Supplement of:

Sensitivity of air quality indicators to emission inventories (EDGAR, EMEP, CAMS-REG) in Europe through FAIRMODE benchmarking methodology.

Alexander de Meij[1], Cornelis Cuvelier[2♦], Philippe Thunis[2], Enrico Pisoni[2], Bertrand Bessagnet[2]
[1]MetClim, Varese, 21025, Italy
[2] European Commission, Joint Research Centre (JRC), 21027, Ispra, Italy
♦ retired with Active Senior Agreement

Table S1 List of local domains selected, with their corresponding area for emission reductions.

Country	City		lon min	lon max	lat min	lat max
Belgium	Brussels	BRU	4.05	4.65	50.55	51.15
Germany	Berlin	BER	12.76	14.06	51.87	53.17
Italy	Rome	ROM	12.09	12.89	41.5	42.3
Spain	Madrid	MAD	-4.15	-3.25	39.96	40.86
Sweden	Stockholm	STO	17.62	18.52	58.88	59.78
Romania	Bucharest	BUC	25.90	26.30	44.23	44.63
Malopolska region		MAL	18.0	23.0	48.7	51.5
Po Valley		POV	6.5	14.0	43.5	47.0

Table S2 Overview GNFR sectors

GNFR sector
A PublicPower
B Industry
C OtherStationaryComb
D Fugitive
E Solvents
F RoadTransport
G Shipping
H Aviation
I OffRoad
J Waste
K AgriLiveStock
L AgriOther
M Other

Table S3. Overview total emissions per emission inventory for the different locations, mg/m2/day

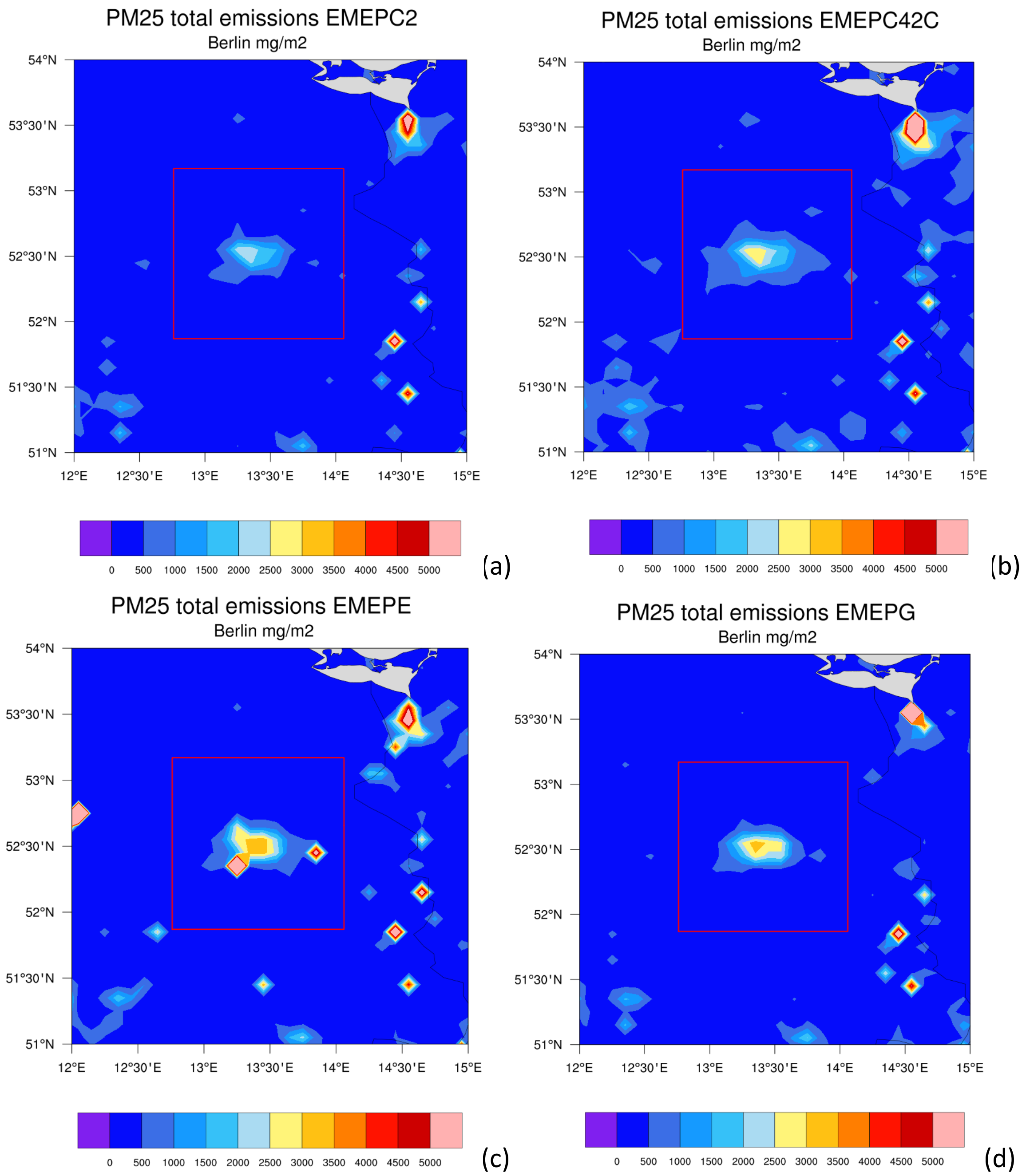
PPM	EMEPE	EMEPG	EMEPC2	EMEPC42C
Berlin	1.82	1.38	1.64	1.93
Brussels	4.38	4.34	5.19	4.94
Bucharest	7.63	3.06	8.04	8.16
Madrid	3.24	2.41	3.06	3.47
Malopolska	3.49	2.41	2.68	3.21
Po Valley	1.65	1.45	1.40	1.51
Rome	2.63	2.48	2.44	2.52
Stockholm	3.33	3.09	1.69	2.19

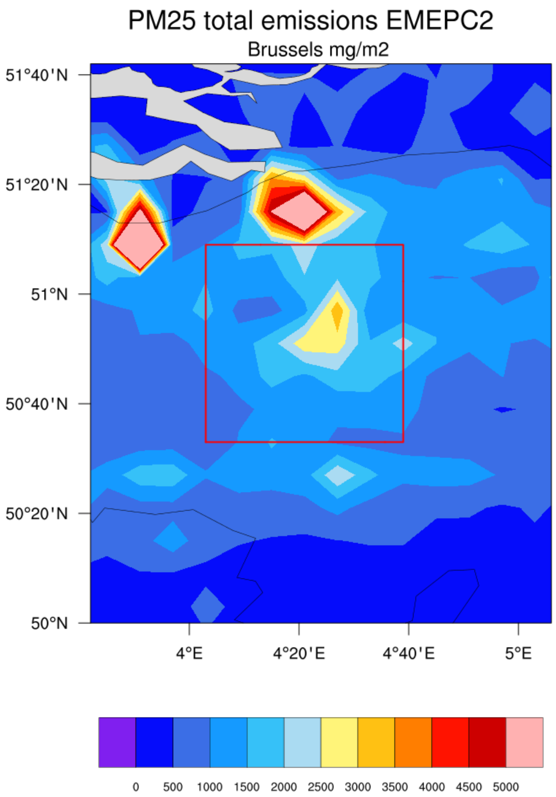
VOC	EMEPE	EMEPG	EMEPC2	EMEPC42C
Berlin	15.65	7.67	8.55	8.78
Brussels	40.50	15.29	16.13	14.93
Bucharest	26.35	15.73	28.15	21.40
Madrid	21.28	18.97	20.31	19.00
Malopolska	12.11	6.71	6.35	7.06
Po Valley	6.65	6.72	6.08	5.74
Rome	21.05	16.66	17.69	16.02
Stockholm	18.13	7.63	9.69	9.46

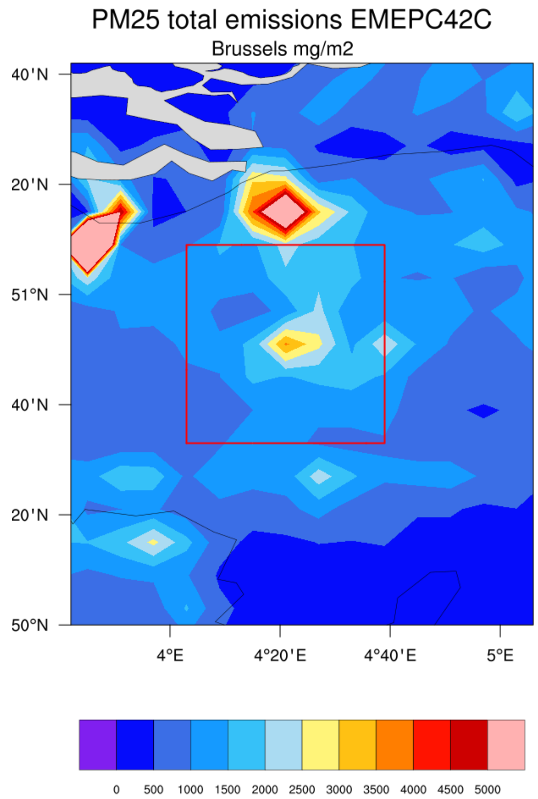
NOx	EMEPE	EMEPG	EMEPC2	EMEPC42C
Berlin	9.76	8.50	7.72	8.24
Brussels	31.57	27.21	31.05	28.16
Bucharest	13.94	17.01	19.93	18.28
Madrid	16.15	16.59	19.44	15.05
Malopolska	7.36	7.79	8.20	8.04
Po Valley	5.23	5.62	5.48	5.16
Rome	12.01	11.54	12.26	10.11
Stockholm	10.71	7.41	7.01	6.03

SOx	EMEPE	EMEPG	EMEPC2	EMEPC42C
Berlin	3.82	1.48	1.65	1.57
Brussels	7.23	2.56	3.07	2.75
Bucharest	9.51	7.49	5.95	6.00
Madrid	6.54	2.43	2.56	2.69
Malopolska	8.72	8.71	8.69	8.86
Po Valley	1.31	0.73	0.82	0.81
Rome	2.25	0.74	0.94	0.79
Stockholm	11.43	0.67	1.03	0.80

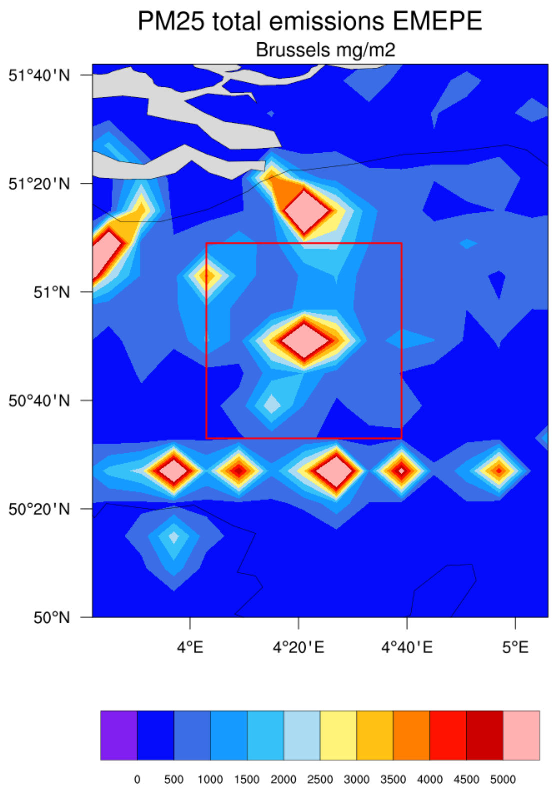
NH3	EMEPE	EMEPG	EMEPC2	EMEPC42C
Berlin	4.02	2.26	3.77	3.25
Brussels	7.69	3.34	5.36	5.11
Bucharest	3.34	4.40	6.89	6.69
Madrid	3.24	1.91	3.13	3.60
Malopolska	3.52	1.27	1.79	2.05
Po Valley	4.58	3.16	3.24	3.17
Rome	3.65	2.41	2.52	1.88
Stockholm	1.67	0.61	1.06	0.60

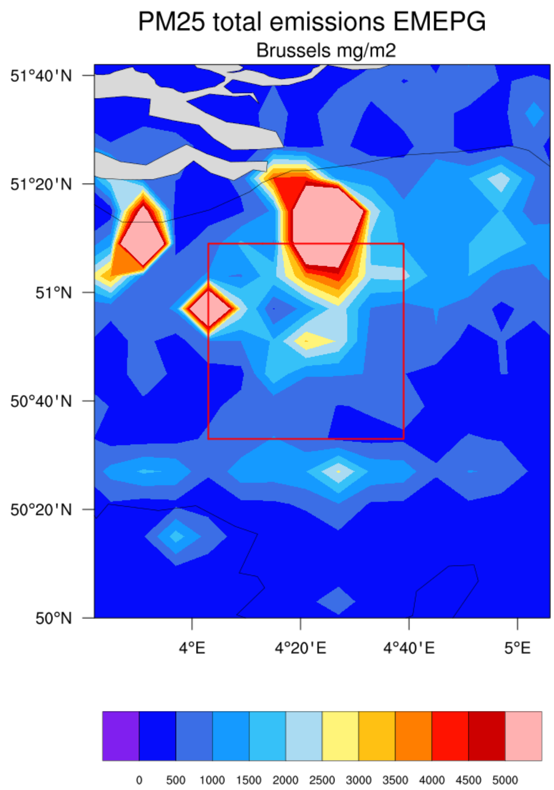

PM25 total emissions EMEPC2
Berlin mg/m2
54°N
53°30'N
53°N
52°30'N
52°N
51°30'N
51°N
12°E
12°30'E
13°E
13°30'E
14°E
14°30'E
15°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
(a)
PM25 total emissions EMEPC42C
Berlin mg/m2
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
(b)
PM25 total emissions EMEPE
Berlin mg/m2
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
(c)
PM25 total emissions EMEPG
Berlin mg/m2
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
(d)


PM25 total emissions EMEPC2
Brussels mg/m2
51°40'N
51°20'N
51°N
50°40'N
50°20'N
50°N
4°E
4°20'E
4°40'E
5°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

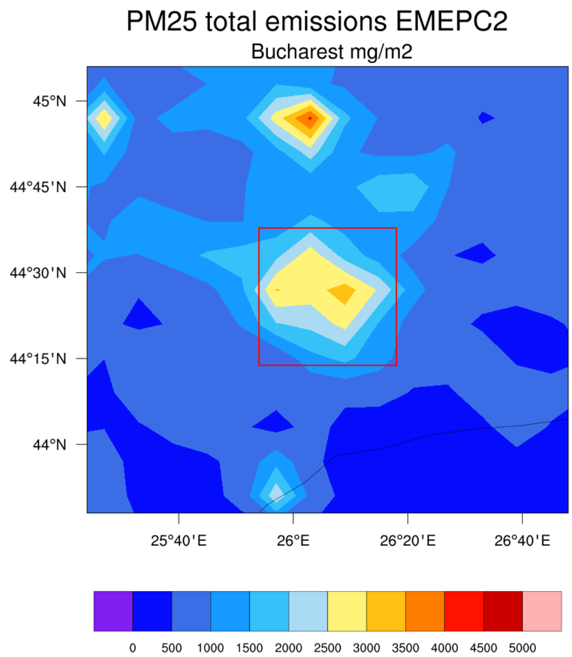

PM25 total emissions EMEPC42C
Brussels mg/m2
40'N
20'N
51°N
40'N
20'N
50°N
4°E
4°20'E
4°40'E
5°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

(e) (f)

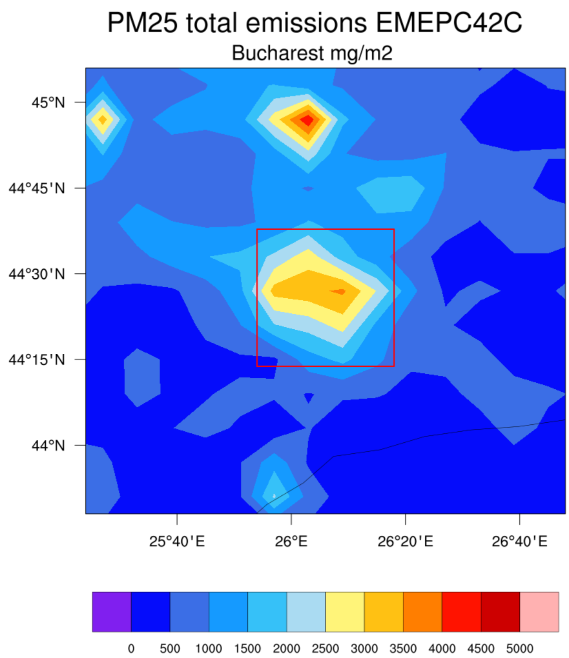

PM25 total emissions EMEPE
Brussels mg/m2
51°40'N
51°20'N
51°N
50°40'N
50°20'N
50°N
4°E
4°20'E
4°40'E
5°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000


PM25 total emissions EMEPG
Brussels mg/m2
51°40'N
51°20'N
51°N
50°40'N
50°20'N
50°N
4°E
4°20'E
4°40'E
5°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

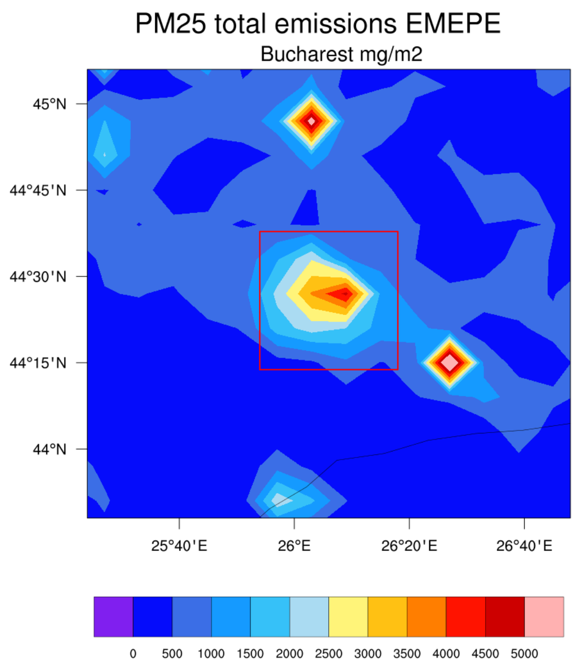
35 (g) (h)


PM25 total emissions EMEPC2
Bucharest mg/m2
45°N
44°45'N
44°30'N
44°15'N
44°N
25°40'E
26°E
26°20'E
26°40'E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

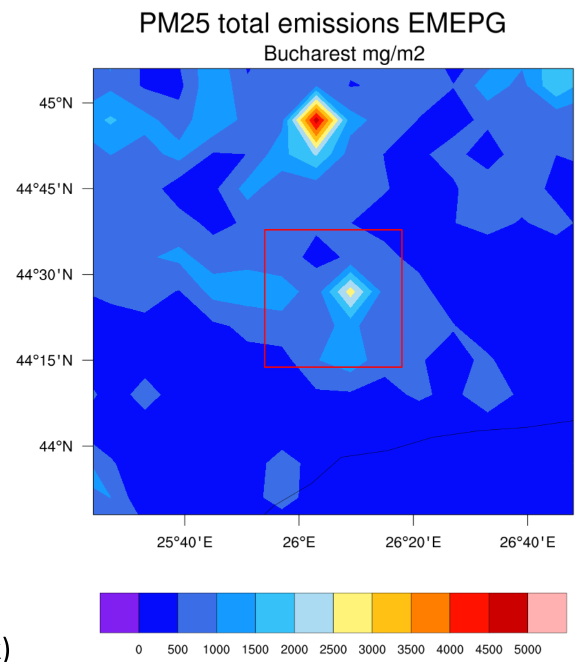
(i)


PM25 total emissions EMEPC42C
Bucharest mg/m2
45°N
44°45'N
44°30'N
44°15'N
44°N
25°40'E
26°E
26°20'E
26°40'E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

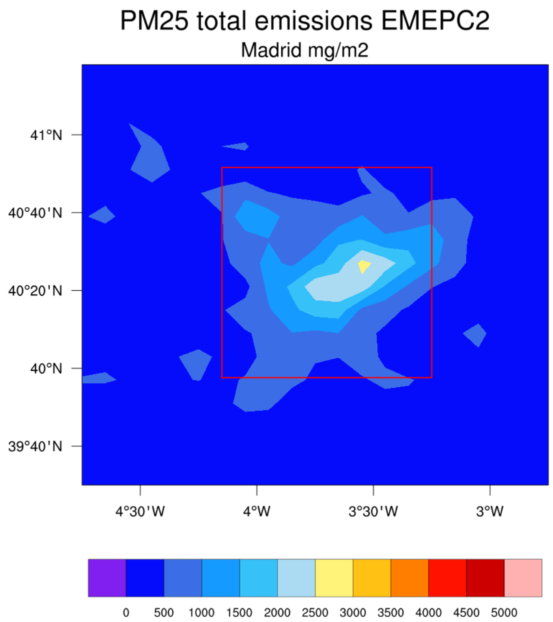
(j)


PM25 total emissions EMEPE
Bucharest mg/m2
45°N
44°45'N
44°30'N
44°15'N
44°N
25°40'E
26°E
26°20'E
26°40'E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

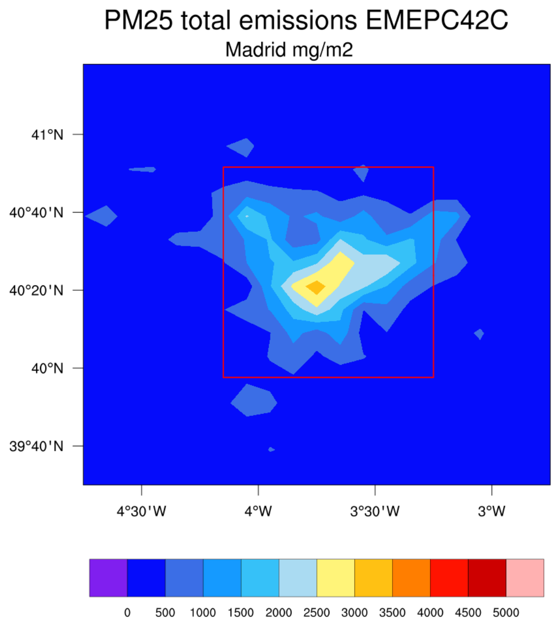
(k)


PM25 total emissions EMEPG
Bucharest mg/m2
45°N
44°45'N
44°30'N
44°15'N
44°N
25°40'E
26°E
26°20'E
26°40'E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

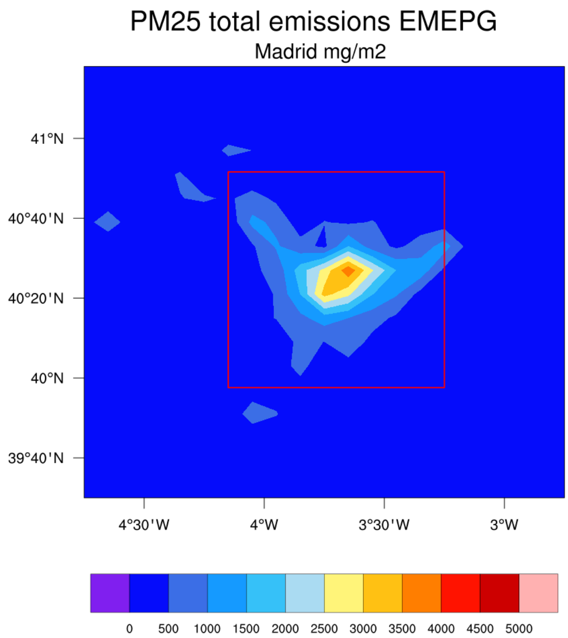
(l)


PM25 total emissions EMEPC2
Madrid mg/m2
41°N
40°40'N
40°20'N
40°N
39°40'N
4°30'W
4°W
3°30'W
3°W
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

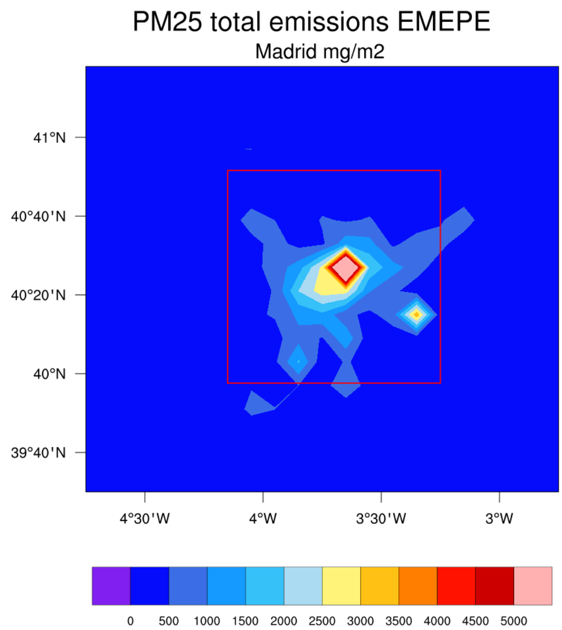
(m)


PM25 total emissions EMEPC42C
Madrid mg/m2
41°N
40°40'N
40°20'N
40°N
39°40'N
4°30'W
4°W
3°30'W
3°W
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

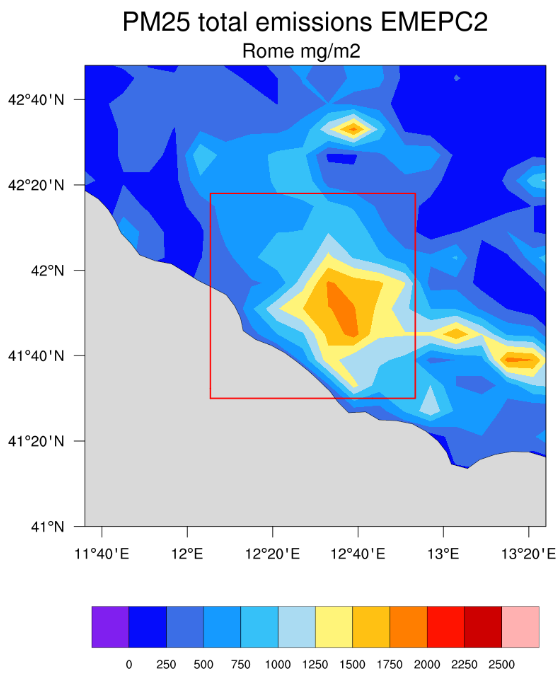
(n)


PM25 total emissions EMEPG
Madrid mg/m2
41°N
40°40'N
40°20'N
40°N
39°40'N
4°30'W
4°W
3°30'W
3°W
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

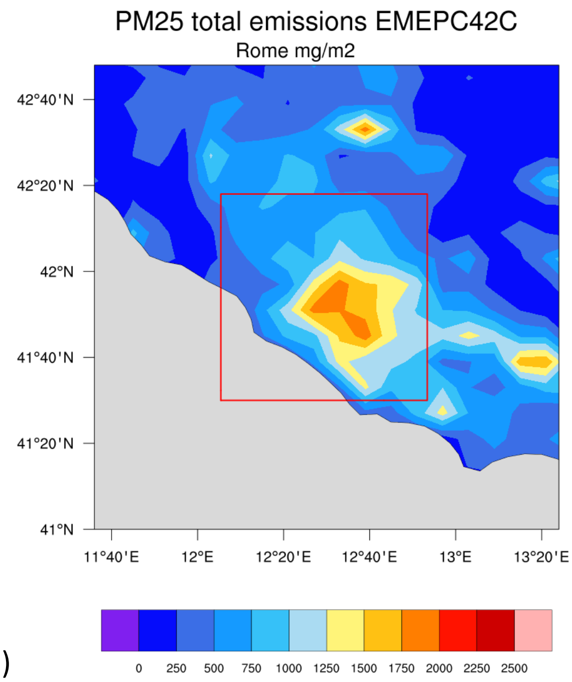
(o)


PM25 total emissions EMEPE
Madrid mg/m2
41°N
40°40'N
40°20'N
40°N
39°40'N
4°30'W
4°W
3°30'W
3°W
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

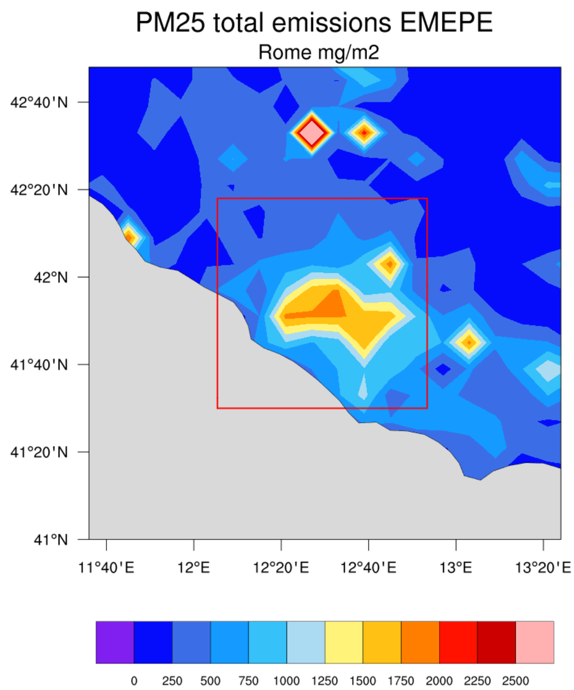
(p)


PM25 total emissions EMEPC2
Rome mg/m2
42°40'N
42°20'N
42°N
41°40'N
41°20'N
41°N
11°40'E
12°E
12°20'E
12°40'E
13°E
13°20'E
0 250 500 750 1000 1250 1500 1750 2000 2250 2500

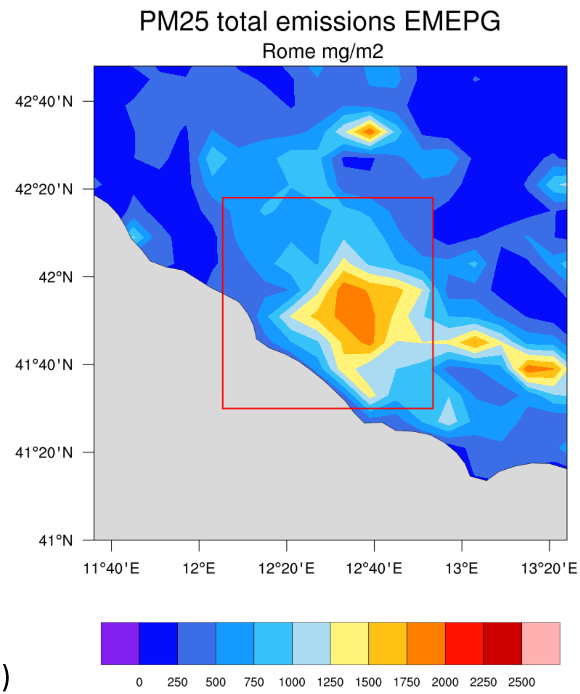
(q)


PM25 total emissions EMEPC42C
Rome mg/m2
42°40'N
42°20'N
42°N
41°40'N
41°20'N
41°N
11°40'E
12°E
12°20'E
12°40'E
13°E
13°20'E
0 250 500 750 1000 1250 1500 1750 2000 2250 2500

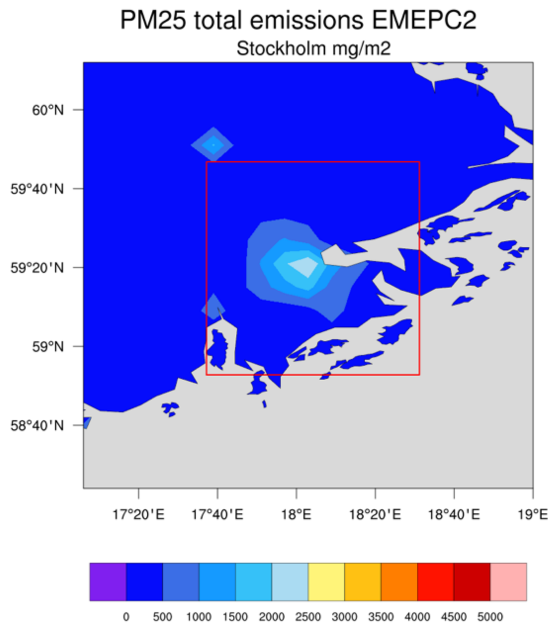
(r)


PM25 total emissions EMEPE
Rome mg/m2
42°40'N
42°20'N
42°N
41°40'N
41°20'N
41°N
11°40'E
12°E
12°20'E
12°40'E
13°E
13°20'E
0 250 500 750 1000 1250 1500 1750 2000 2250 2500

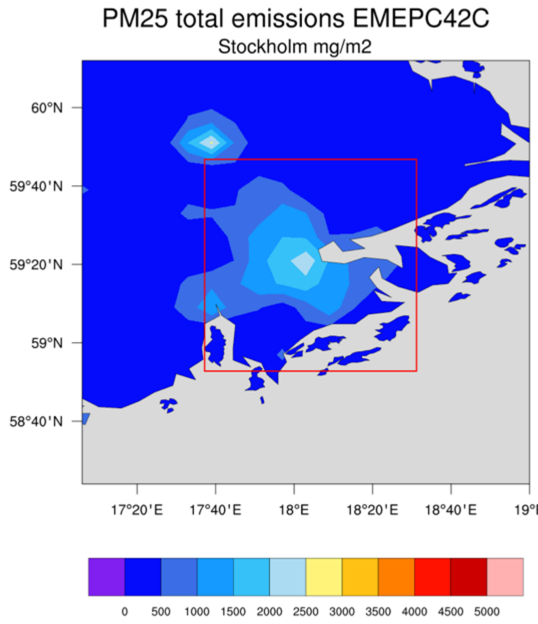
(s)


PM25 total emissions EMEPG
Rome mg/m2
42°40'N
42°20'N
42°N
41°40'N
41°20'N
41°N
11°40'E
12°E
12°20'E
12°40'E
13°E
13°20'E
0 250 500 750 1000 1250 1500 1750 2000 2250 2500

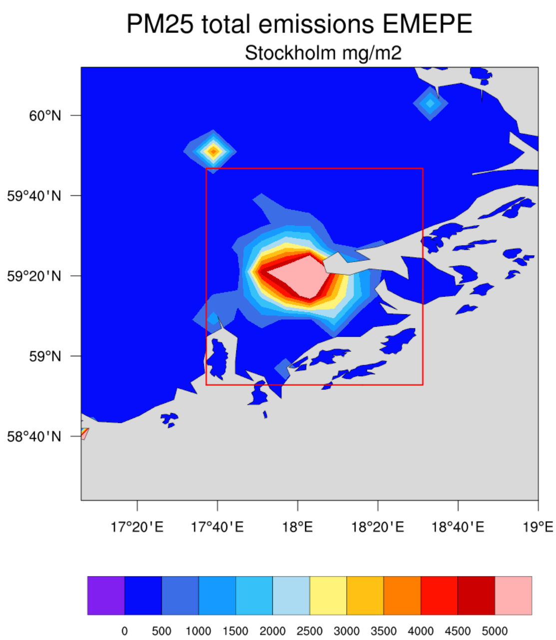
(t)


PM25 total emissions EMEPC2
Stockholm mg/m2
60°N
59°40'N
59°20'N
59°N
58°40'N
17°20'E
17°40'E
18°E
18°20'E
18°40'E
19°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

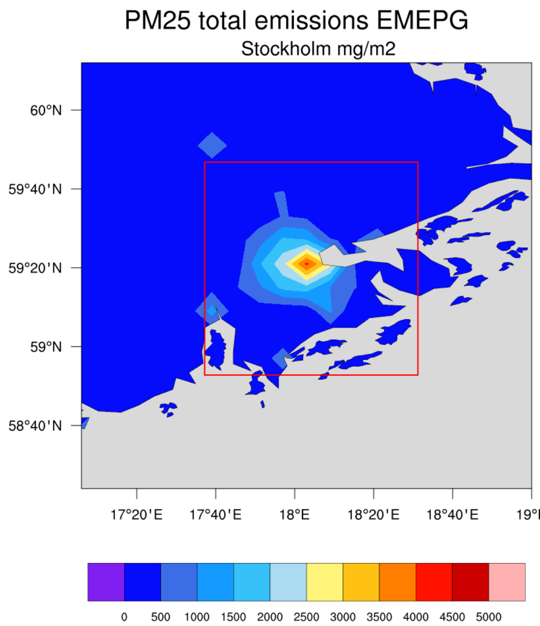
(u)


PM25 total emissions EMEPC42C
Stockholm mg/m2
60°N
59°40'N
59°20'N
59°N
58°40'N
17°20'E
17°40'E
18°E
18°20'E
18°40'E
19°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

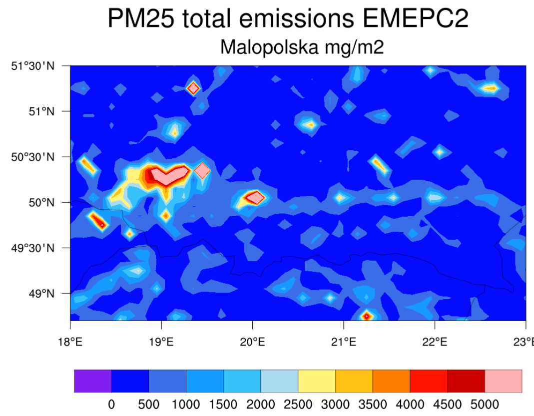
(v)


PM25 total emissions EMEPE
Stockholm mg/m2
60°N
59°40'N
59°20'N
59°N
58°40'N
17°20'E
17°40'E
18°E
18°20'E
18°40'E
19°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

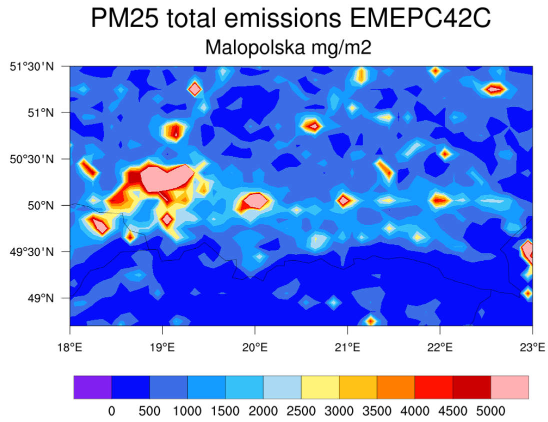
(w)


PM25 total emissions EMEPG
Stockholm mg/m2
60°N
59°40'N
59°20'N
59°N
58°40'N
17°20'E
17°40'E
18°E
18°20'E
18°40'E
19°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

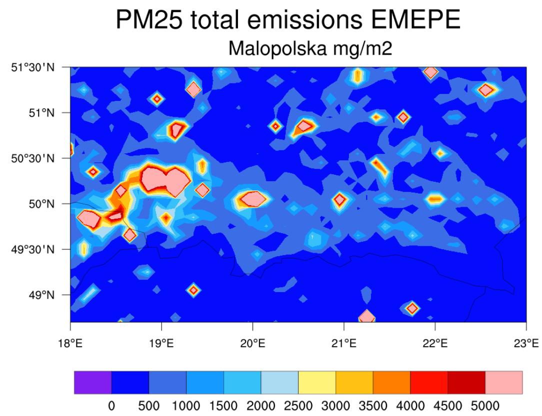
(x)


PM25 total emissions EMEPC2
Malopolska mg/m2
51°30'N
51°N
50°30'N
50°N
49°30'N
49°N
18°E
19°E
20°E
21°E
22°E
23°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

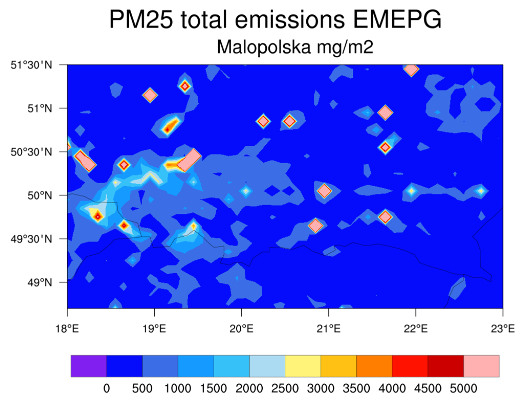
(y)


PM25 total emissions EMEPC42C
Malopolska mg/m2
51°30'N
51°N
50°30'N
50°N
49°30'N
49°N
18°E
19°E
20°E
21°E
22°E
23°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

(z)


PM25 total emissions EMEPE
Malopolska mg/m2
51°30'N
51°N
50°30'N
50°N
49°30'N
49°N
18°E
19°E
20°E
21°E
22°E
23°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

(aa)


PM25 total emissions EMEPG
Malopolska mg/m2
51°30'N
51°N
50°30'N
50°N
49°30'N
49°N
18°E
19°E
20°E
21°E
22°E
23°E
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

(ab)

55

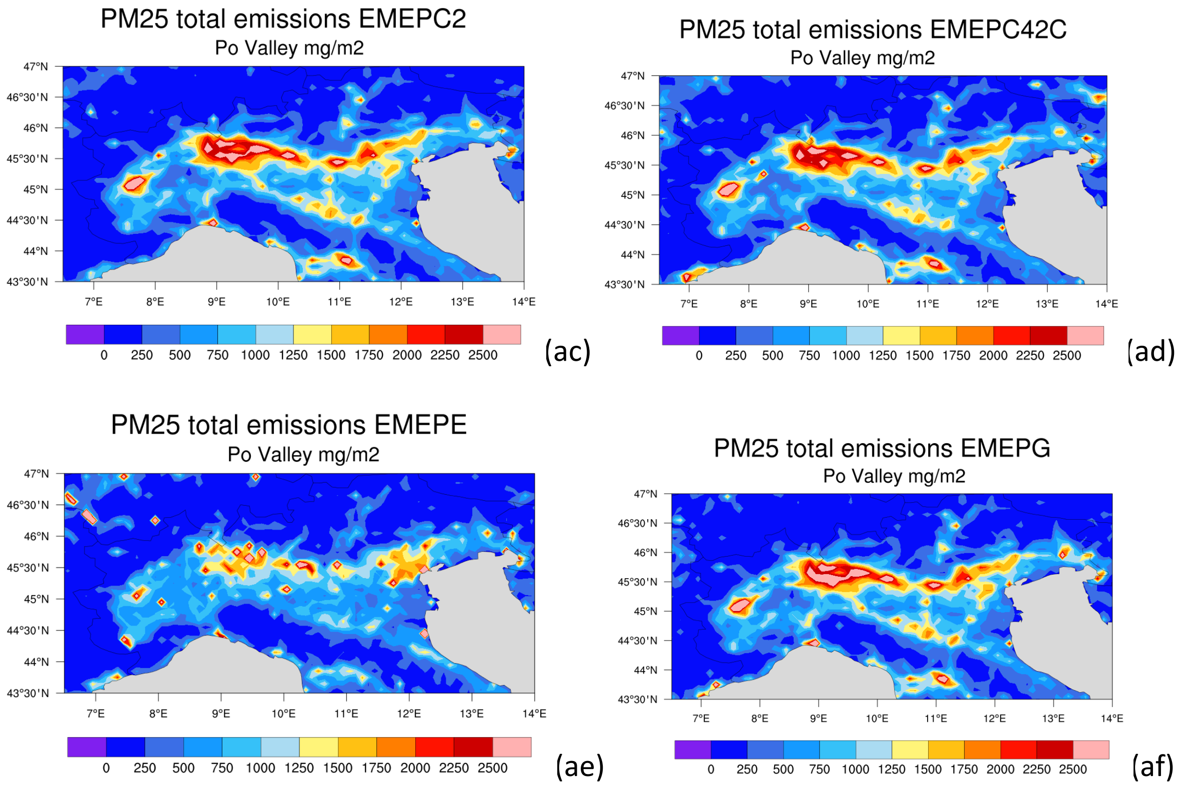


Figure S1: PM25 geographical distribution (mg/m2/year) for EMEPC2, EMEPC42C, EMEPE and EMEPG for Berlin, (a-d) Brussels (e-h), Bucharest (i-l), Madrid (m-p), Rome (q-t), Stockholm (u-x), Malopolska (y-ab) and Po Valley (ac-af). The red rectangle represents the area for which the emissions were reduced, as indicated in Table S1.

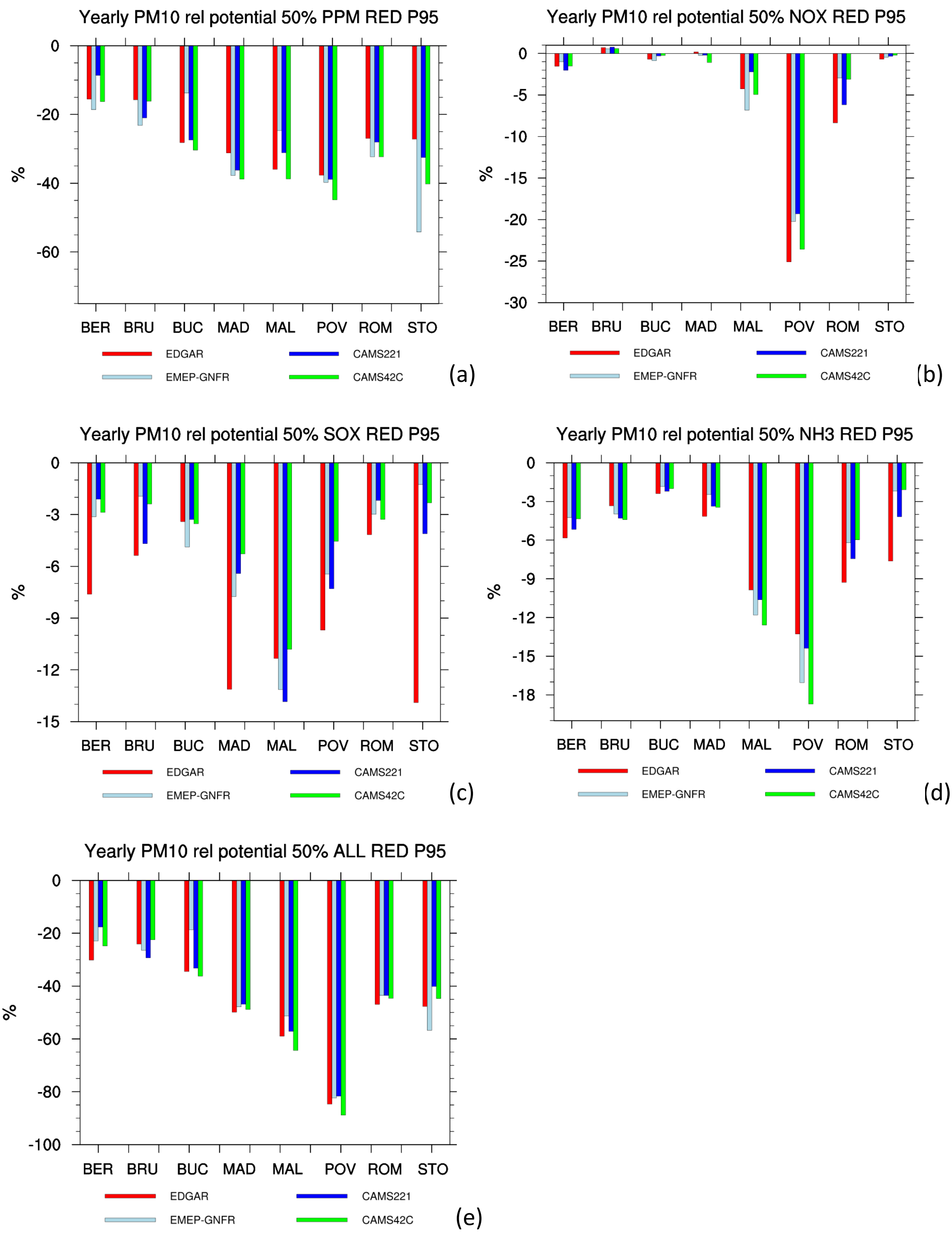


Figure S2: Yearly average relative potential for 50% reduction of (a) NOx, (b) SOx, (c) NH3 and (d) all precursors together (ALL: VOC, SOx, NH3, PPM) on relative PM10 concentration change. The values given represent 95 Percentile values (P95), showing the highest 5% values in the domain for the BaseCase. EMEPE (red), EMEPG (light blue), EMEPC2 (blue) and EMEPC42C (green), for the eight locations (Berlin, Brussels, Bucharest, Madrid, Malopolska region, Po Valley region, Rome and Stockholm.

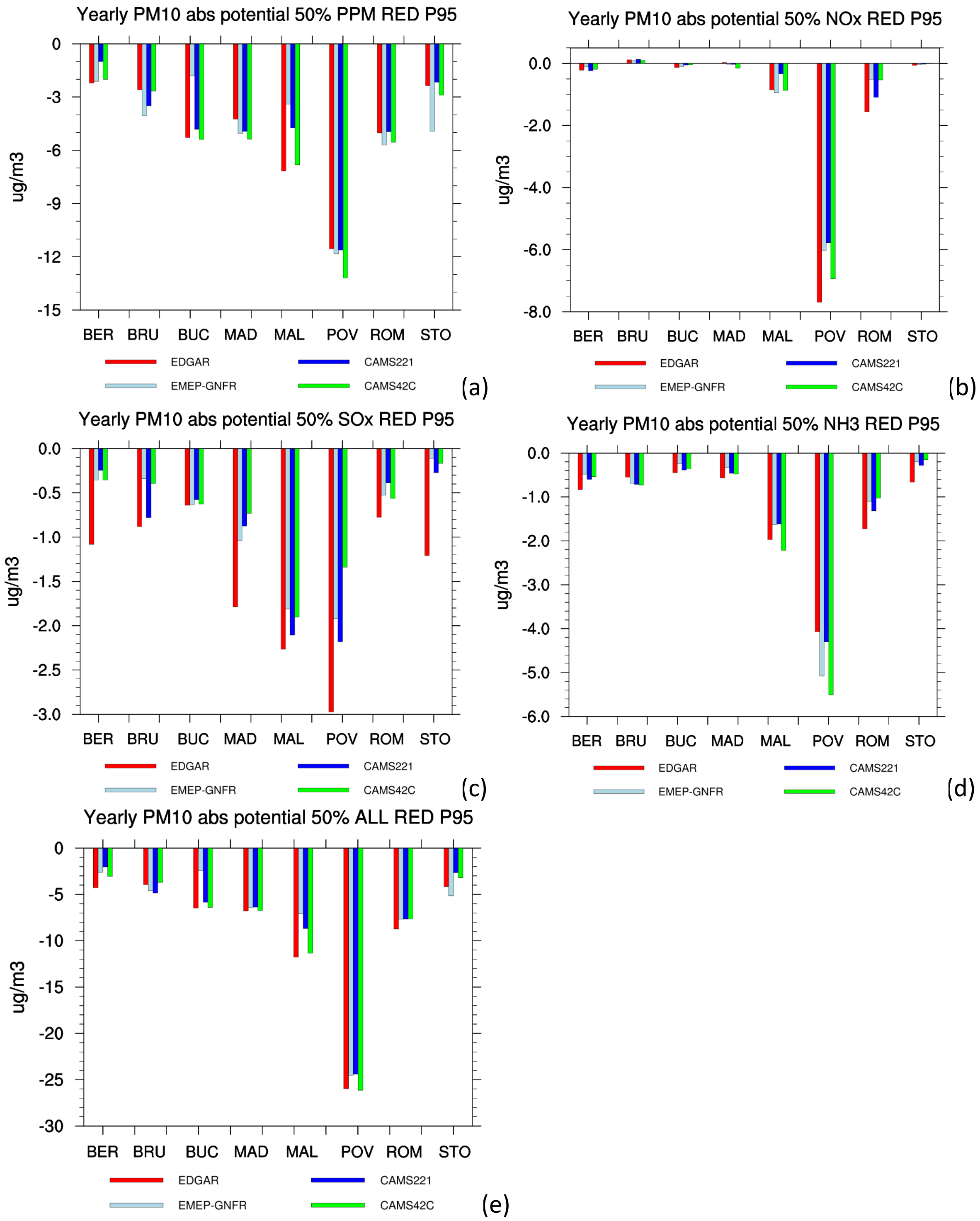


Figure S3: Yearly average absolute potential for 50% reduction of (a) NOx, (b) SOx, (c) NH3 and (d) all precursors together (ALL: VOC, SOx, NH3, PPM) on relative PM10 concentration change. The values given represent 95 Percentile values (P95), showing the highest 5% values in the domain for the BaseCase. EMEPE (red), EMEPG (light blue), EMEPC2(blue) and EMEPC42C (green), for the eight locations (Berlin, Brussels, Bucharest, Madrid, Malopolska region, Po Valley region, Rome and Stockholm.

When NOx emissions are reduced by 50% (Fig. S2 and S3), we see in general a decrease in calculated PM10 concentrations, but for Brussels we see a slight increase. The reason for this is that over urbanized areas, lower

NO2 concentrations at constant or similar VOC concentrations lead to an increase of ozone (O3) values. O3 is a reactive oxidant in natural and polluted atmosphere and increasing levels of O3 concentrations lead to an enhancement of the atmospheric oxidizing capacity, which might lead to an increase in the Secondary Organic Aerosol (SOA) formation and Organic Aerosol (OA) components (Thunis et al., 2021a and references therein).
It appears that reducing PPM emissions by 50% shows the largest effective measure to reduce PM10 concentrations when compared to the aerosol precursors.

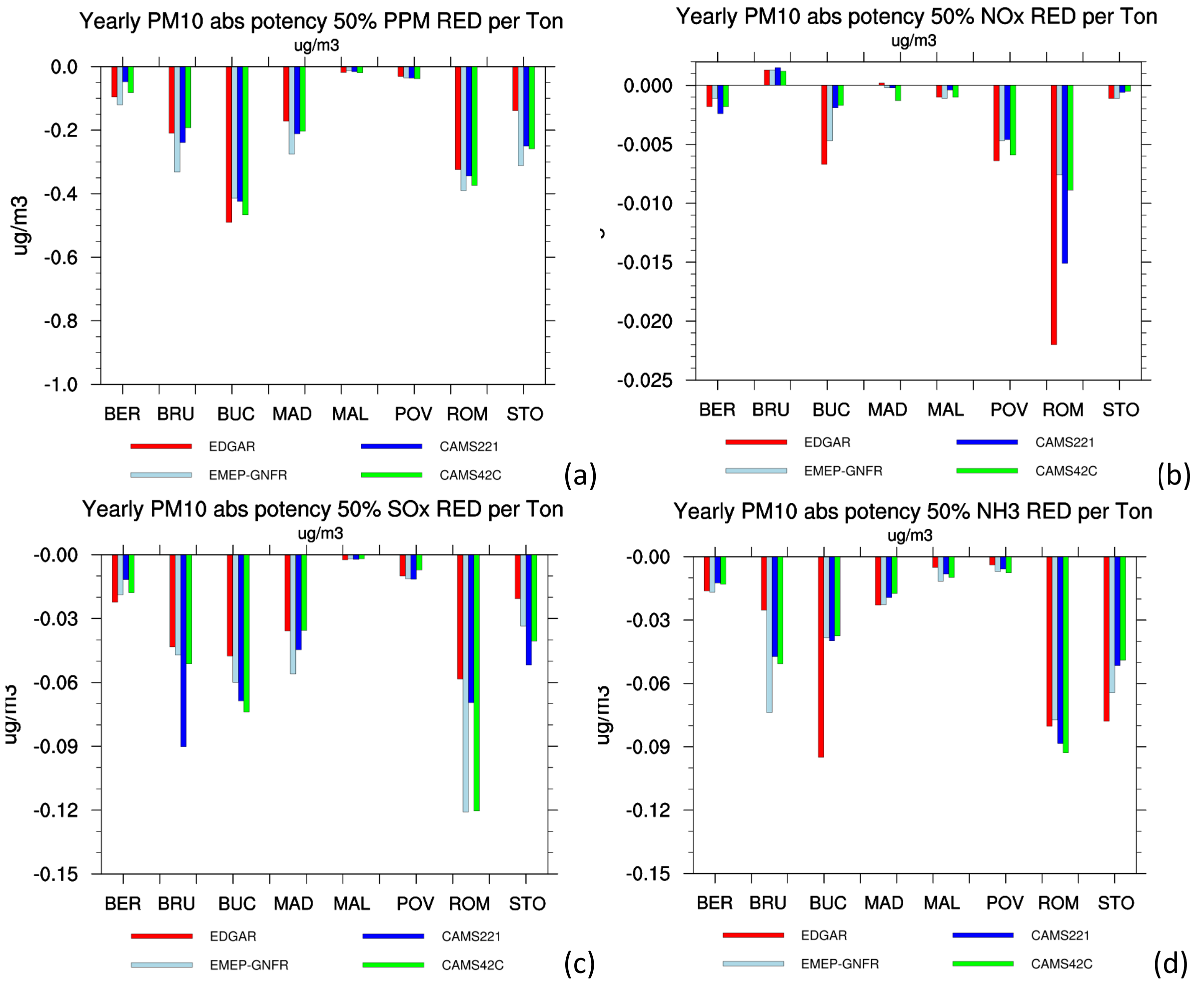


Figure S4: Yearly average absolute potency for 50% reduction of (a) PPM, (b) NOx, (c) SOx, (d) NH3 on PM10 concentration change. The values given represent 95 Percentile values, showing the highest 5% values in the domain for the BaseCase. EMEPE (red), EMEPG (light blue), EMEPC2 (blue) and EMEPC42C (green), for the eight locations (Berlin [BER], Brussels [BRU], Bucharest [BUC], Madrid [MAD], Malopolska region [MAL], Po Valley region [POV], Rome [ROM] and Stockholm [STO]).

The very low values in the potencies for Malopolska and Po Valley can be explained by the fact that we divide by the emissions that are much larger, because they cover an entire region rather than a city.

We see that the most effective reduction of the secondary aerosol part is obtained by reducing SOx emissions, because the potencies for SOx are in general higher than for NOx.

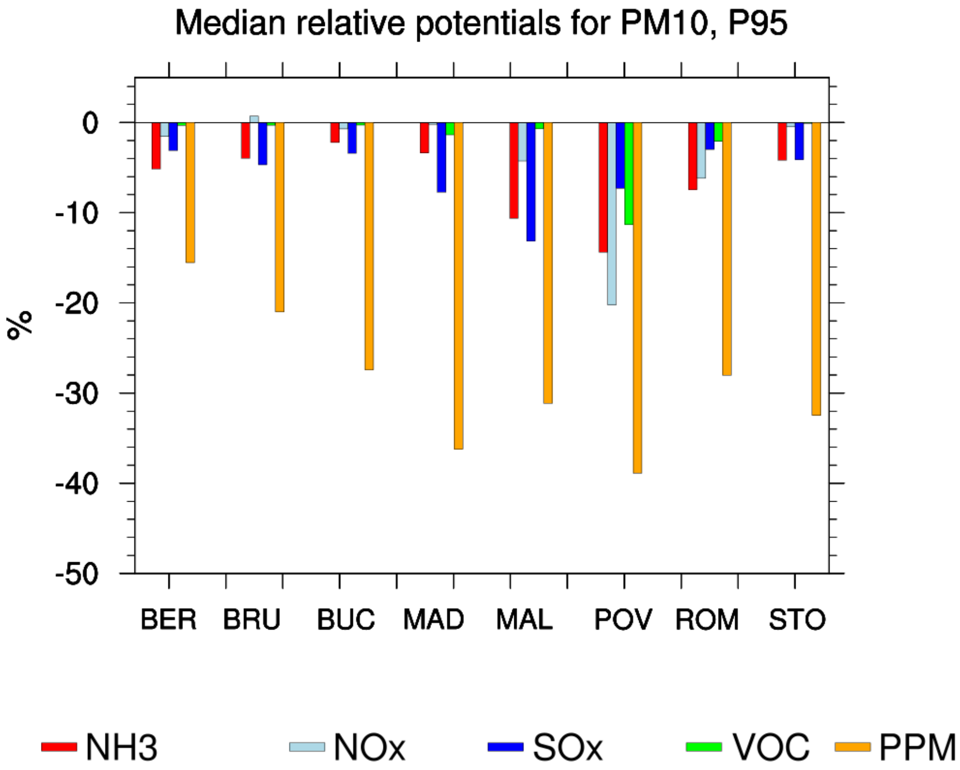


Figure S5: Median relative potential for PM10 for the eight locations, Berlin [BER], Brussels [BRU], Bucharest [BUC], Madrid [MAD], Malopolska region [MAL], Po Valley region [POV], Rome [ROM] and Stockholm [STO]). The median is based on EMEPE, EMEPC2 and EMEPG. The values given represent 95 Percentile values, showing the highest 5% values in the domain for the BaseCase.

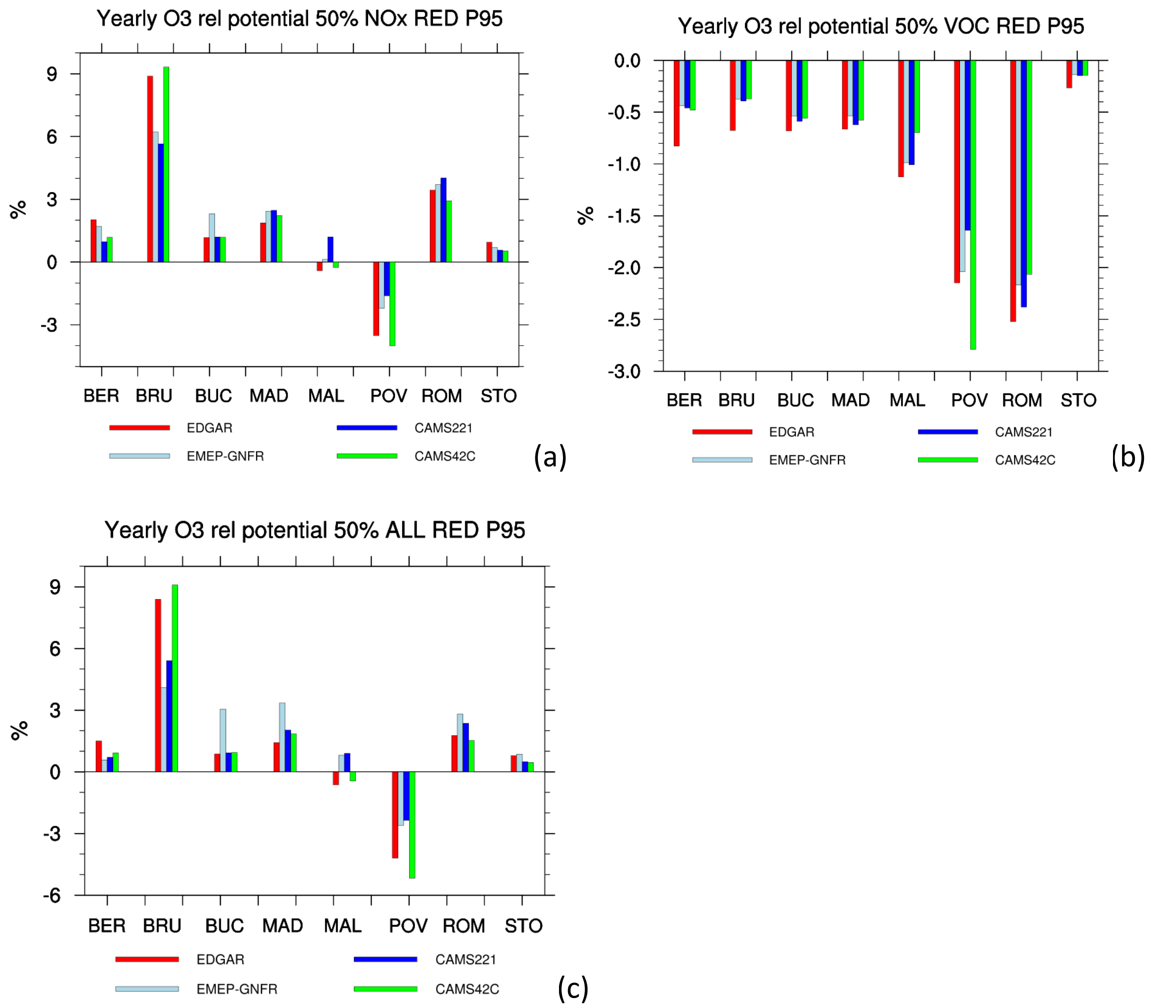


Figure S6: Yearly average relative potential for 50% reduction of (a) NOx, (b) VOC and (c) ALL (NOx + VOC) on relative O3 concentration change. The values given represent 95 Percentile values (P95), showing the highest 5% values in the domain for the BaseCase. EMEPE (red), EMEPG (light blue), EMEPC2 (blue) and EMEPC42C (green), for the eight locations (Berlin [BER], Brussels [BRU], Bucharest [BUC], Madrid [MAD], Malopolska region [MAL], Po Valley region [POV], Rome [ROM] and Stockholm [STO]).

Whether reductions in NOX or VOC emissions will lead to lower O3 concentrations depend on location and on the type of chemical regime, also better known as NOx - or VOC-limited regimes. This means that for NOx - limited regimes (locations downwind of urban and suburban areas), lowering NOx concentrations at constant VOC levels or in combination with lowering VOCs results in lower O3 peak concentrations. So, decreasing the available NOx leads directly to a decrease in ozone. In VOC-limited areas (highly polluted urban areas), where VOCs are kept constant, but NOx emissions are reduced, lead to, opposite, higher O3 concentrations (Fig. S6a). On the other hand, lowering VOCs and keeping NOx constant lead to reduced O3 values (Fig. S6b). When VOCs and NOx are decreased proportionately at the same time O3 increase (Fig. S6c).

The underlying reason for the increase when NOx emissions are reduced is that less O3 is removed by NO (NOx -titration), therefore augmenting O3 values in VOC-limited zones, as mentioned earlier. Therefore, we see in general an increase in O3 values over the urban areas. The side-effect of reducing NOx emissions in urban areas (e.g. via traffic) lead to higher O3 concentrations and possible exceedances in cities that are currently below the O3 limit values.

The negative RP and AP for POV (Fig. S6 and S7) can be explained by the fact that the domain is large when compared to cities (e.g. Brussels, Bucharest, Madrid) and that background concentrations might have an impact on the P95 values. In sub-urban and background areas O3 decrease when NOx emissions are reduced, as mentioned in the main text.

Fig. S6a shows that for Malopolska, the 50% NOx reduction can lead to an increase or decrease on O3 concentrations depending on the choice of emission inventory.

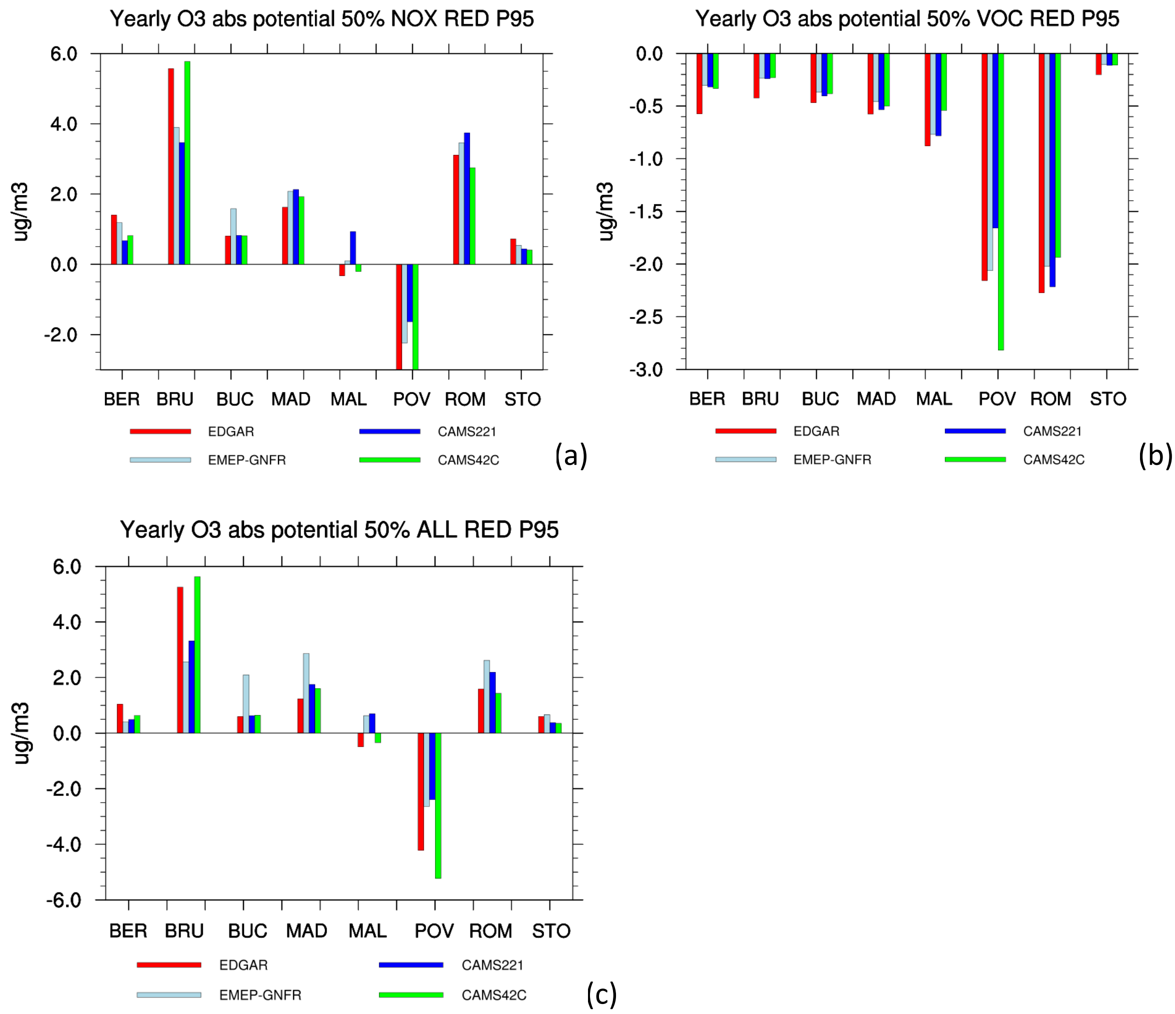


Figure S7: Yearly average absolute potential for 50% reduction of (a) NOx, (b) VOC and (c) ALL (NOx + VOC) on relative O3 concentration change. The values given represent 95 Percentile values (P95), showing the highest 5% values in the domain for the BaseCase. EMEPE (red), EMEPG (light blue), EMEPC2 (blue) and EMEPC42C (green), for the eight locations (Berlin [BER], Brussels [BRU], Bucharest [BUC], Madrid [MAD], Malopolska region [MAL], Po Valley region [POV], Rome [ROM] and Stockholm [STO]).

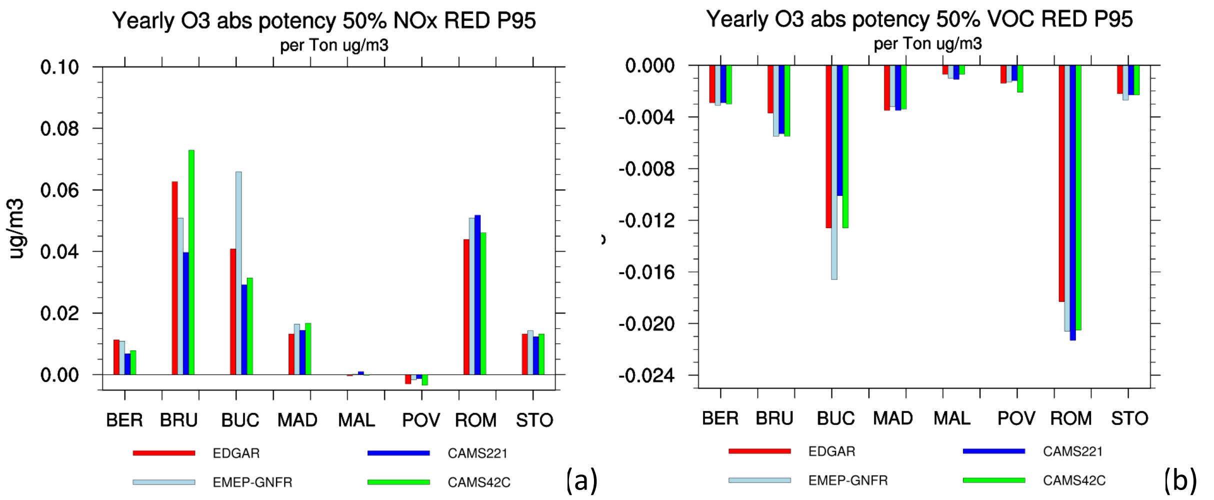


Figure S8: Yearly average potency for (a) 50% NOx and (b) 50% VOC reduction on O3 concentration change (µg/m3) per ton emission reduction by EMEPE (red), EMEPG (light blue), EMEPC2 (blue) and EMEPC42C (green), for the eight locations (Berlin [BER], Brussels [BRU], Bucharest [BUC], Madrid [MAD], Malopolska region [MAL], Po Valley region [POV], Rome [ROM] and Stockholm [STO]). The values given in (a) and (b) represent 95 Percentile values (P95), showing the highest 5% values in the domain for the BaseCase.

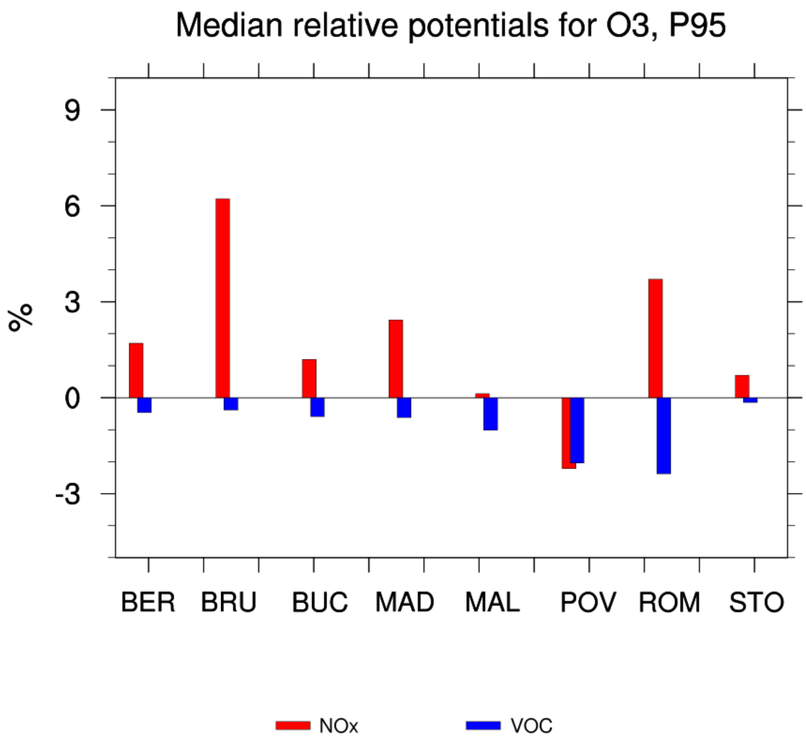


Figure S9: Median relative potential for O3 for the eight locations, Berlin [BER], Brussels [BRU], Bucharest [BUC], Madrid [MAD], Malopolska region [MAL], Po Valley region [POV], Rome [ROM] and Stockholm [STO]). The median is based on EMEPE, EMEPC2 and EMEPG. The values given represent 95 Percentile values, showing the highest 5% values in the domain for the BaseCase.