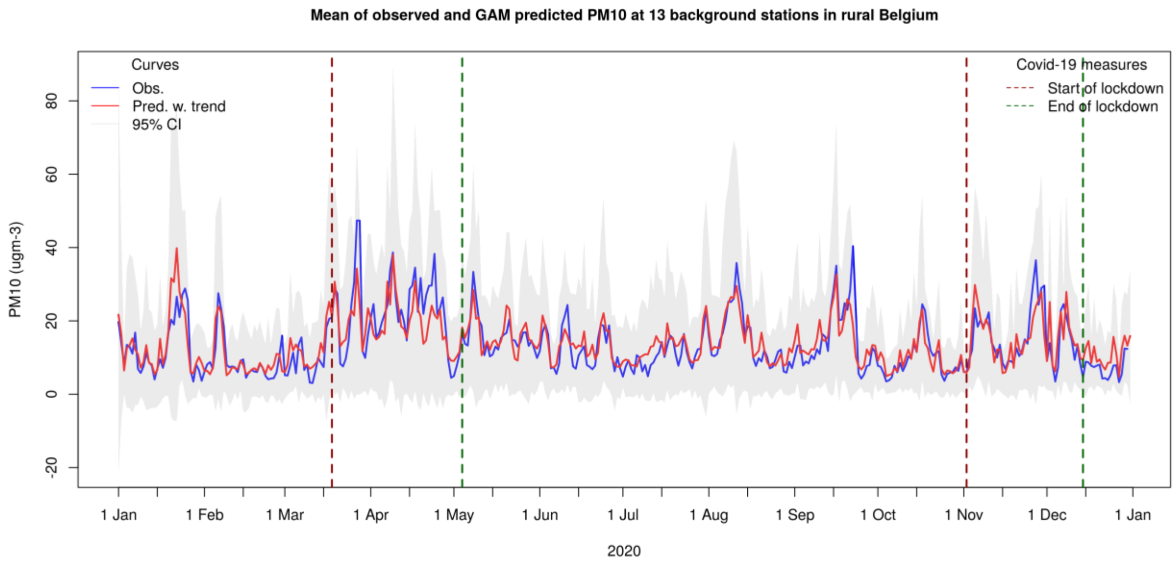
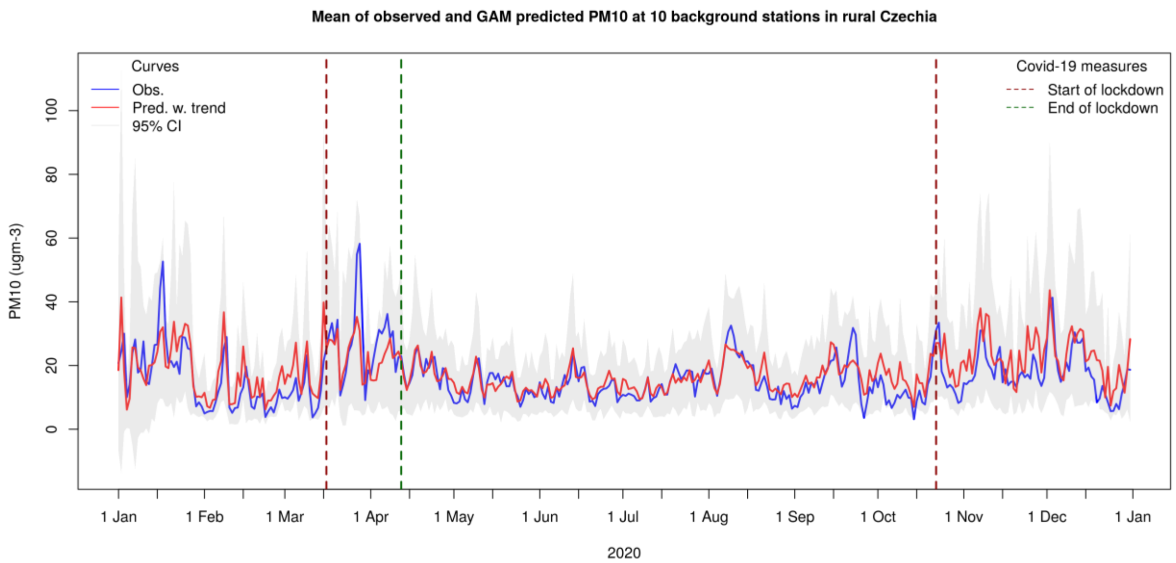

Mean of observed and GAM predicted PM10 at 3 background stations in rural Poland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
20
40
60
80
100
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

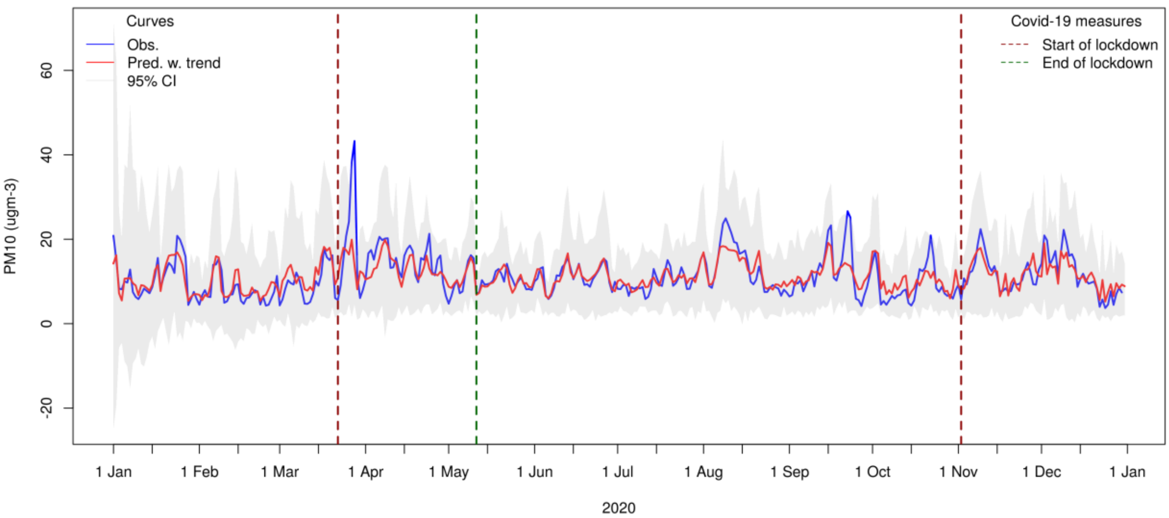
*Figure A.20 $PM_{10}$ suburban*



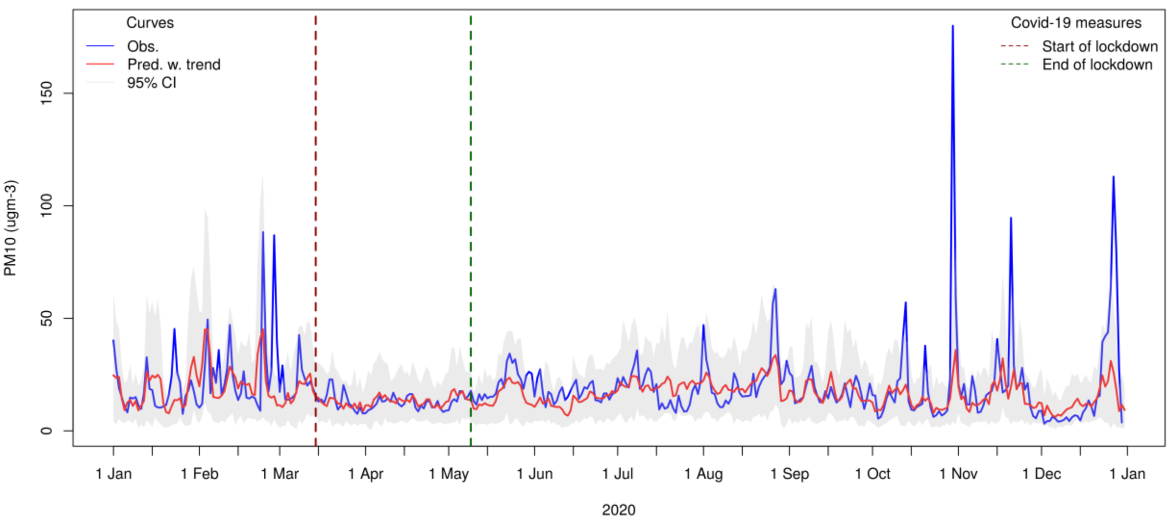



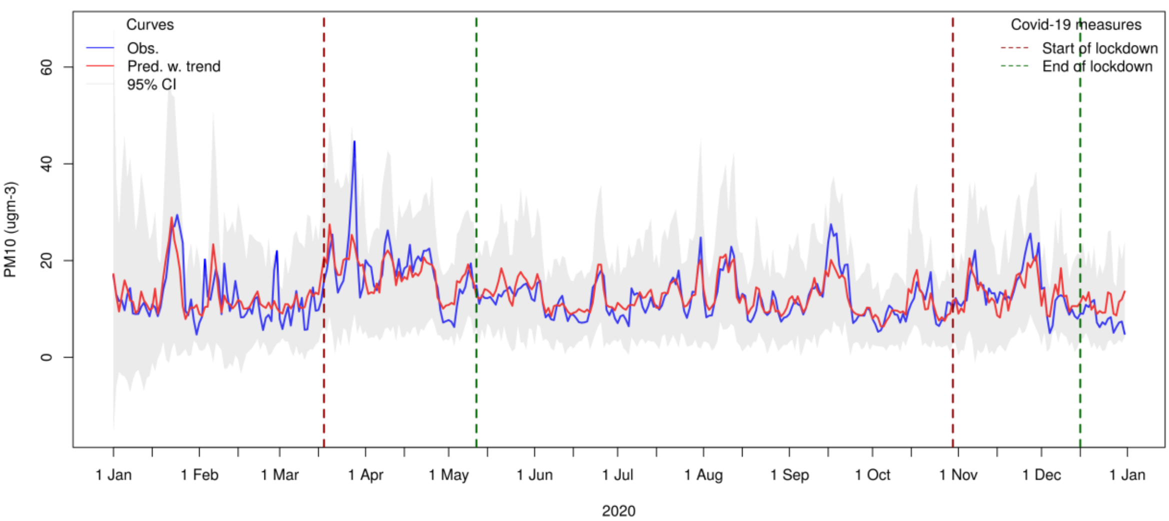
Mean of observed and GAM predicted PM10 at 59 background stations in rural Germany

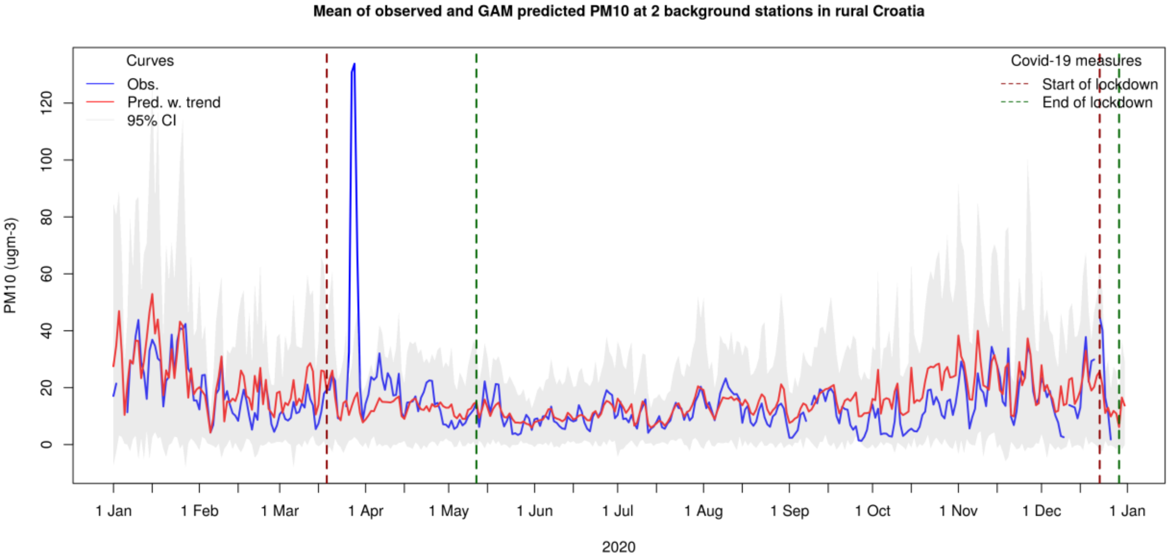


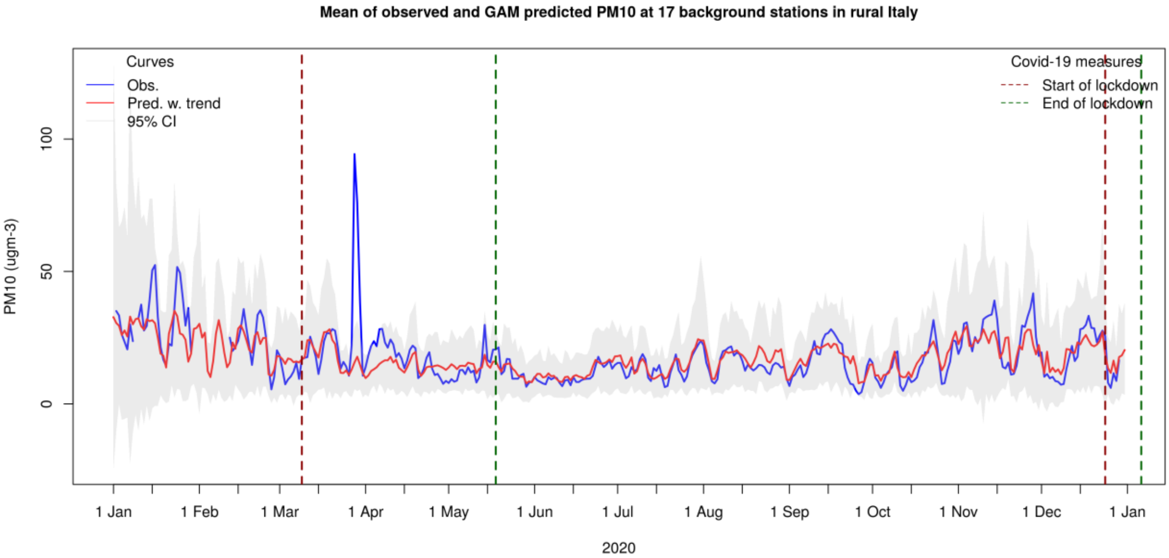

Mean of observed and GAM predicted PM10 at 3 background stations in rural Spain

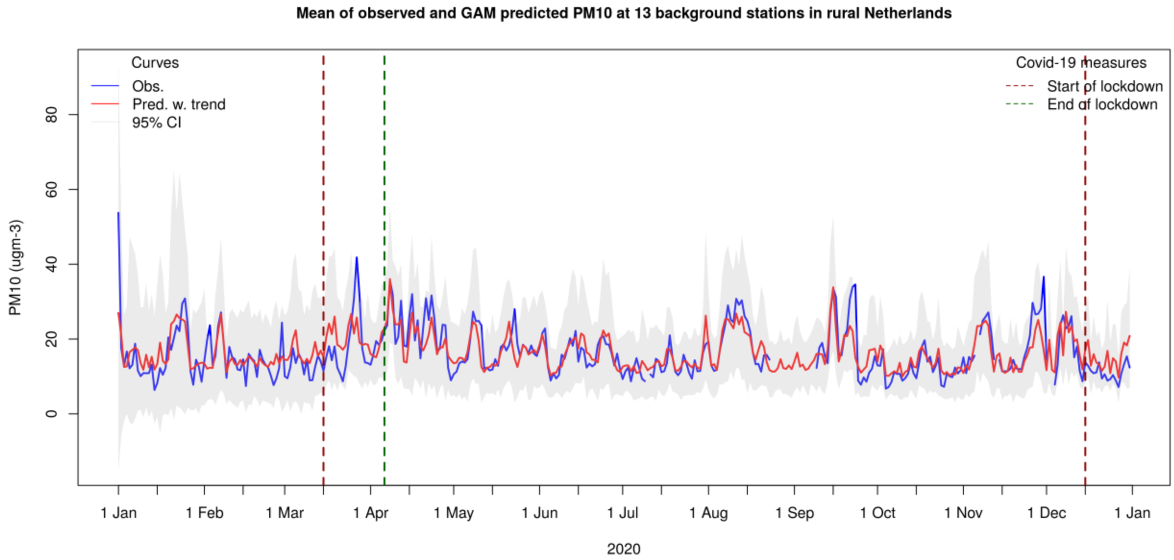



Mean of observed and GAM predicted PM10 at 17 background stations in rural France




Mean of observed and GAM predicted PM10 at 2 background stations in rural Croatia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
20
40
60
80
100
120
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted PM10 at 17 background stations in rural Italy
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
50
100
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020


Mean of observed and GAM predicted PM10 at 13 background stations in rural Netherlands
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
20
40
60
80
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

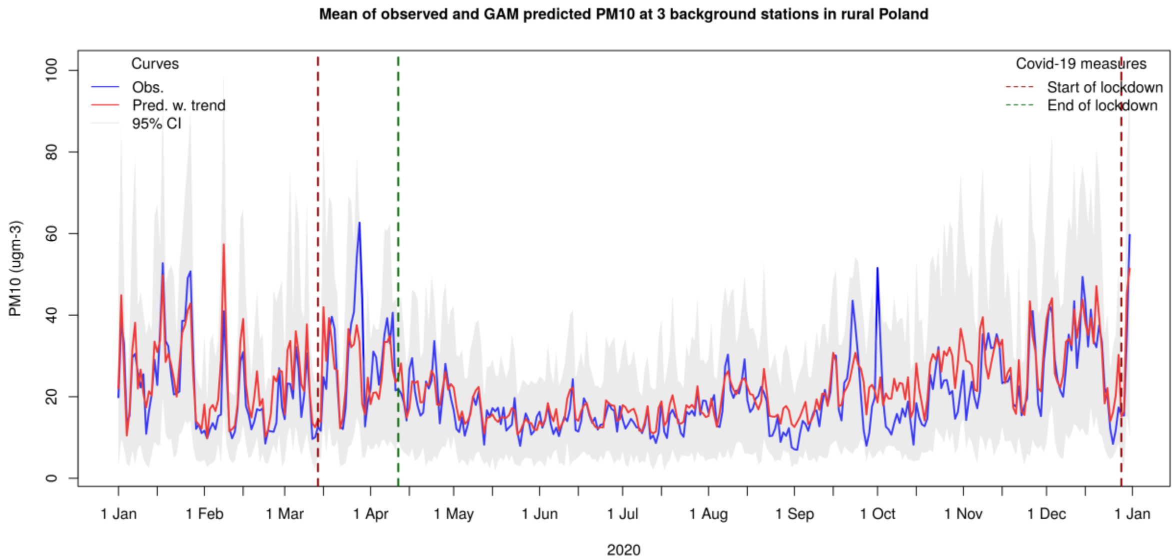
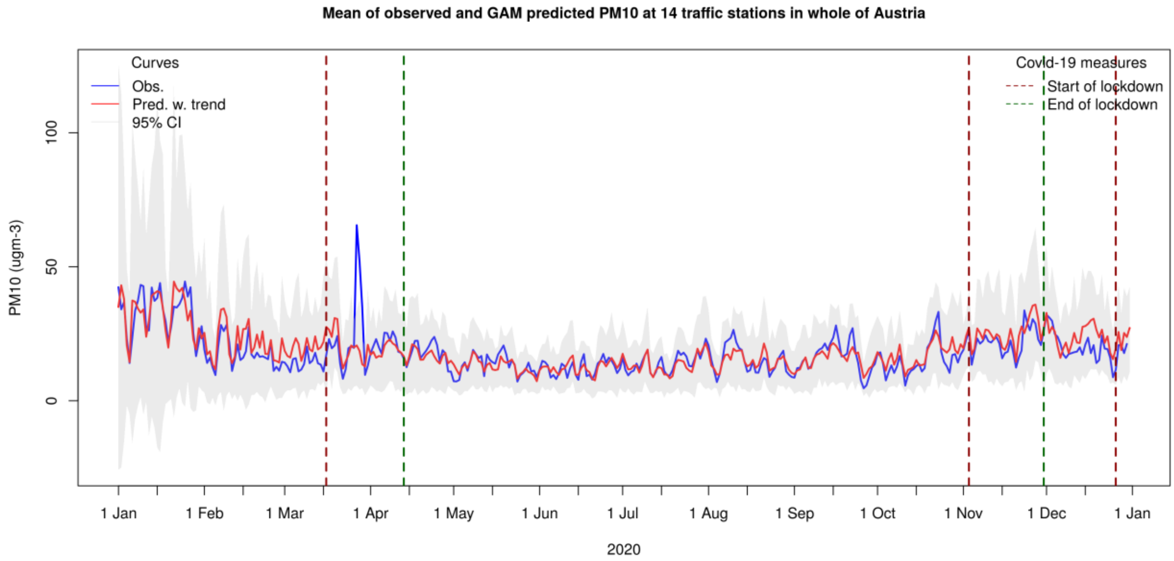
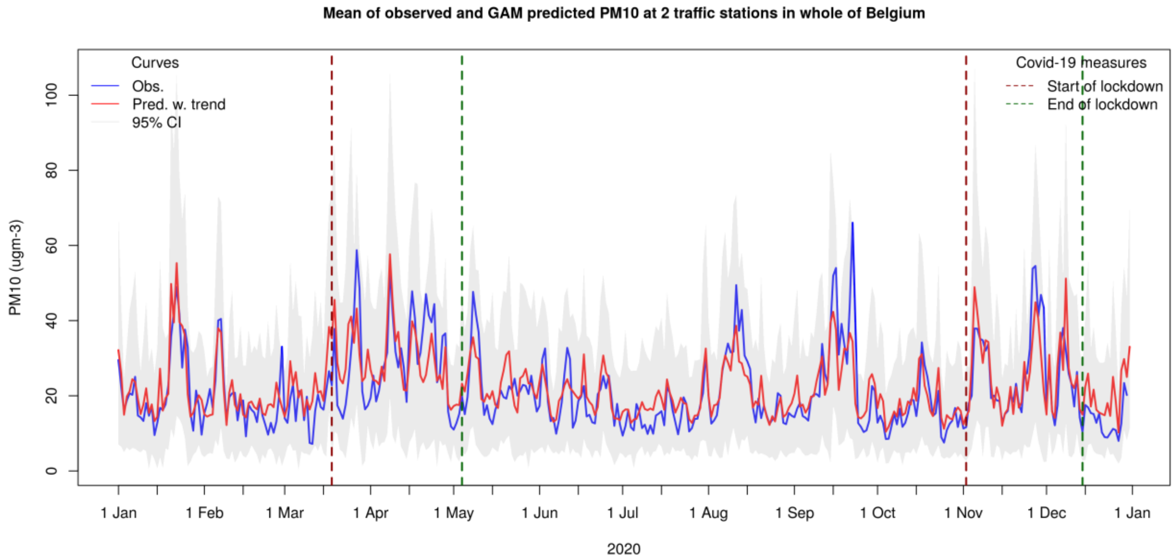
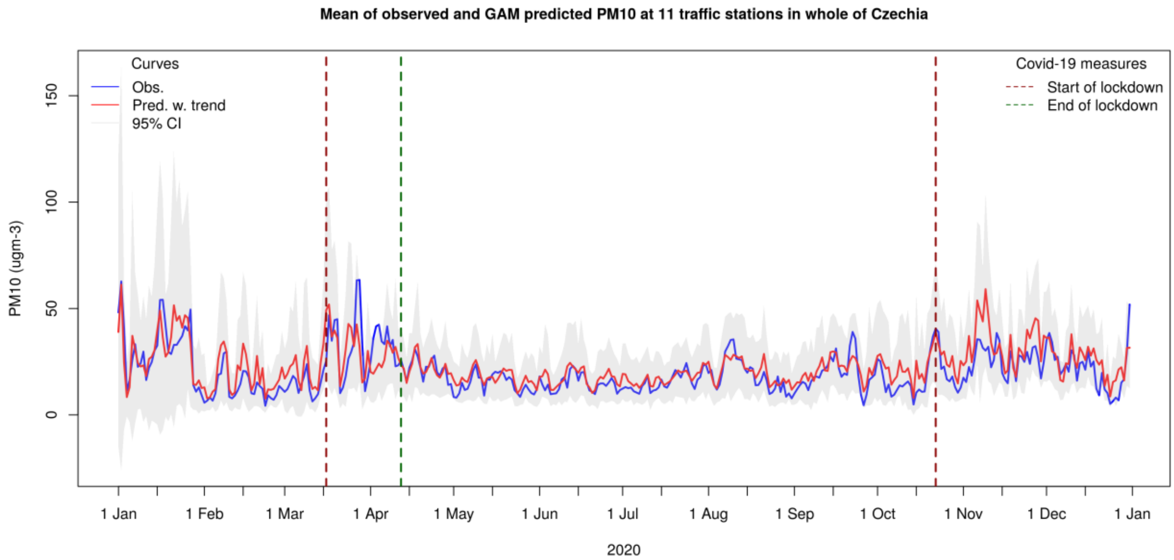

Mean of observed and GAM predicted PM10 at 3 background stations in rural Poland
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
20
40
60
80
100
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

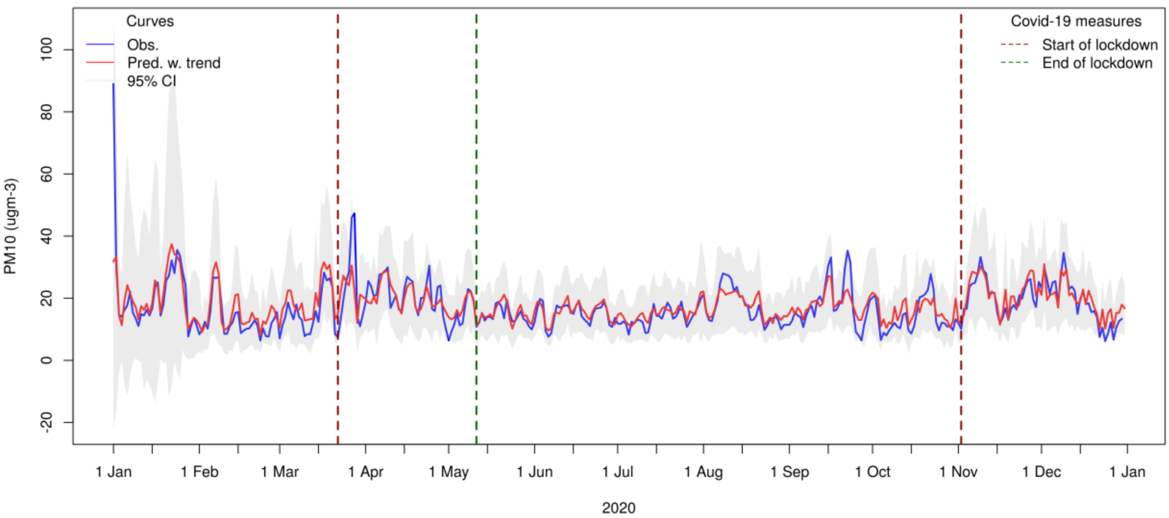
*Figure A.21 $PM_{10}$ traffic*



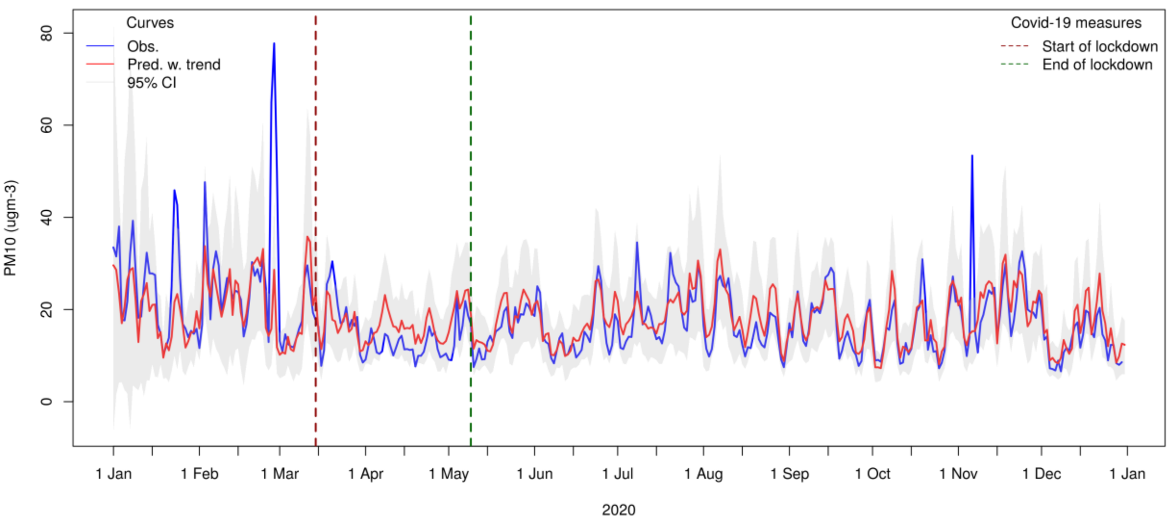



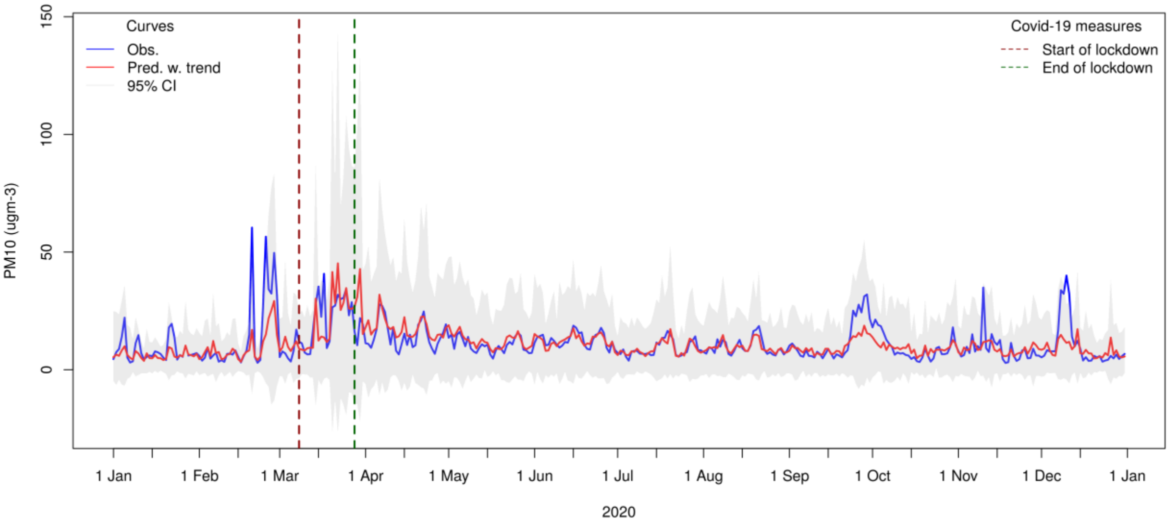
Mean of observed and GAM predicted PM10 at 107 traffic stations in whole of Germany



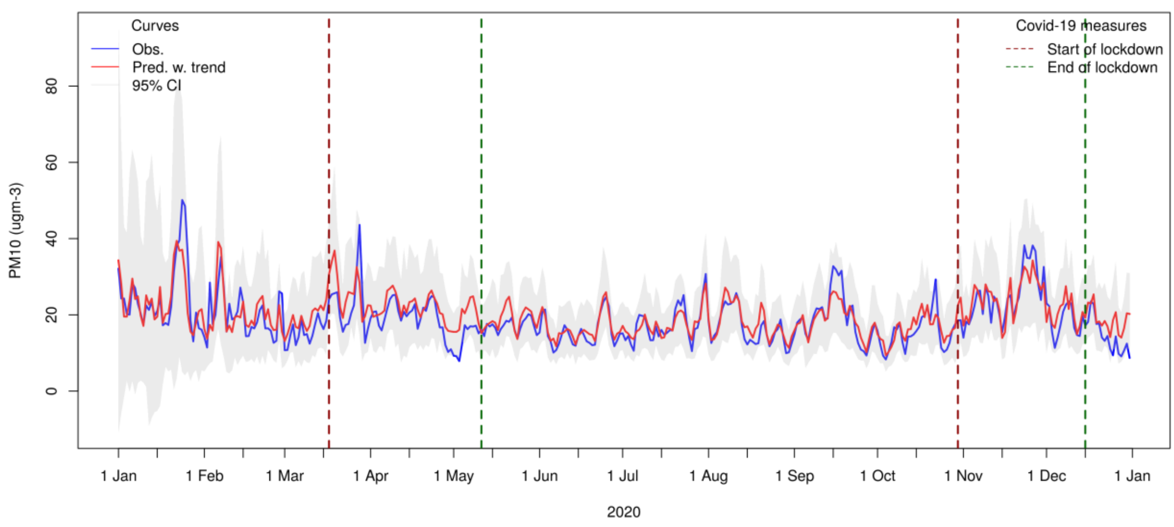

Mean of observed and GAM predicted PM10 at 30 traffic stations in whole of Spain



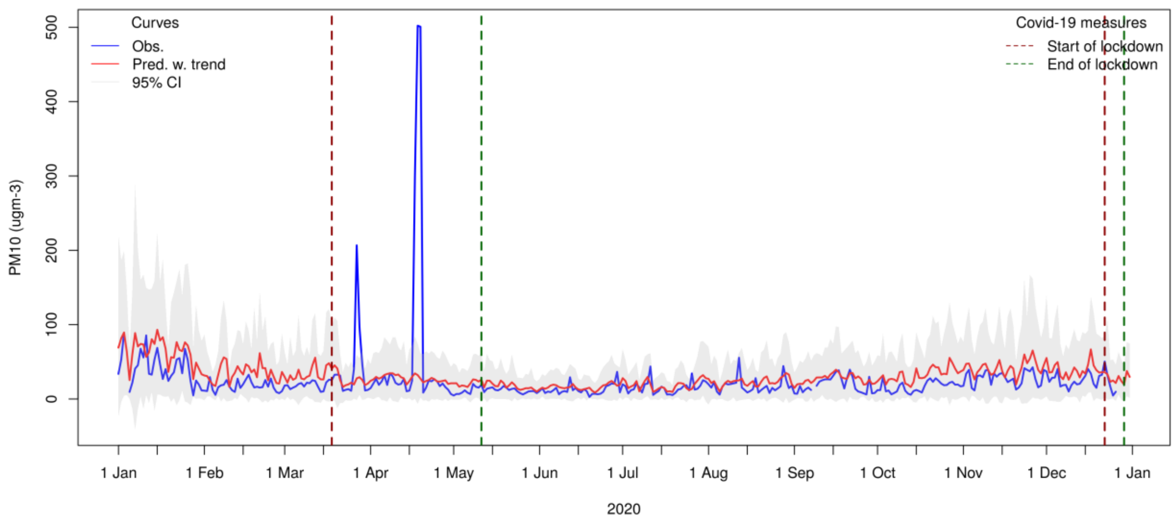

Mean of observed and GAM predicted PM10 at 7 traffic stations in whole of Finland



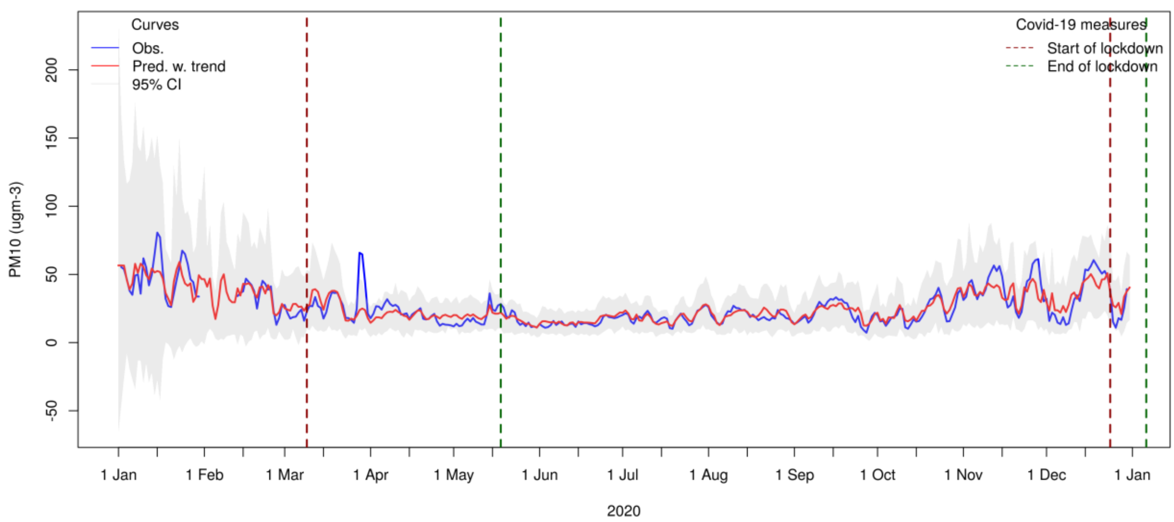
Mean of observed and GAM predicted PM10 at 40 traffic stations in whole of France



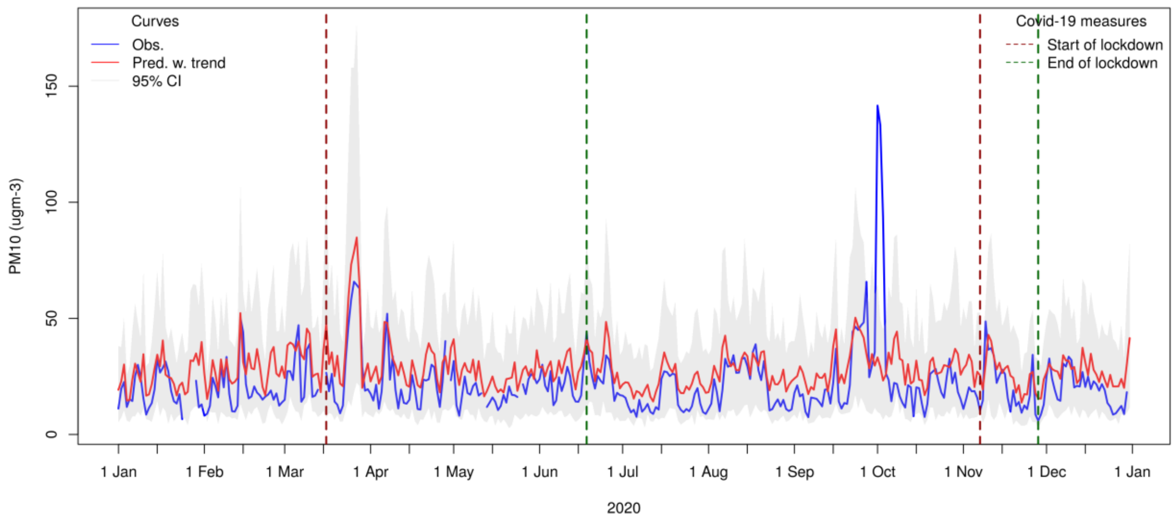

Mean of observed and GAM predicted PM10 at 2 traffic stations in whole of Croatia



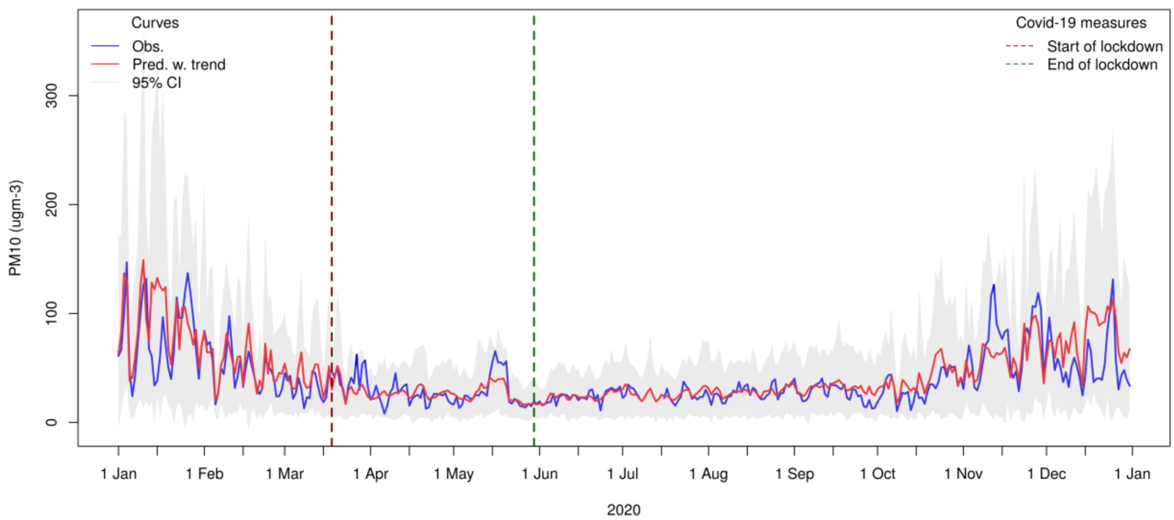

Mean of observed and GAM predicted PM10 at 55 traffic stations in whole of Italy



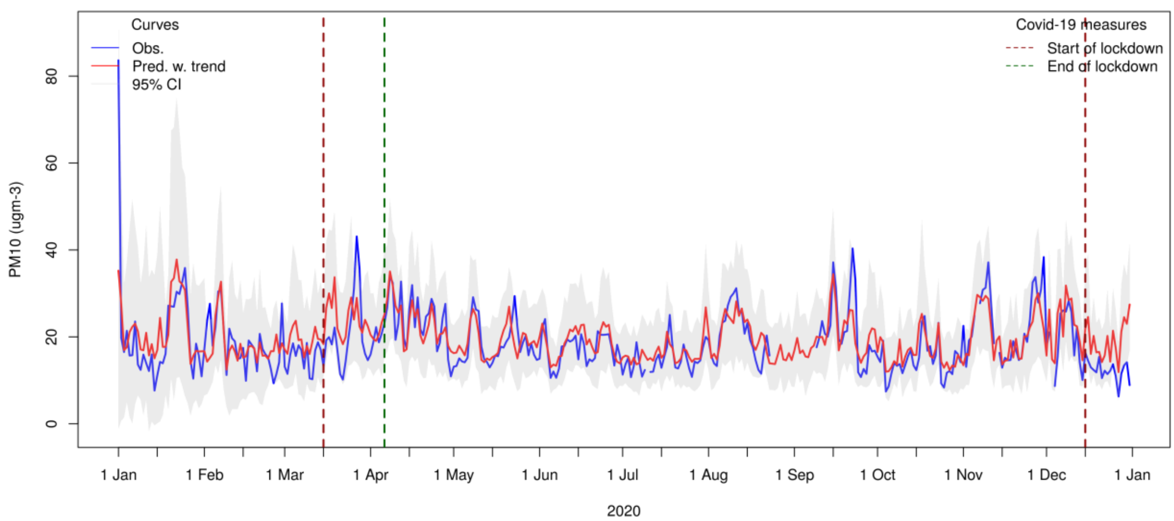
Mean of observed and GAM predicted PM10 at 2 traffic stations in whole of Lithuania



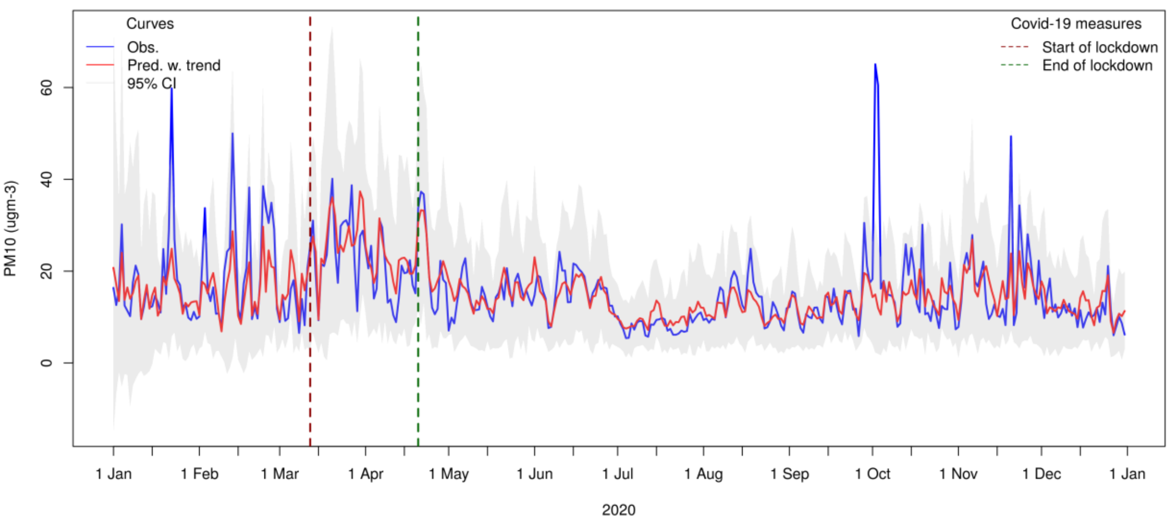

Mean of observed and GAM predicted PM10 at 2 traffic stations in whole of North Macedonia



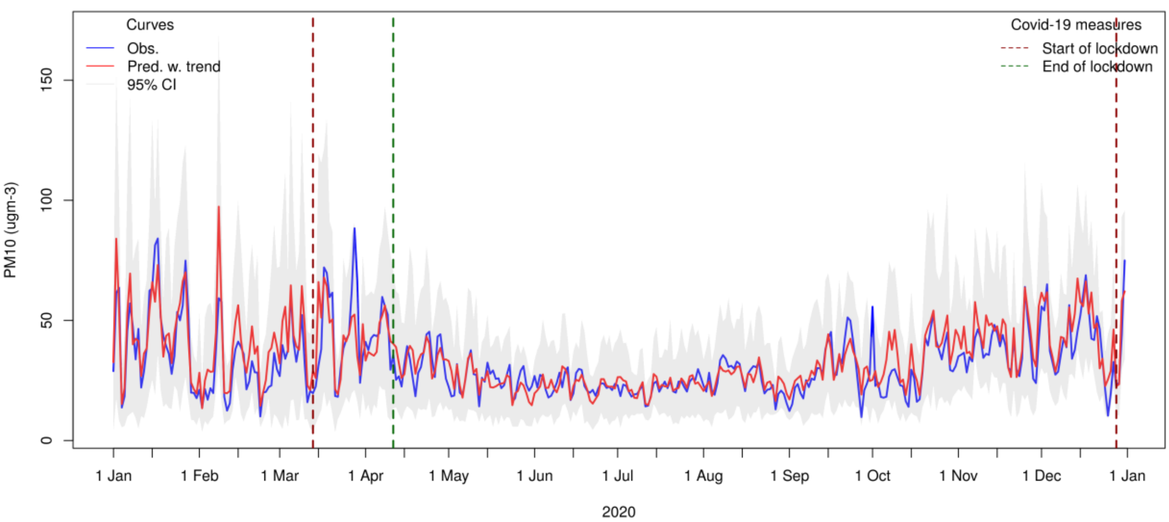

Mean of observed and GAM predicted PM10 at 10 traffic stations in whole of Netherlands



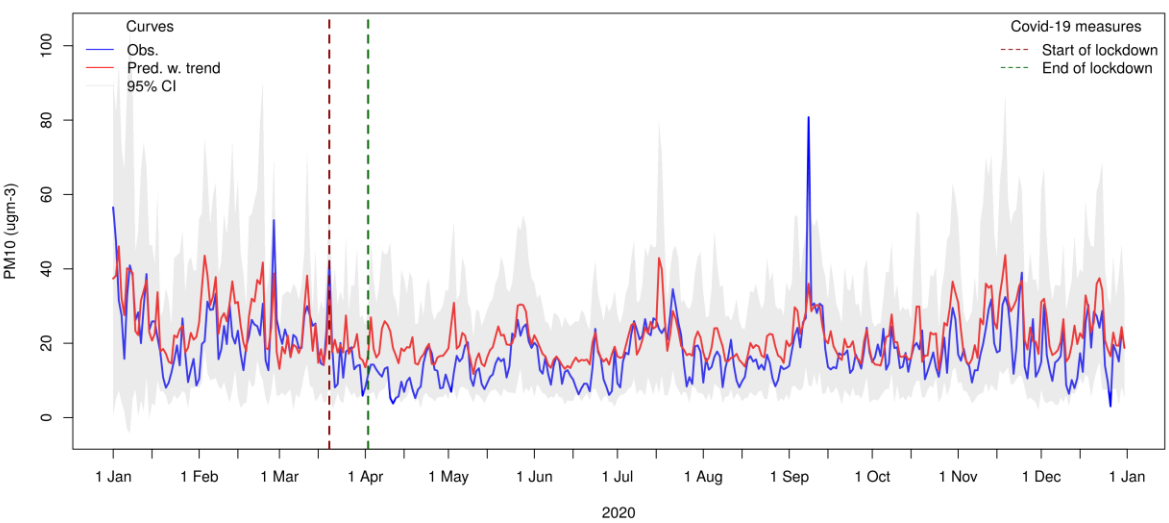
Mean of observed and GAM predicted PM10 at 13 traffic stations in whole of Norway

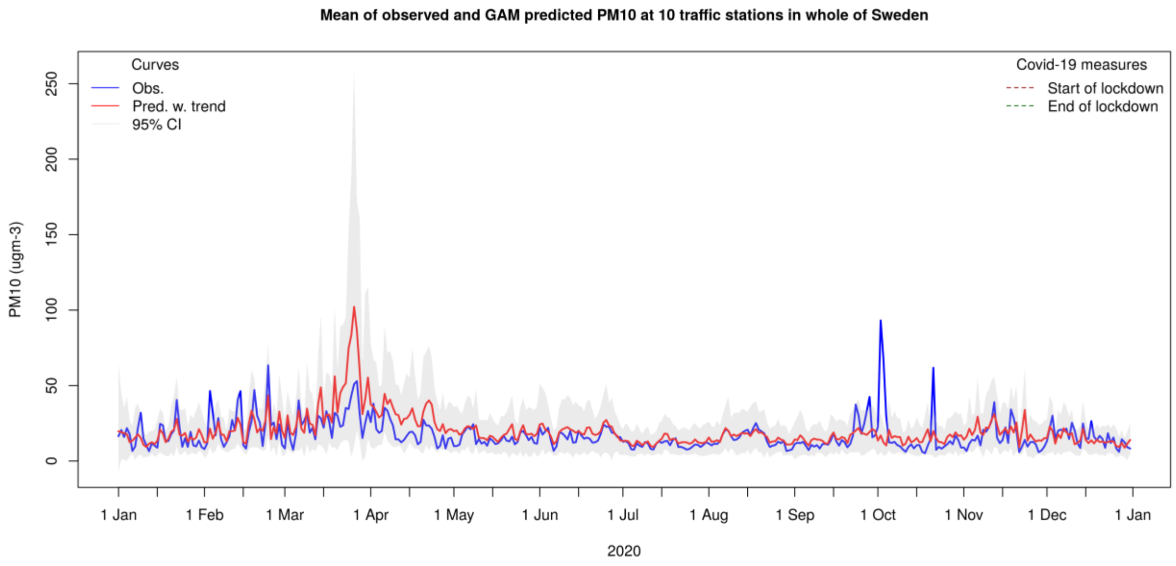



Mean of observed and GAM predicted PM10 at 4 traffic stations in whole of Poland

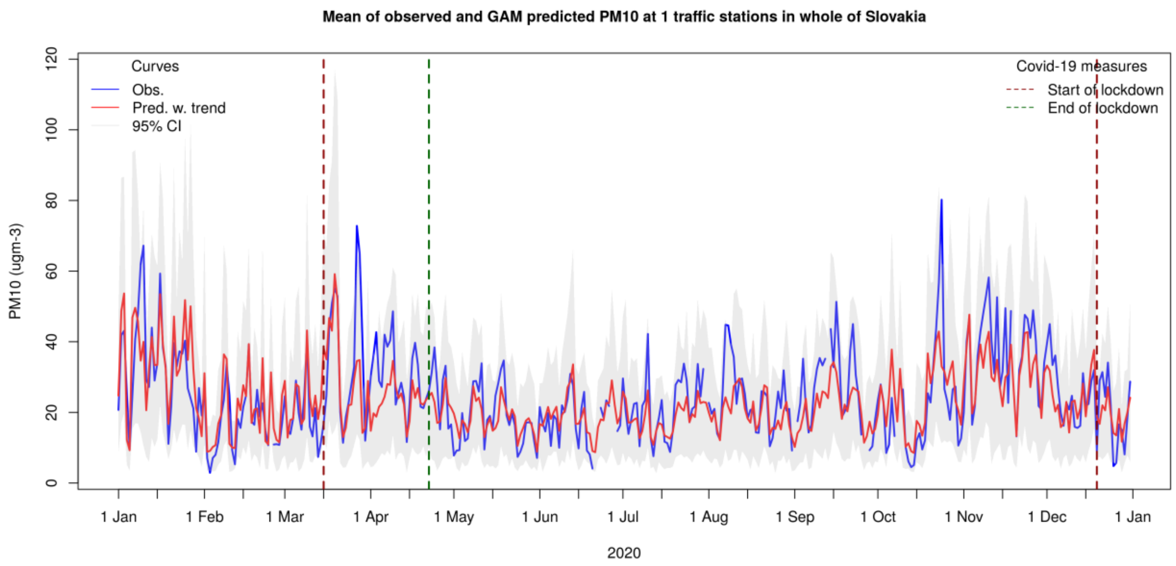



Mean of observed and GAM predicted PM10 at 4 traffic stations in whole of Portugal





Mean of observed and GAM predicted PM10 at 10 traffic stations in whole of Sweden
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
50
100
150
200
250
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

Mean of observed and GAM predicted PM10 at 1 traffic stations in whole of Slovakia
Curves
Obs.
Pred. w. trend
95% CI
Covid-19 measures
Start of lockdown
End of lockdown
PM10 (ugm-3)
0
20
40
60
80
100
120
1 Jan
1 Feb
1 Mar
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
1 Jan
2020

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The European Topic Centre on Air pollution, transport, noise and industrial pollution (ETC/ATNI) is a consortium of European institutes under a framework partnership contract to the European Environment Agency.

European Environment Agency
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transport, noise and industrial pollution