Time-resolved emission reductions for atmospheric chemistry modelling in Europe during the COVID-19 lockdowns

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Overview and objective

To control the spread of the COVID-19 disease, European governments implemented emergency measures going from light social distancing to strict lockdowns, which resulted in an unprecedented drop of anthropogenic emissions.

A complete understanding of the lockdown impacts upon air quality and climate requires quantifying the reduction of primary emissions.

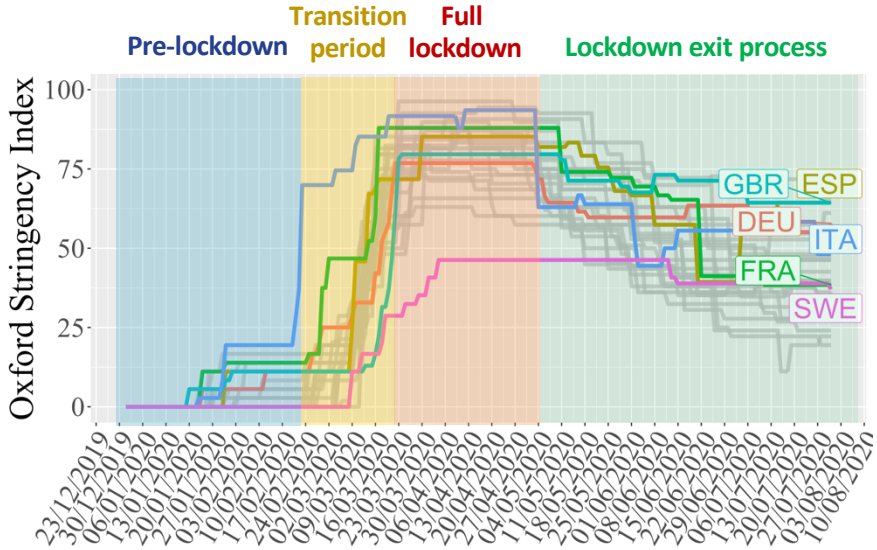
Objective: To develop emission reduction factors attributable to the COVID-19 measures, which can be combined with the Copernicus CAMS European emission inventory for emissions & air quality modelling

Heterogeneous implementation of restrictions across EU:

- Different starting dates (e.g. Italy vs. UK)
- Different levels of restriction (e.g. Spain vs. Sweden)
- Changes in time of the restriction levels

Requirements of the reduction factors:

- Country-dependent
- Sector-dependent
- Vary on a daily basis



Oxford COVID-19 Government Response Tracker (OxCGRT) (Hale et al., 2020)

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Methodology

Sectors considered: Energy and manufacturing industry, other stationary combustion activities, road transport, shipping and aviation (LTO cycles)

Temporal coverage: 21/02/2020 until 31/07/2020

Spatial coverage: European domain (30° W – 60° E and 30° N – 72°N) giving a special priority to EU28 + Norway + Switzerland

General approach: Collection and processing of measured time-series representing the main activities of each sector.

Sector	Description	Sources of information
GNFR_A	Energy industry	• Electricity demand data: ENTSO-E (2020); FGC UES (2020) • Outdoor temperature: C3S (2017) • Population map: CIESIN (2016)
GNFR_B	Manufacturing industry	• Electricity demand data: ENTSO-E (2020); FGC UES (2020) • Outdoor temperature: C3S (2017) • Population map: CIESIN (2016) • Energy balances: Eurostat (2020a)
GNFR_C	Other stationary combustion activities	• Movement trend reports: Google (2020) • Consumption by use for the commercial sectors: IDAE (2018) • EMEP/CEIP official reported emissions: EMEP/CEIP (2020)
GNFR_F	Road Transport	• Movement trend reports: Google (2020)
GNFR_G	Shipping	• Port call trends: EMSA (2020) • European shipping emission inventory (Jalkanen et al., 2016)
GNFR_H	Aviation	• Airport movement statistics: EUROCONTROL (2020)

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Emission reduction factors

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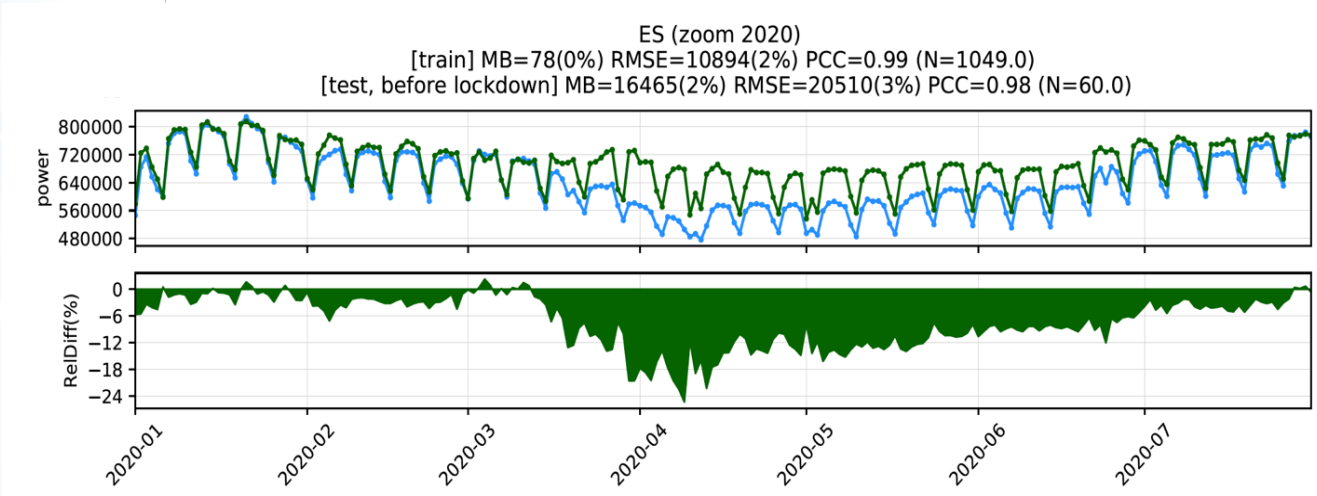
GNFR_A: Energy Industry

Use of **Machine Learning** to estimate national business-as-usual electricity demand (i.e. without the lockdown effect)

- Features: ENTSO-E electricity demand (Jan-Jul 2015-2020), population-weighted ERA5 temperature, date
- Gradient boosting machine model similar to the one used to model Spanish BAU NO_2 (Petetin et al., 2020, ACP)

Reduction factors estimated as the difference between BAU and measured demand



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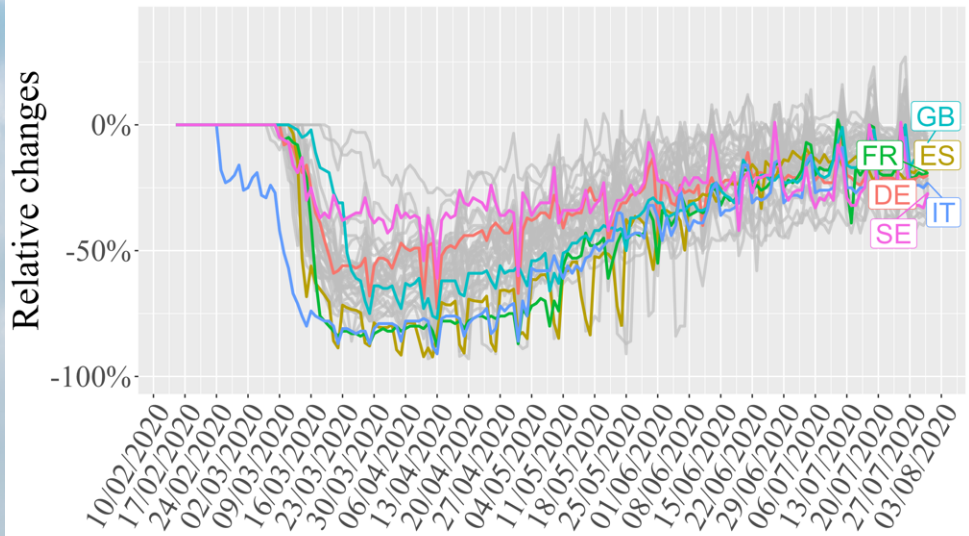
Emission reduction factors

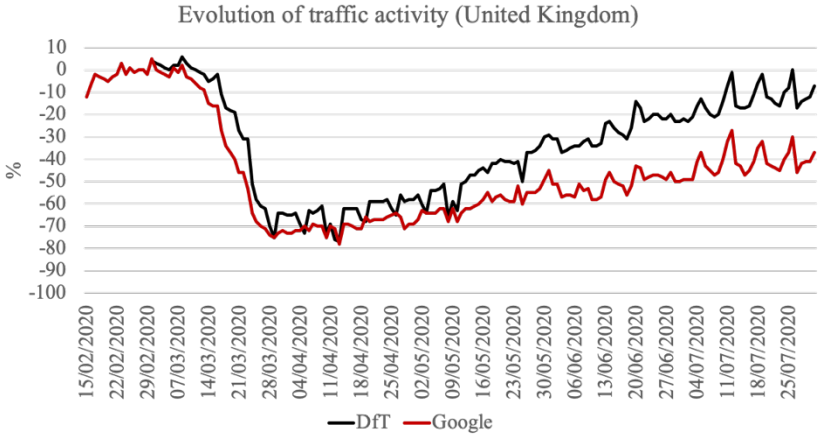
GNFR F: Road transport

Based on the Google COVID-19 Mobility Reports (Google, 2020) - Transit stations category

Replaced by national trends derived from measured traffic count information where available

Limitation 1: Google trends underestimate the recovery of traffic activity during the lockdown exit process. Google data is based on mobility trends in public transport hubs and therefore may be affected by the fact that, with the virus still circulating, many people remain wary of using this mode of transport





Similar pattern observed for: Norway, Switzerland, Germany, Denmark, Italy, France, Poland, Milano, Rome, Barcelona, Madrid

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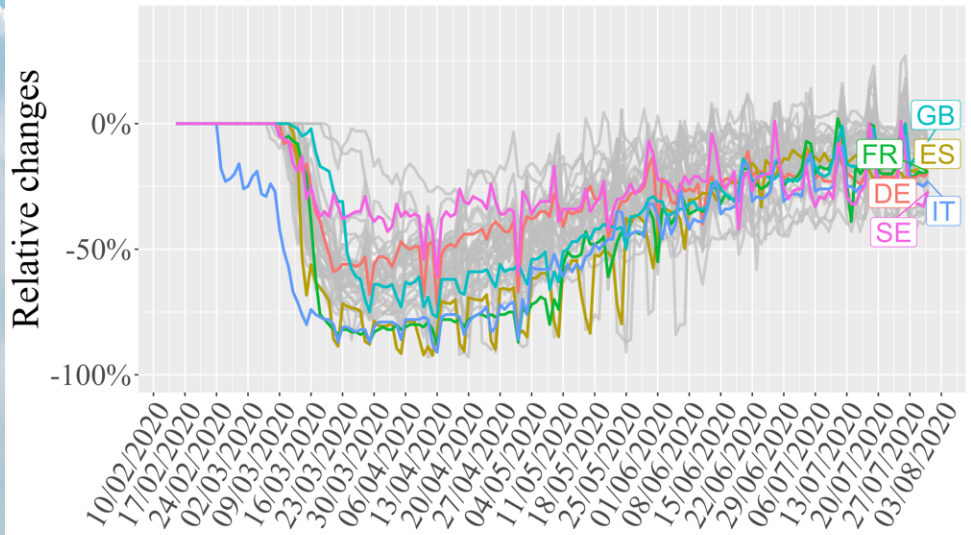
Emission reduction factors

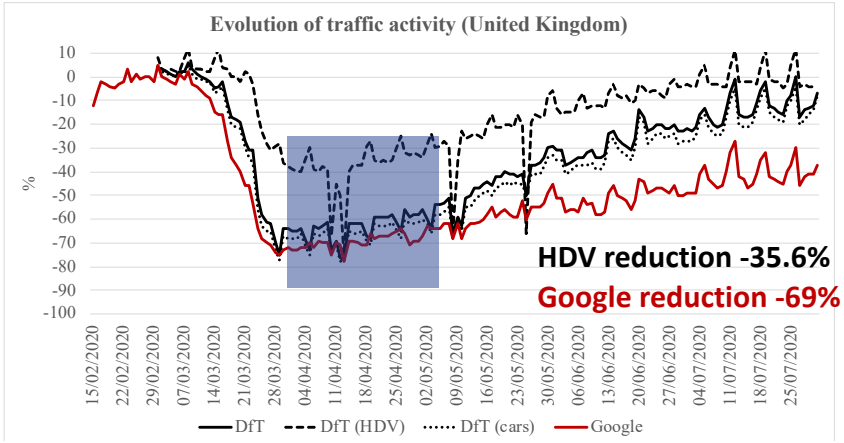
GNFR F: Road transport

Based on the Google COVID-19 Mobility Reports (Google, 2020) - Transit stations category

Replaced by national trends derived from measured traffic count information where available

Limitation 2: Google trends are not representative of the observed changes in heavy-duty vehicle's activity. Current reduction factors may overestimate the overall reduction of emissions, especially in interurban roads





Similar pattern observed for: Switzerland, Germany, Denmark, Italy, France, Poland, Spain

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Emission reduction factors

GNFR_C: Other stationary combustion activities

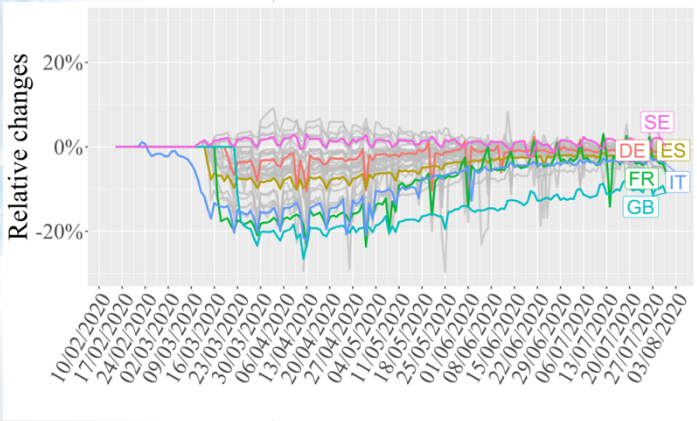
Based on the Google COVID-19 Mobility Reports (Google, 2020) – Residence/Workplaces/Retailing stations category

Original values (changes in movements) were scaled to fit max/min observed changes in energy consumption

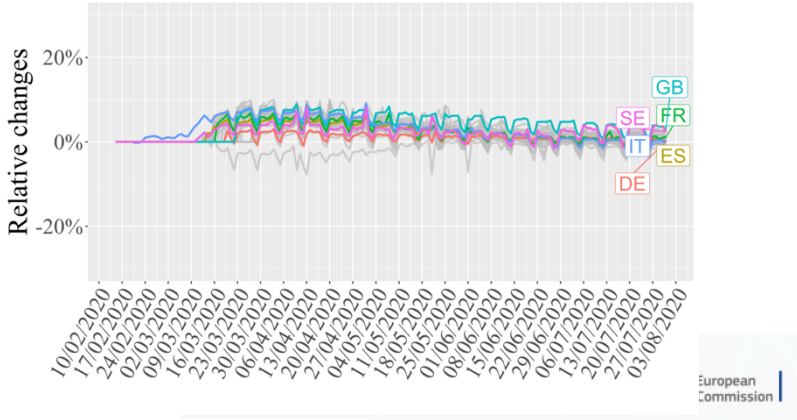
Opposite trends in subcategories
- Commercial/institutional ⬇⬇
- Residential ⬆
- Agriculture/fishing/forestry ≈

\+ contribution to total emissions varies per pollutant

GNFR_C: Other Stationary Combustion (NO_x)



GNFR_C: Other Stationary Combustion (PM_{10})



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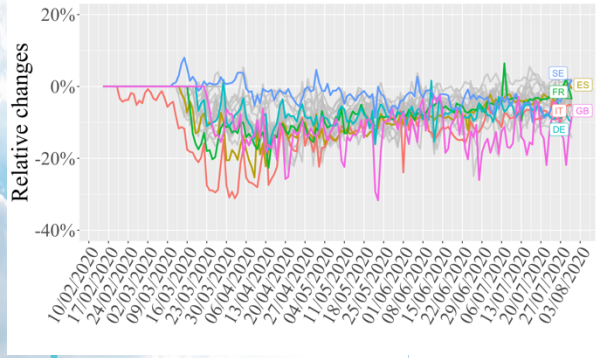
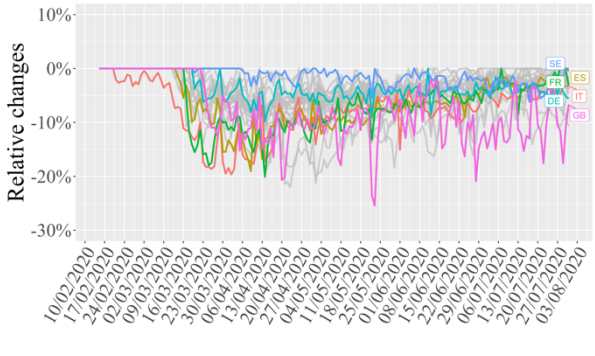
Emission reduction factors

Final product: Open-source dataset of daily emission reduction factors expressed as % of emission changes compared to a business as usual scenario (no COVID-19 measures).

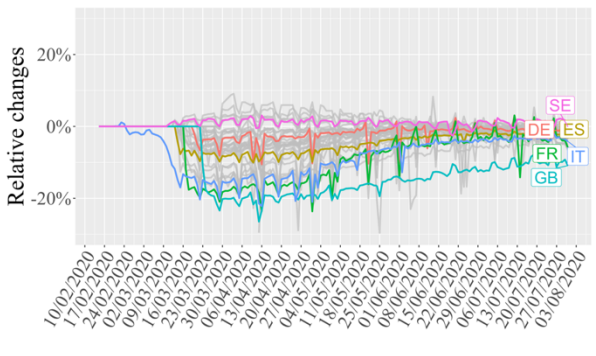
Public Energy



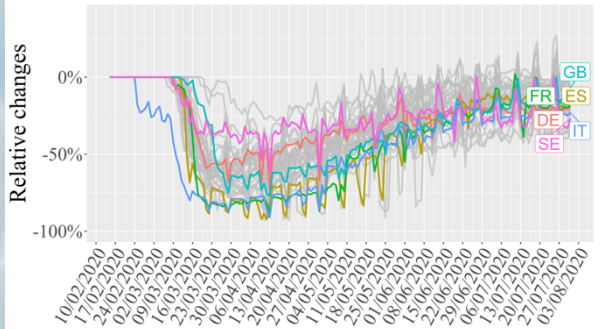
Manufacturing Industry



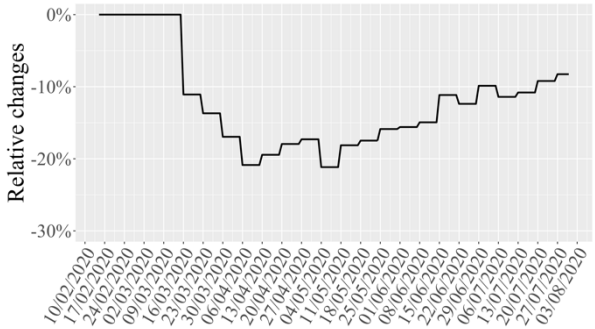
Other Stationary Combustion activities (NO_x)



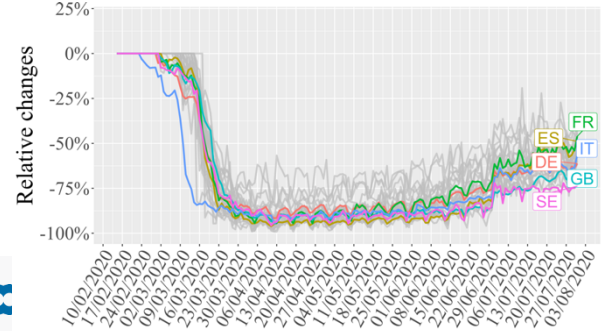
Road Transport



Shipping



Aviation



Adaptation for modelling purposes

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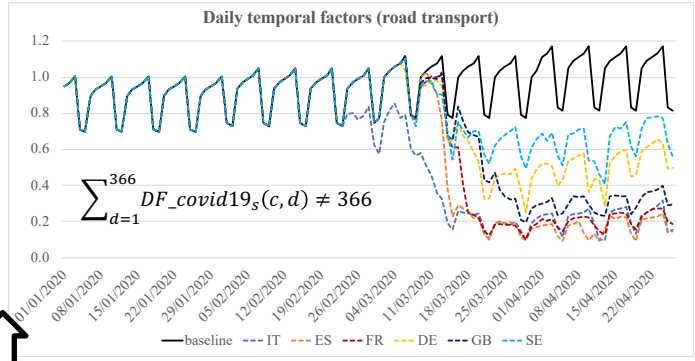
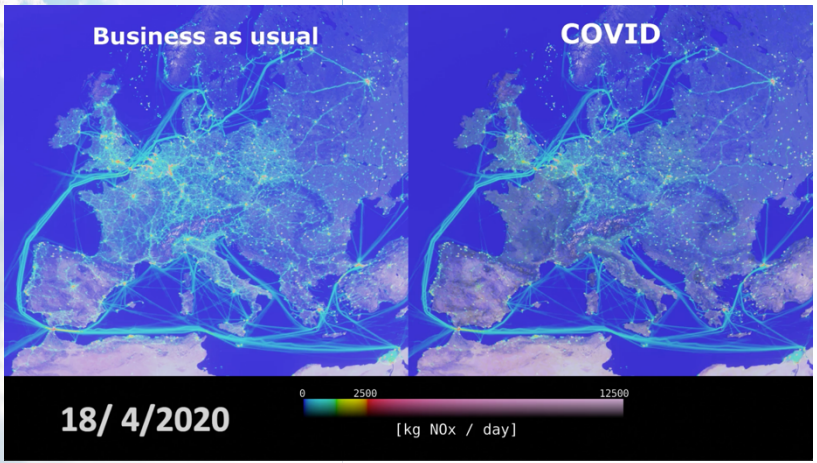
1. Development of COVID-19 daily emission temporal profiles using:

- $DF_s(d)$: TNO temporal profiles per sector (Denier van der Gon et al., 2011)
- $RF_s(c)$: Computed emission reduction factors per sector/country

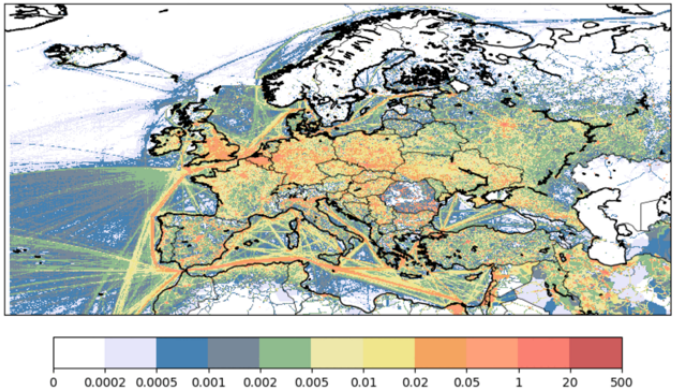
$$DF\_covid19_s(c,d) = DF_s(d) * \left(1 + \frac{RF_s(c)}{100}\right)$$



2. Processing of the annual CAMS-REG inventory (Kuenen et al. 2020, in preparation) using the HERMESv3 system (Guevara et al., 2019)



3. Time-resolved emission reductions for AQ modelling



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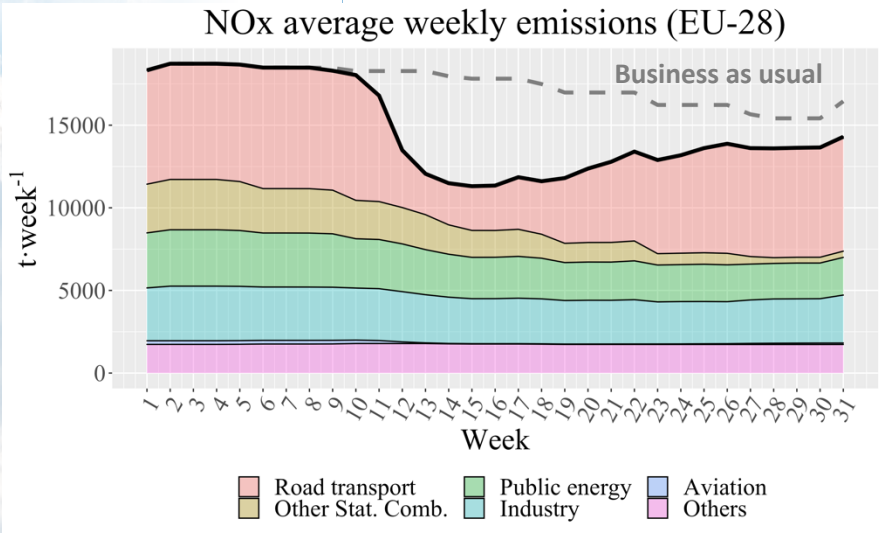
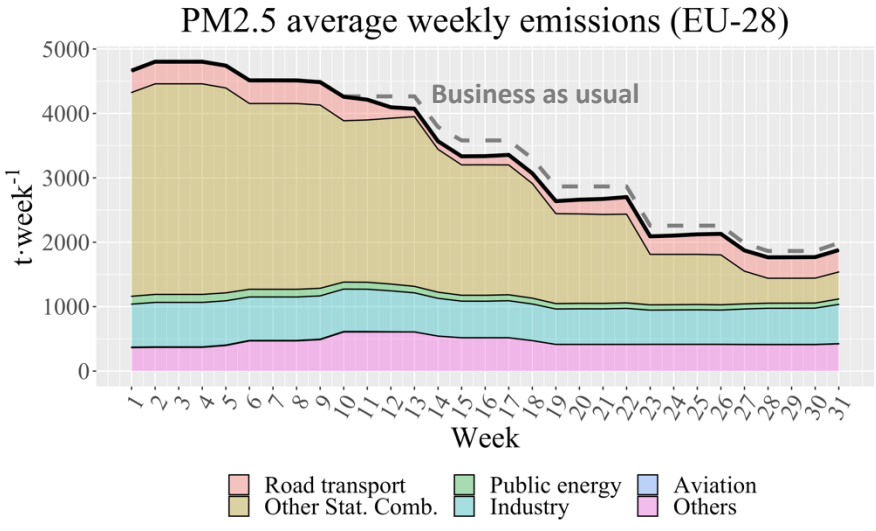
Emission modelling results for EU

Heterogeneous impact on total emission changes as a function of the pollutant:

- **NO_x** average reduction: -15.2% ; maximum reduction: -36.5% (week 15)
- **$PM_{2.5}$** average reduction: -3.2% ; maximum reduction: -7.9% (week 19)

Emissions changes mainly driven by road transport sector and its contribution to total emissions





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Conclusions & Future works

- We constructed a dataset of daily-, sector-, pollutant- and country-dependent emission reduction factors that allows quantifying the impact of the COVID-19 measures on European primary emissions.

- The computed emission reduction factors can be combined with the Copernicus CAMS European emission inventory using adjusted temporal profiles in order to derive time-resolved emissions for AQ modelling.

- Large contrast between NO_x and $PM_{2.5}$ emission reductions, which is in line with results found through the analysis of air quality ground-based and satellite observations

- The dataset is readily available upon request and a description/evaluation of a previous version is available at Guevara et al. (2020, ACPD).

- Road traffic is driving the main changes in EU emissions, and therefore there is a need to amend identified shortcomings of the Google movement trends :
  - Correcting the general underestimation observed during lockdown exit process
  - Discriminating between passenger cars' and heavy-duty vehicles' activity changes

- The evaluation of the constructed emission reduction factors in reproducing observed changes in European air pollutants (NO_2, O_3 , PM) will be addressed in the future.

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