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Forty years of improvements in European air quality: regional policy-industry interactions with global impacts

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S1 Comparison of reference 2010 emissions and retrospective scenarios

Table S1.1 reports the ratios of the STAG_TECH to REF emission scenarios for the global and European scales in 2010. These ratios range from 1.06 to 2.40 for the power and industrial sectors at the global scale, corresponding to a change in technology and implementation of abatement measures; a much higher ratio of 8.6 is indeed obtained for SO_2 for road transport, reflecting the use of lower sulfur content fuels for vehicles. Much higher ratios are associated with Europe, due to the strongest impact of the implementation of European legislation. In Europe, for components other than NH_3, ratios of 1-3.2 and 6.2-8 are found for the energy sector for gaseous and particulate matter pollutants, respectively; lower ratios ranging from 1.2 to 2.6 are obtained for industry, while higher ratios are found for road transport (ranging from 2.5 to 165 for gaseous components and around 4 for PM). Further discussion on these ratios at sector level is reported in sections 3.2, 3.3 and 3.4 of the manuscript.

Table S1.1: Coupled effect of EU legislation and constant Emission Factor (EF) on pollutant emissions at global and European scales (year 2010). The ratio between STAG_TECH and REF scenarios for the year 2010 is reported for each emission sector. EU27 emission ratios are reported in brackets.

Emission sector	Emission ratio: STAG_TECH to REF (2010) – Globe (EU27)								
	SO_2	NOx	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC
Power	1.39 (3.19)	1.07 (1.70)	1.50 (1.00)	1.07 (1.10)	1.24 (2.72)	1.23 (6.28)	1.21 (6.49)	1.68 (6.18)	1.27 (7.99)
Industry	1.28 (2.02)	1.06 (1.23)	2.40 (1.63)	1.15 (1.32)	1.28 (3.87)	1.21 (1.72)	1.17 (1.58)	1.52 (2.60)	1.11 (2.42)
Road Transport	8.55 (164.76)	1.57 (2.46)	1.75 (6.05)	1.62 (5.54)	0.70 (0.18)	2.09 (4.51)	2.09 (4.50)	1.98 (4.11)	2.11 (4.48)

Table S1.2 shows the ratios between STAG_ENERGY and REF global and European emissions in 2010. Global ratios of STAG_ENERGY to REF emissions for energy are 0.12-0.26, for industry between 0.37 and 0.61, and for road-transport between 0.36 and 0.75. For Europe these ratios are 0.12-0.35 for the power generation sector, 1.59-1.93 for industry and 0.41-0.70 for road transport.

Table S1.2: Impact of 1970 energy consumption on 2010 pollutant emissions considering current energy efficiency and fuel mix. The ratio between STAG_ENERGY and REF scenarios for the year 2010 is reported for each emission sector. EU27 emission ratios are reported in brackets.

Emission sector	Emission ratio: STAG_ENERGY to REF (2010) – Globe (EU27)								
	SO_2	NOx	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC
Power	0.14 (0.13)	0.18 (0.27)	0.25 (0.31)	0.26 (0.35)	0.11 (0.17)	0.16 (0.15)	0.16 (0.16)	0.12 (0.12)	0.16 (0.17)
Industry	0.44 (1.81)	0.61 (1.83)	0.38 (1.93)	0.46 (1.84)	0.50 (1.59)	0.42 (1.75)	0.43 (1.76)	0.40 (1.78)	0.37 (1.70)
Road Transport	0.75 (0.41)	0.59 (0.46)	0.62 (0.59)	0.64 (0.70)	0.36 (0.42)	0.64 (0.42)	0.64 (0.42)	0.61 (0.44)	0.63 (0.42)

S2 Scenarios overview: emissions comparison (2010)

In this section, from Table S2.1 to Table S2.9 2010 pollutant emissions are reported for the STAG_ENERGY, STAG_TECH and REF scenarios, in decreasing order of magnitude of STAG_ENERGY for 24 world regions. All anthropogenic emission sectors are considered with the exception of large scale biomass burning, international shipping and aviation, and the sum of regional emissions corresponds to the world totals. China, India and USA are the countries contributing most to today's gaseous emissions (SO_2, NOx and CO for the REF case), as well as to the STAG_ENERGY scenario, due to their high consumption. In addition to China and India, also Africa contributes significantly to actual global PM emissions, while industrialized countries are contributing less due to the deployment of cleaner technologies and particulate abatement measures. Among all world regions, Europe shows the strongest differences between the STAG_TECH and REF scenarios due to the role played by European legislation and abatement measures included in the STAG_TECH scenario.

Table S2.1 Comparison of SO_2 emission scenarios per world region (year 2010). Emissions are expressed in Gg SO_2/yr and include all emission sectors; numbers in brackets refer to the corresponding power, industry and transport emissions.

SO2 - 2010	STAG_ENERGY	STAG_TECH	REF_2010
Globe	36932 (6651.1;11077.7;582.2)	125600 (67726.8;32623.3;6612.9)	93700 (48841.5;25464.2;773.2)
China +	22567 (2105;2935.1;16.7)	37800 (13343.7;17538.8;821.3)	31600 (11103;14298.5;48.9)
India +	5004 (290.2;669.7;52)	11500 (6167.3;2703;449.8)	10900 (6167.3;2505.3;53)
Southern Africa	2795 (2093.5;261.7;19.8)	2800 (1996.2;304.4;128.7)	2700 (1996.2;291.3;18.9)
Middle East	2187 (137.5;192.2;85.5)	8300 (5446.5;1334.8;743.1)	7500 (5446.5;1223.6;102.3)
OECD Europe	2104 (60.1;1014.3;1.8)	8700 (5165.7;1310.3;828.3)	3200 (1153.7;622.1;4.4)
USA	2041 (445.5;1564.8;6.8)	20800 (17059.7;2213.4;818.2)	10100 (8493.8;839.6;14.5)
Southeastern Asia	1761 (190.4;432.8;167.4)	2800 (895.8;960.7;331.2)	2500 (895.8;804.6;201.2)
Rest South America	1413 (214.4;185.1;6.2)	2500 (939.7;547.1;312.6)	2200 (939.7;484.9;19.5)
Russia +	1309 (214.9;325.7;27.2)	4200 (2980.6;317;205.5)	2700 (1580.3;281.1;57.4)
Korea	1276 (93.9;517.6;16.7)	1800 (426.3;821.9;165.7)	1600 (426.3;727.6;20.4)
Central Europe	1069 (323.3;476.3;0.6)	5500 (4463.3;374.5;142.7)	3000 (2257.1;225.7;1.5)
Indonesia +	1037 (81;25.3;78.3)	2200 (1041.6;617.4;145.3)	2000 (1041.6;516.2;92.9)
Brazil	951 (24.8;142.6;3.6)	1600 (217.2;595;320.3)	1200 (216.7;476.6;12)
Japan	870 (9.1;422.6;3.1)	1700 (292;786.3;117.8)	1100 (234.9;380.8;3.5)
Turkey	772 (0.7;43.3;7.4)	1600 (724.1;383.4;111)	1500 (724.1;357.6;16)
Asia-Stan	658 (51.2;756.5;6.9)	1900 (1189.4;334;19.7)	1800 (1189.4;262.2;7.3)
Rest Central America	571 (53.5;202;3.1)	1400 (781.1;250.5;65.3)	1300 (781;226.5;4.1)
Oceania	502 (12.1;91.2;3.4)	1600 (870;192.9;145.5)	1100 (602.6;121.3;9.8)
Mexico	494 (40.4;108.9;21.8)	1600 (899.3;239.4;228.3)	1300 (845.5;175.6;21.6)
Northern Africa	488 (12.1;45.7;31)	1700 (985.9;206.1;255.1)	1500 (985.9;191.3;32.1)
Canada	474 (18.5;84.4;0)	1300 (621.5;199.8;90)	1000 (540.9;113;1.6)
Ukraine +	424 (143.7;523.5;7)	1300 (919.1;196.4;41)	1200 (918.4;156.2;10.7)
Western Africa	359 (8.8;37.4;11.1)	600 (145;124.9;72.2)	500 (145;115.7;12.9)
Eastern Africa	269 (26.9;18.8;4.9)	400 (156;71.3;54.2)	400 (156;66.7;6.7)

Table S2.2 Comparison of NO_x emission scenarios per world region (year 2010). Emissions are expressed in Gg NO_x /yr and include all emission sectors; numbers in brackets refer to the corresponding power, industry and transport emissions.

NOx - 2010	STAG_ENERGY	STAG_TECH	REF_2010
Globe	53595 (5725.4;10071.8;16151.4)	115700 (33491.5;17496.8;43066.9)	96900 (31363.4;16502.8;27387.5)
China +	14806 (1350.6;1437.3;1227.4)	27200 (9674.8;6989.7;5303.1)	25100 (9674.8;6972.8;3193.1)
USA	6680 (625.7;2549.9;2320)	13400 (3925.4;1368.7;5683.3)	12500 (3423.4;1368.2;5337.4)
India +	5860 (193.4;359.2;2107.5)	10300 (4169;1467.6;2417)	9900 (4169;1382.9;2148.1)
OECD Europe	4628 (391;1483.1;1226.7)	13000 (2838;1129.8;6953.5)	7200 (1514.6;881.4;2674.8)
Middle East	3688 (106.2;98;2416.9)	8200 (2396.9;699;4604.7)	6100 (2396.9;679.8;2549.5)
Southeastern Asia	2602 (157.1;368.4;794.5)	4100 (690.1;710.4;1653.3)	3300 (690.1;667.8;959.9)
Russia +	2365 (1006.1;380.5;340.6)	4900 (2071.6;331.9;1739.5)	3900 (2071.6;324.5;814.4)
Mexico	1799 (22.1;93.5;1303.8)	2200 (323.8;159;1442)	2100 (323.8;150.7;1303)
Southern Africa	1739 (970.3;157.6;284.7)	2200 (938.4;244.4;715.7)	1800 (938.4;188;372.6)
Brazil	1730 (5.6;135.2;185.9)	3600 (190.7;471.1;1811.6)	3100 (190.7;451.8;1310.6)
Indonesia +	1689 (25.2;21.1;457.9)	2500 (498.4;534.7;742)	2200 (498.4;475.9;506.8)
Rest South America	1580 (124.6;163.7;461.5)	3100 (532.6;419.8;1515.4)	2900 (532.6;414.7;1313.7)
Japan	1554 (42.9;539.7;329.1)	3800 (564.2;670;1881.9)	2200 (485.8;486.3;527.4)
Central Europe	1295 (221.2;562;361)	3200 (1085.5;261.8;1374.4)	2300 (861.1;257.7;730.2)
Korea	1194 (42.7;195.2;516.4)	1700 (426.4;382.4;663.9)	1700 (426.4;381.3;664.4)
Western Africa	1123 (6;57.7;420.1)	1500 (112;345.5;493.1)	1300 (112;189.5;487)
Northern Africa	930 (70;28.5;592.8)	1900 (488;142.6;1053.6)	1500 (488;129.9;632.9)
Canada	875 (31.7;194.3;23.6)	1700 (307.1;261.3;615.2)	1700 (307.1;260.1;572.8)
Oceania	646 (27.8;109.9;89.3)	2100 (582.1;154.6;952.2)	1400 (582.1;149.3;289)
Rest Central America	605 (37.4;93.5;178.6)	1100 (485.5;139.3;253.5)	1100 (485.5;133.4;225.7)
Asia-Stan	594 (114.4;493;84.9)	1100 (412.3;194.6;206.1)	900 (412.3;190.2;88.8)
Ukraine +	564 (121.9;519;109)	1100 (392;177.2;318.5)	900 (392;156.5;178.7)
Eastern Africa	534 (21.9;12.2;160.7)	800 (141.1;82.9;223.5)	700 (141.1;51.6;207.2)
Turkey	527 (9.5;19.2;158.6)	1100 (245.9;158.4;449.9)	900 (245.9;158.4;299.4)

Table S2.3 Comparison of CO emission scenarios per world region (year 2010). Emissions are expressed in Gg CO/yr and include all emission sectors; numbers in brackets refer to the corresponding power, industry and transport emissions.

CO - 2010	STAG_ENERGY	STAG_TECH	REF_2010
Globe	523999 (1590.4;17591.2;103046.7)	811600 (9721.2;111877.5;288233)	620000 (6490.8;46679.2;165060)
China +	161425 (115.2;5578.6;9794.5)	218500 (974.5;46438;47068.3)	165500 (960.9;27508.1;12994.5)
India +	95176 (21.8;1938;16828.6)	108100 (736.2;13961.8;22461)	96200 (729.3;7415.7;17099.9)
Southeastern Asia	45199 (10.4;749.5;7751.3)	59400 (271.4;5094.9;18102)	48300 (262.9;1513.5;10600.1)
Western Africa	37693 (1.5;365.4;4166.8)	55600 (38.4;18635.5;4608.9)	38200 (37.9;1234.1;4608.9)
Indonesia +	35906 (1.2;46;13889.5)	47000 (101.2;7751;18214.8)	36200 (100.3;1032.4;14094.7)
Brazil	24336 (0.3;219.3;2542.6)	30700 (78.8;1121.8;8409.4)	27800 (71.4;732.7;5868.9)
Eastern Africa	20205 (6.9;49.4;713.4)	24000 (55.2;3680.5;1011)	20500 (54.1;244.6;961.5)
USA	19620 (263.7;2140.2;8610.5)	48200 (1030;1443.6;36120.6)	47700 (896.4;1148.4;36028.7)
Southern Africa	16935 (33.3;591.3;1158.4)	23500 (41.5;4787.3;3619)	17500 (41.3;711.9;1686.2)
Middle East	14267 (42.2;31;12254.2)	25200 (606.9;495.1;22315.5)	15300 (604.7;176.7;12735.9)
Rest South America	13839 (14;237.1;3507.3)	27500 (178.6;905.3;16675.2)	25800 (111.9;587.5;15304.4)
OECD Europe	13492 (153.9;1414.1;2173.4)	42600 (3131.6;1381.5;27760.7)	15400 (599.8;791.9;3635)
Mexico	9627 (2.8;62.1;7373.3)	9800 (133;224.3;7313.9)	9600 (77.8;100.1;7271.2)
Rest Central America	7120 (10.4;213.5;3434.9)	8700 (163.7;462.9;4727.2)	8000 (144.7;293.8;4180.1)
Central Europe	6725 (78.7;688.9;1116.1)	11200 (397.9;444.1;5096.5)	7700 (172.4;322.3;2004.9)
Russia +	6131 (630.5;163.3;986.6)	14200 (871.3;172.2;8827.7)	9000 (861.3;139.5;3631.5)
Japan	4800 (10.5;323.7;2343.3)	21700 (244.2;776.8;18528.5)	5400 (124.8;291.7;2800.5)
Korea	4549 (2.9;986.3;1217.1)	5400 (102;1572;1701.3)	4900 (95;1253.8;1496.4)
Turkey	3812 (3.6;40.5;163.3)	4800 (64.8;382.8;1075.5)	4400 (62.4;334.6;699.5)
Northern Africa	2700 (40;21;1387.8)	6000 (148.2;986.5;3620)	3300 (147.8;94.5;1839.2)
Oceania	2691 (9.4;65.2;387.3)	7300 (96.2;217.8;4741.1)	3200 (94.4;94.5;811)
Ukraine +	2613 (56.6;606.8;354.6)	3800 (104.8;257.1;1412.7)	3000 (104.8;180.8;696.3)
Asia-Stan	2083 (69;954.8;665.4)	3100 (73.6;462.6;1536)	2200 (73.6;335.3;748.9)
Canada	2012 (11.6;105.2;226.6)	5200 (77.2;221.9;3286.8)	5100 (61.1;140.9;3261.8)

Table S2.4 Comparison of NMVOC emission scenarios per world region (year 2010). Emissions are expressed in Gg NMVOC/yr and include all emission sectors; numbers in brackets refer to the corresponding power, industry and transport emissions.

NMVOC - 2010	STAG_ENERGY	STAG_TECH	REF_2010
Globe	120828 (184.8;3835.8;16076.8)	151700 (752.3;9620.7;40853.8)	134800 (704.9;8396.2;25183.2)
China +	23070 (17;727.6;1259.5)	27100 (122.6;4187.9;4739.5)	24200 (122.6;3583.6;2473.2)
India +	14896 (2.1;353.3;1857.2)	15500 (70.9;1402.7;2346.4)	15000 (70.9;1341.4;1885.1)
Western Africa	11407 (0.1;102.5;772.8)	11500 (3.1;347.5;855)	11500 (3.1;346.2;855)
Middle East	10758 (2.4;17.4;3103.2)	13500 (43.9;163.7;5730.2)	11100 (43.9;126.8;3405.9)
Southeastern Asia	9971 (2.1;144.2;888.8)	11000 (19.4;361.7;1936.4)	10300 (19.4;332.4;1201)
Eastern Africa	7745 (0.6;14;146.8)	7800 (5.1;70.9;207.7)	7800 (5.1;69.4;197.3)
Southern Africa	7669 (8.1;133.2;300.1)	8200 (8.4;183;825.8)	7800 (8.4;168.4;422.9)
USA	5406 (22.6;647.5;868.5)	8200 (108.2;474.9;3447.5)	7900 (78.5;347.4;3298.3)
Brazil	4795 (0;165.8;491.2)	6200 (7;586.6;1802.8)	5400 (6.9;553.8;1067.3)
Indonesia +	4651 (0.1;9.2;1290.4)	5100 (7.5;211;1645.8)	4700 (7.5;198.6;1334.8)
OECD Europe	4254 (35.8;461.4;537.4)	8700 (133.2;364.6;4820.3)	4500 (118.8;271.1;699.8)
Rest South America	3556 (1.8;81.9;485.6)	5500 (12.1;214.7;2328.2)	5000 (11.6;199;1897.8)
Russia +	2813 (60.1;69.9;421.1)	5300 (81.8;80.1;2857.3)	4100 (81.8;59.6;1693.1)
Mexico	2112 (0.2;25.7;1327.6)	2100 (7.3;45;1351.2)	2100 (6.9;41.4;1308.8)
Korea	2056 (0.2;117.4;179.8)	2200 (8.4;217;233.4)	2100 (8.4;168.2;221.3)
Northern Africa	1971 (2.1;9.1;410.1)	2400 (10.8;45.3;878.4)	2100 (10.8;41.8;495.2)
Rest Central America	1844 (0.7;55.4;609.1)	2100 (14.7;77.4;830)	2000 (14.4;73.3;751.6)
Japan	1453 (3.9;150.2;411.8)	2100 (28.6;172.7;941.4)	1500 (28.6;135.3;425.7)
Central Europe	1325 (10.6;163.3;220.5)	2100 (19.5;89.9;955)	1500 (19.3;74.8;387.2)
Canada	908 (1.3;55.7;19.5)	1300 (8.6;93.9;317.9)	1200 (7;74.6;305.1)
Asia-Stan	864 (6.4;180.1;237.2)	1000 (7.2;73.6;423.8)	900 (7.2;64.7;272.3)
Oceania	713 (1;25.8;66.1)	1300 (8.5;47.6;696)	800 (8.3;35.6;145.8)
Ukraine +	552 (5.3;119.2;125.8)	800 (10.2;40.2;433.4)	700 (10.2;37.4;274.7)
Turkey	479 (0.3;6.2;46.7)	700 (5.3;68.9;250.6)	600 (5.3;51.6;163.9)

Table S2.5 Comparison of NH_3 emission scenarios per world region (year 2010). Emissions are expressed in Gg NH_3/yr and include all emission sectors; numbers in brackets refer to the corresponding power, industry and transport emissions.

NH3 - 2010	STAG_ENERGY	STAG_TECH	REF_2010
Globe	54099 (9.4;307.2;179.5)	54800 (102;791.2;347.5)	54800 (82.2;617.2;497.9)
China +	14078 (0.1;1.4;8.4)	14100 (2.8;6.2;6)	14100 (2.8;6.2;25.4)
India +	8595 (0.1;38.1;8.5)	8600 (4.9;145.7;6.1)	8600 (4.9;145.7;8.6)
OECD Europe	4166 (0.8;27;19.2)	4300 (27.5;80.6;7.5)	4200 (7.7;19;46.7)
USA	3696 (4.9;92.2;62.4)	4000 (12.7;122.3;256.4)	3900 (12.7;49.5;256.4)
Brazil	2887 (0;37;1.7)	2900 (4.2;123.5;2.1)	2900 (4.2;123.5;8.1)
Southeastern Asia	2794 (0;7.7;7.1)	2800 (2.8;39;2.8)	2800 (2.8;39;10.3)
Rest South America	2188 (0.2;12.4;1.5)	2200 (3.4;30.7;3.6)	2200 (3.4;30.7;8)
Indonesia +	1899 (0;1.3;3.4)	1900 (1.4;29.8;0.7)	1900 (1.4;29.8;3.7)
Western Africa	1798 (0;22.3;0.2)	1800 (0.5;75.5;0.3)	1800 (0.5;75.5;0.3)
Eastern Africa	1699 (0.1;3;0.1)	1700 (0.8;15;0.1)	1700 (0.8;15;0.2)
Central Europe	1393 (1.1;10.9;2.8)	1400 (3.8;11.9;1.9)	1400 (3.8;5.1;6.8)
Russia +	1087 (0.7;1.3;2.4)	1100 (3.1;1.5;1.2)	1100 (3.1;1.2;12.9)
Southern Africa	997 (0;18.1;3.1)	1000 (0.2;25.2;0.3)	1000 (0.2;25.2;4.4)
Middle East	980 (0.3;1.3;12.9)	1000 (13.8;7.8;5.6)	1000 (13.8;7.9;19.3)
Mexico	898 (0;1.6;15.3)	900 (2.4;5.2;15.3)	900 (2.4;2.5;15.3)
Oceania	892 (0.1;3.4;6.4)	900 (1.6;11.4;1.1)	900 (1.6;4.8;12.7)
Turkey	799 (0;0;0.2)	800 (0.2;0.2;1.1)	800 (0.2;0.2;1.4)
Northern Africa	797 (0;1.1;4.1)	800 (2.4;4.8;0.8)	800 (2.4;4.8;4.2)
Canada	677 (0.3;8.2;1.3)	700 (1.7;27.6;22.8)	700 (1.7;11;22.8)
Rest Central America	596 (0.2;9.3;1.3)	600 (3.9;10.9;1.6)	600 (3.9;10.9;2)
Ukraine +	498 (0.2;1.2;0.9)	500 (1.1;0.7;0.2)	500 (1.1;0.5;2)
Asia-Stan	498 (0;0.9;1.8)	500 (0.2;0.3;0.2)	500 (0.2;0.3;2)
Japan	385 (0.1;7.1;9.3)	400 (5.3;12.7;2.6)	400 (5.3;6.4;17)
Korea	297 (0;0.5;5.2)	300 (1.2;2.9;7.4)	300 (1.2;2.5;7.4)

Table S2.6 Comparison of PM_{10} emission scenarios per world region (year 2010). Emissions are expressed in Gg PM_{10}/yr and include all emission sectors; numbers in brackets refer to the corresponding power, industry and transport emissions.

PM10 - 2010	STAG_ENERGY	STAG_TECH	REF_2010
Globe	54576 (766.4;3421.8;555.5)	67400 (6003.1;9786.7;1831)	63700 (4876.7;8117;874)
China +	17788 (327;883.5;35.6)	19960 (1877.3;4731.9;279)	19370 (1824.5;4353.4;114.9)
India +	10383 (82.6;275.6;103.2)	12120 (1610.4;1219;134.8)	11720 (1413.9;1043;105.6)
Western Africa	5190 (2.3;61.4;9.6)	5330 (5;339.4;12.2)	5200 (4.8;206.7;12.2)
Southeastern Asia	4779 (20.4;90.3;53.7)	5030 (101.2;345.3;119.1)	4860 (89.4;238.3;65.5)
Brazil	3159 (0.4;162;8.6)	3310 (29.2;595.1;74.7)	3250 (28.9;541.2;60.3)
Indonesia +	3009 (5.9;6.6;50.9)	3150 (64.6;200.7;77.2)	3060 (55.6;143.8;56.3)
Eastern Africa	2952 (3.4;8.6;7.9)	2990 (8.1;69;11.9)	2960 (7.8;42.1;11.6)
Southern Africa	2516 (145.3;107.9;26.1)	2570 (151.4;169.3;25.5)	2500 (133.9;128.7;16.4)
USA	1720 (22.7;686.6;31.1)	2320 (452.1;488.1;80.2)	2160 (428.4;368.4;60.2)
OECD Europe	1306 (7.4;344.5;47.9)	2430 (466.8;397.3;535.3)	1450 (88;220.7;111.1)
Rest South America	1302 (60.8;59.4;27.1)	1400 (98.2;158.3;55.7)	1360 (89.3;139.7;45.4)
Central Europe	913 (14.4;178.8;10.3)	1510 (498.8;121.6;82.7)	1050 (133.6;83.9;28.8)
Rest Central America	578 (1.9;40.3;5)	620 (33.1;61.4;7.6)	610 (32.3;48;6.4)
Russia +	502 (24.5;33.5;10.8)	640 (138.9;35.1;26.7)	610 (128.8;28.8;14.9)
Turkey	469 (0;6.4;4.5)	520 (29.4;61.2;18.3)	500 (26.8;52.7;9.9)
Mexico	410 (1.8;22.5;14.7)	440 (22.8;43.8;14.6)	430 (21.7;36.3;14.5)
Korea	389 (29.9;96.8;9.8)	530 (141.2;182.1;13.1)	480 (123.7;149.4;12.9)
Middle East	339 (3.1;8.5;48.7)	460 (76.6;63.5;82.9)	410 (73.4;45.3;53.2)
Canada	303 (2.7;57.9;0.3)	430 (69.8;128;8.3)	370 (61.2;77.5;8.2)
Oceania	281 (1.1;24.1;2.8)	370 (36.3;54;36.3)	320 (33.8;32.5;9)
Northern Africa	261 (1.2;4.9;31.6)	310 (18.6;28.4;54.8)	280 (17.6;19.4;31.8)
Ukraine +	234 (5;84.1;2.1)	280 (32.9;38.3;5.9)	260 (30.1;25.9;4.1)
Japan	230 (0.9;54.4;10.7)	470 (28;200.5;70.1)	260 (18.3;49;18.3)
Asia-Stan	205 (1.5;123.3;2.6)	240 (12.2;55.6;3.8)	220 (11.2;42.2;2.7)

Table S2.7 Comparison of $PM_{2.5}$ emission scenarios per world region (year 2010). Emissions are expressed in Gg $PM_{2.5}$/yr and include all emission sectors; numbers in brackets refer to the corresponding power, industry and transport emissions.

PM2.5 - 2010	STAG_ENERGY	STAG_TECH	REF_2010
Globe	34594 (484;2943.5;555.5)	44100 (3654.1;8096;1827.9)	41400 (3011.5;6903.7;874)
China +	12315 (187.6;770.6;35.6)	13660 (1005;4078.9;279)	13190 (978.7;3799.8;114.9)
India +	6974 (63;243.6;103.2)	8210 (1176.9;1006.8;134.8)	7980 (1063.6;921.9;105.6)
Southeastern Asia	3356 (9.9;83.7;53.7)	3520 (57.4;269.7;119.1)	3410 (52.2;215;65.5)
Western Africa	2611 (1.7;57.2;9.6)	2670 (3.4;241.8;12.2)	2620 (3.2;194;12.2)
Brazil	2308 (0.2;89.2;8.6)	2580 (13.5;479;74.7)	2380 (13.3;298;60.3)
Indonesia +	2106 (3.8;6;50.9)	2190 (39.8;155.7;77.2)	2140 (36.1;130.9;56.3)
Eastern Africa	1414 (2.5;8;7.9)	1430 (5;49.4;11.9)	1420 (4.7;39.7;11.6)
Southern Africa	1243 (92.4;82.5;26.1)	1280 (93.3;128.6;25.5)	1230 (84.3;102;16.4)
USA	1050 (14.6;635.8;31.1)	1410 (269.9;390.5;79.8)	1330 (260.8;341.1;60.2)
Rest South America	907 (46;36.3;27.1)	1010 (69.1;125.9;55.7)	950 (63.5;86;45.4)
OECD Europe	830 (5.1;299;47.9)	1690 (262.9;312.6;534.5)	940 (51.8;191.7;111.1)
Central Europe	548 (8.7;155.8;10.3)	950 (306.6;97.8;82.5)	630 (73.1;71.3;28.8)
Turkey	355 (0;5.3;4.5)	390 (11.7;49.2;18.2)	370 (10.6;43.6;9.9)
Russia +	331 (14.6;28.1;10.8)	410 (74.1;28.1;26.7)	390 (70;24.2;14.9)
Rest Central America	312 (1.3;28;5)	340 (18.5;48.2;7.6)	330 (18;34.4;6.4)
Korea	272 (22.7;78.6;9.8)	350 (82.2;145.6;13.1)	320 (73.8;124.8;12.9)
Mexico	260 (0.7;15.8;14.7)	280 (11.2;34.9;14.6)	270 (10.9;25.5;14.5)
Middle East	231 (2.2;7.4;48.7)	320 (51.7;50.4;82.8)	280 (49.9;39.6;53.2)
Oceania	223 (0.4;20.4;2.8)	290 (12.3;43.2;36.3)	240 (11.6;27.6;9)
Canada	215 (1.4;55;0.3)	290 (42.1;102.4;8.3)	260 (38.2;73.6;8.2)
Asia-Stan	161 (1;109.7;2.6)	180 (5;45;3.8)	170 (4.7;37.6;2.7)
Northern Africa	156 (0.9;4.3;31.6)	190 (12.6;21.2;54.8)	170 (12;17.7;31.8)
Ukraine +	156 (2.8;80;2.1)	180 (16.7;30.5;5.9)	170 (15.6;24.7;4.1)
Japan	138 (0.6;43.1;10.7)	330 (13.3;160.4;68.6)	160 (10.6;38.8;18.3)

Table S2.8 Comparison of BC emission scenarios per world region (year 2010). Emissions are expressed in Gg BC/yr and include all emission sectors; numbers in brackets refer to the corresponding power, industry and transport emissions.

BC - 2010	STAG_ENERGY	STAG_TECH	REF_2010
Globe	3874 (14.6;312.3;395.6)	5900 (199.2;1184.8;1287)	4700 (118.6;781.7;648.5)
China +	1511 (5;59.1;19.8)	1730 (29.8;327.4;169.3)	1590 (25.4;290.5;77.5)
India +	860 (2.1;52.7;71)	1020 (77.8;262.8;92.3)	900 (40.7;199.4;72.7)
Western Africa	357 (0;15.8;6.4)	380 (0.4;67.7;8.3)	360 (0.3;53.7;8.3)
Southeastern Asia	259 (0.3;9.5;31.2)	330 (3.7;47.3;73.7)	270 (3.2;28.5;39.3)
Eastern Africa	187 (0.1;2.2;5.8)	190 (0.5;14.1;8.7)	190 (0.4;11.2;8.4)
Indonesia +	173 (0.3;1.2;20.7)	200 (3.2;31.8;36.4)	180 (3.1;25.9;25)
Southern Africa	167 (2.5;12;19.8)	180 (6.2;27.2;18.9)	160 (2.3;17.2;12)
Brazil	139 (0;8.1;4.7)	280 (0.9;118.7;53.2)	180 (0.8;27.1;43.7)
USA	122 (0.6;61.9;19.6)	210 (17.3;76.2;46.5)	160 (12.5;33.2;44.9)
OECD Europe	116 (0.2;22.4;39.8)	530 (15.6;37.6;415.1)	170 (3;14.1;91)
Rest South America	83 (1.2;5;21.1)	130 (5.2;31.8;42.6)	100 (2.6;12.5;34.8)
Central Europe	61 (0.3;10.3;12.9)	130 (11.9;10.2;66.6)	80 (3.1;4.8;28.7)
Middle East	60 (0.1;2.6;34.5)	100 (7.7;25;59)	70 (6.9;14.3;37.9)
Northern Africa	38 (0;1.1;23.7)	60 (1.2;6.2;41.4)	40 (1;4.7;23.9)
Rest Central America	38 (0.1;5.1;3.5)	50 (1.5;13.5;5.4)	40 (1.2;5.7;4.5)
Korea	36 (0.6;5.2;20.4)	50 (5.4;11.8;22.7)	40 (2.4;8.8;22.6)
Turkey	31 (0;0.3;3.7)	40 (0.3;3.5;17)	40 (0.3;2.5;12.5)
Mexico	29 (0.1;1.7;11.8)	40 (0.7;6.5;11.8)	30 (0.7;2.8;11.8)
Russia +	23 (0.6;3;7.4)	40 (3.8;3.7;19.2)	30 (3.8;2.6;11)
Japan	22 (0;6;11.1)	70 (1.4;18.9;39.5)	30 (1.2;5.4;16.2)
Canada	22 (0.1;5.6;0.2)	50 (2.7;26.4;5.9)	30 (2.2;7.5;5.8)
Asia-Stan	18 (0;9.1;1.6)	20 (0.2;4.4;2.4)	20 (0.2;3.2;1.7)
Oceania	11 (0;2.2;3.1)	50 (0.7;8.1;26.7)	20 (0.7;2.9;11.1)
Ukraine +	8 (0.1;10.3;1.8)	20 (1.1;4;4.4)	10 (0.8;3.1;3.3)

Table S2.9 Comparison of OC emission scenarios per world region (year 2010). Emissions are expressed in Gg OC/yr and include all emission sectors; numbers in brackets refer to the corresponding power, industry and transport emissions.

OC - 2010	STAG_ENERGY	STAG_TECH	REF_2010
Globe	11991 (24.7;555.9;242.5)	13800 (194.6;1655.6;812.4)	13200 (153.1;1494.4;384.9)
China +	3839 (9.4;176.7;17)	4000 (51.1;880.6;125.6)	3910 (49.8;877.8;46.6)
India +	2767 (3.2;61.1;39.8)	2840 (59.3;233.5;52.3)	2820 (53.7;231.9;40.6)
Southeastern Asia	1161 (0.5;31.3;24.3)	1210 (3.7;59.8;53.7)	1170 (3.5;50.1;30.5)
Western Africa	1088 (0.1;15.1;4)	1090 (0.2;51.6;4.9)	1090 (0.2;51.4;4.9)
Indonesia +	736 (0.2;1.8;27.3)	760 (2;41.7;39.6)	740 (1.8;41.2;29.8)
Brazil	623 (0;13.6;4)	690 (1.8;78.5;35.4)	650 (1.8;45.6;28.1)
Eastern Africa	588 (0.1;2.1;3.4)	590 (0.4;10.4;5)	590 (0.4;10.3;4.8)
Southern Africa	454 (4.6;11.6;11)	450 (4.7;21.4;10.3)	450 (4.2;16.7;6.5)
Rest South America	268 (2.3;4.5;12.9)	290 (4.1;19.4;26.9)	280 (3.8;11.1;21.9)
USA	252 (0.6;145.7;14.6)	300 (14.2;81.2;42.8)	280 (7;78.2;34.5)
OECD Europe	220 (0.3;28.6;21.7)	470 (15.8;46;236.1)	250 (2.5;19;49.4)
Central Europe	189 (0.3;14.8;4.5)	240 (14.5;17;35.7)	200 (3.4;7.1;12.6)
Turkey	127 (0;0.4;1.6)	140 (0.6;9.5;7.5)	130 (0.6;3.4;4.1)
Rest Central America	108 (0.1;3.6;2.1)	110 (1.9;6.5;3.4)	110 (1.9;4.4;2.8)
Russia +	85 (1.1;6.6;4.4)	90 (4.6;7.7;10.6)	90 (4.4;5.7;5.9)
Mexico	79 (0;1.7;7.2)	90 (1.1;10.9;7.2)	80 (1;2.8;7.1)
Oceania	56 (0;2;1.2)	80 (1.2;5.8;15.5)	60 (1.1;2.8;3.6)
Middle East	55 (0.1;1.9;18.8)	70 (3;7.5;31.7)	60 (2.9;6.4;20.7)
Northern Africa	49 (0.1;1.6;14.1)	60 (0.7;5.8;24.6)	50 (0.7;5.6;14.2)
Korea	47 (1.1;4.2;4)	60 (4.4;16.5;5.2)	50 (4;7.5;5.1)
Ukraine +	38 (0.2;9.5;0.8)	40 (1.3;6;2.3)	40 (1.2;2.9;1.6)
Canada	34 (0.1;4.1;0.2)	50 (2.4;15.5;4.1)	40 (2.2;5.5;4)
Asia-Stan	29 (0.1;9;1.2)	40 (0.3;7.7;1.7)	30 (0.3;3.3;1.2)
Japan	17 (0;4.4;2.6)	50 (1.2;15;30)	20 (0.6;3.9;4.3)

S3 Comparison of EDGAR4.3.1 reference emission scenario with other reported emissions

In order to evaluate the consistency of the EDGARv4.3.1 reference scenario, used in this study, a comparison with other official and science based national/regional emission inventories and regional databases (e.g. HTAP_v2 and MACCity) is performed (see Figs. S3.1 and S3.2). The HTAP_v2 includes official regional emission data provided by the Environmental Protection Agency (EPA)'s for USA, EPA and Environment Canada's for Canada, the European Monitoring and Evaluation Programme (EMEP) and Netherlands Organisation for Applied Scientific Research (TNO)'s for Europe, and the Model Inter-comparison Study for Asia (MICS-Asia III)'s for China, India and other Asian countries (Janssens-Maenhout, et al., 2015). In the following, we show the good agreement obtained for SO_2 and BC, but similar results are found for all gaseous and particulate matter pollutants. Here we present the comparison at regional level aggregated for all sectors, although the comparison was also performed at sector level for specific regions of interest but not presented here. Considering Europe, USA, China and India, the agreement of regional emissions between EDGARv4.3.1 and HTAP_v2 is quite good. Differences between EDGARv4.3.1 and HTAP_v2 are between -4% and +4% for SO_2, -20% and +20% for NOx, -13% and 26% for CO, -48% and 6% for NMVOC, while larger deviations are found for PM and its components ranging from -53% to 14%.

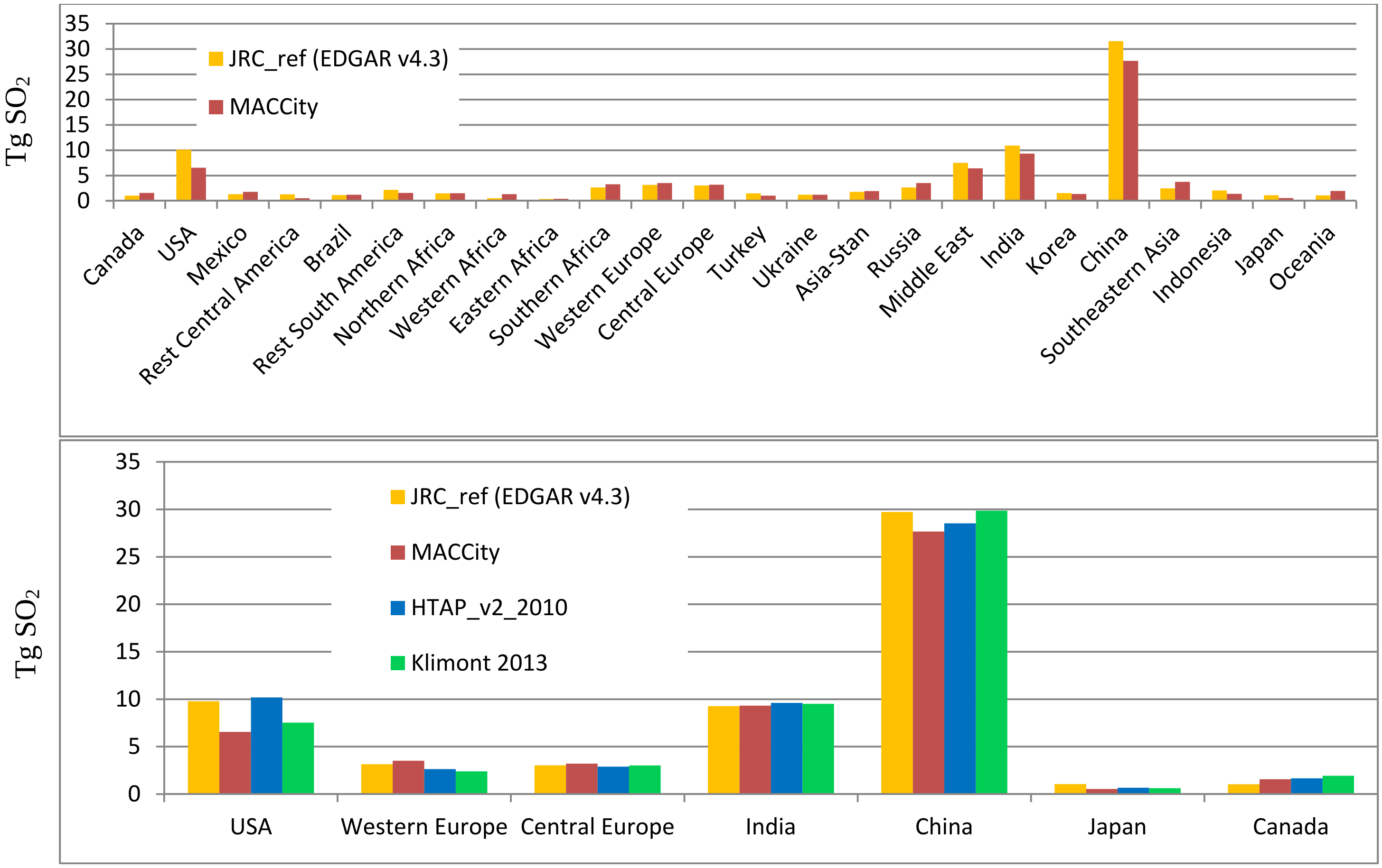

Figure S3.1 – Comparison of 2010 SO_2 emission data from EDGAR v4.3.1, HTAP_v2, MACCity and literature works at regional level.

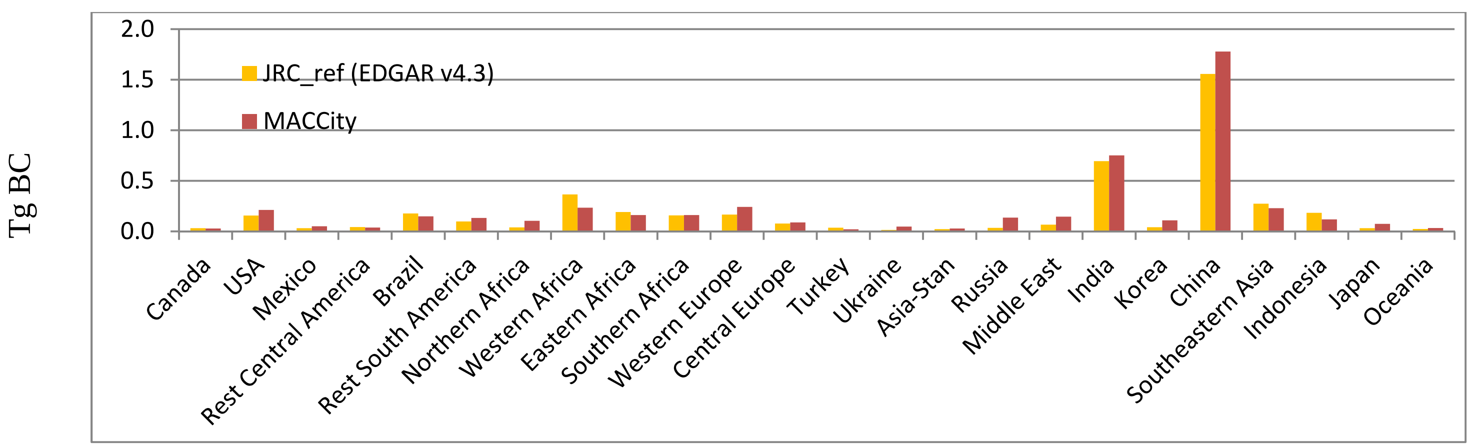

Figure S3.2 – Comparison of 2010 BC emission data from EDGAR v4.3.1 and MACCity at regional level.

Figures S3.3, S3.4 and S3.5 show the comparison of the emission time series (1970-2010) for selected pollutants (SO_2, NOx, CO, BC and OC) provided by the EDGARv4.3.1 and MACCity databases for groups of regions. The comparison of the two emission databases present some sense of uncertainty; however, we remark here that to some extent the two datasets cannot be considered fully independent. It is beyond the scope of this manuscript to analyze these dependencies. The relative difference between these two inventories is calculated for each year as VAR = (EDGARv4.3.1-MACCity)/MACCity and then averaged over time. Table S3.1 summarizes the averaged relative difference (VAR) between the emissions estimated by MACCity and EDGARv4.3.1 over time (1970-2010). At global level, the relative difference of these two sets of emission estimates is lower than considering specific regions. Groups of regions are defined as following: emerging countries include China, India, other Asian countries, Russia, Turkey and Middle East, developing countries include Central and South America and Africa, while the industrialized ones account for Oceania, USA, Canada, Easter and Western Europe. In general, the two emission inventories show similar trends over time, although specific differences can be observed in some regions. Our uncertainty evaluation is consistent with the estimates for the year 2010 provided by Janssens-Maenhout et al. (2015) using the HTAP_v2 database, where they estimate an uncertainty of 8% for SO_2, 4-5% for NOx and CO and larger values for BC (29%).

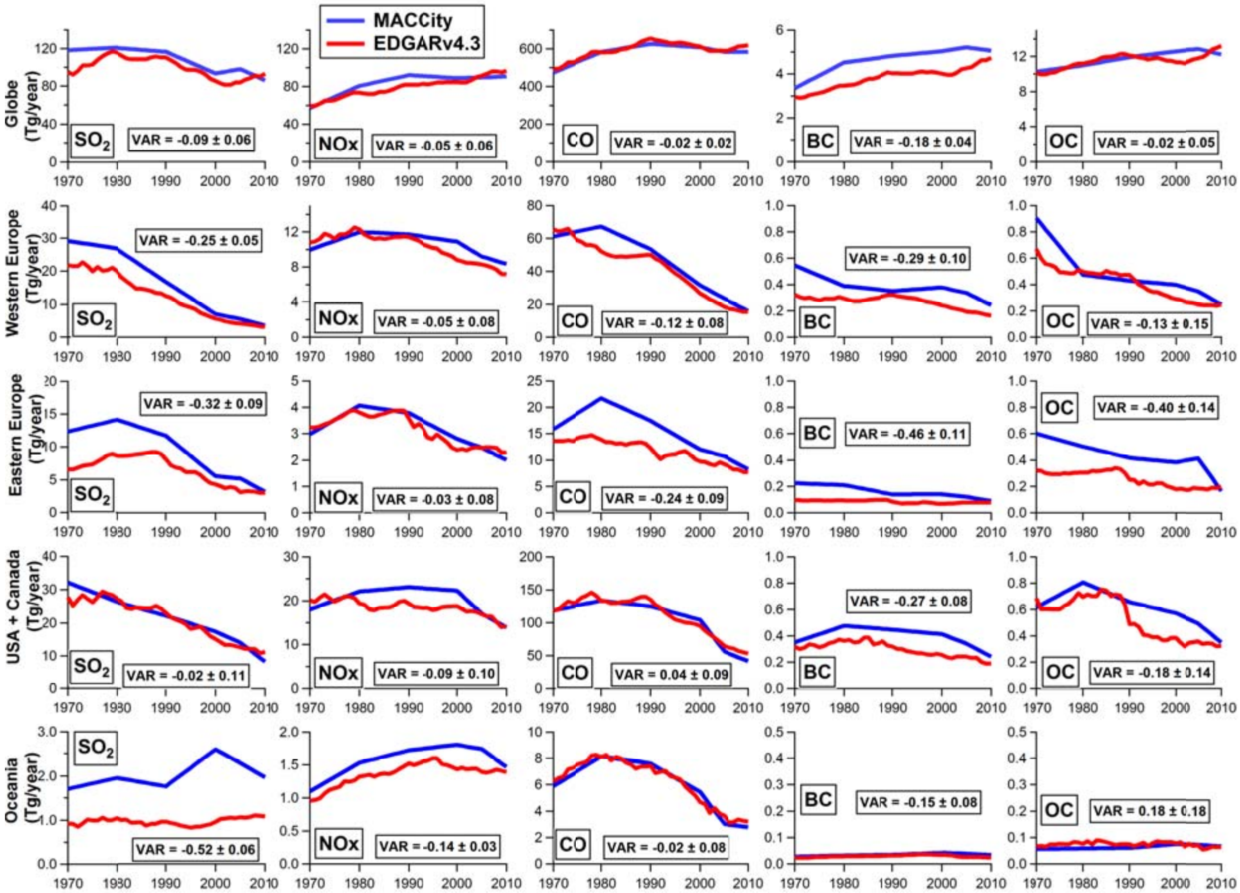

Figure S3.3 – MACCity vs EDGARv4.3.1 time series comparison (industrialized countries).

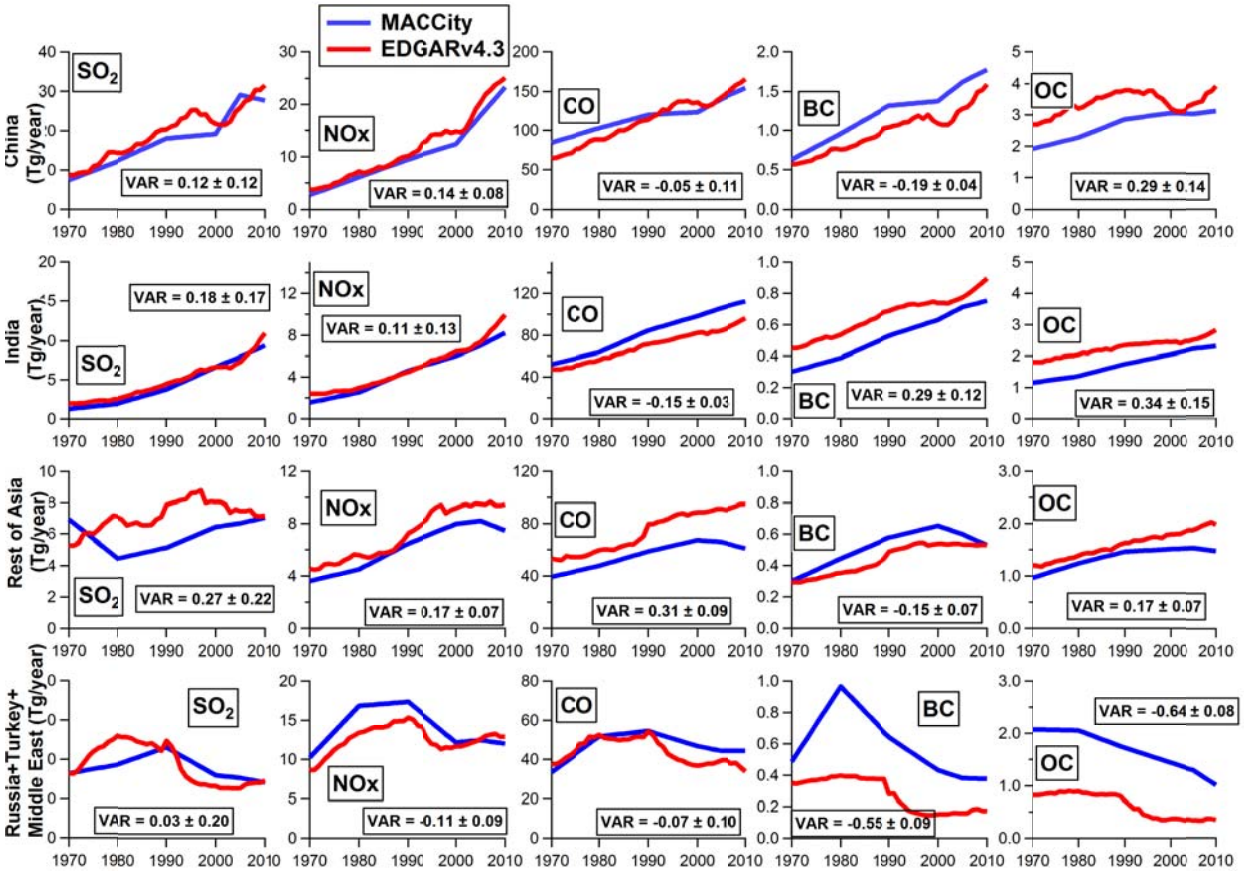

Figure S3.4 – MACCity vs EDGARv4.3.1 time series comparison (emerging countries).

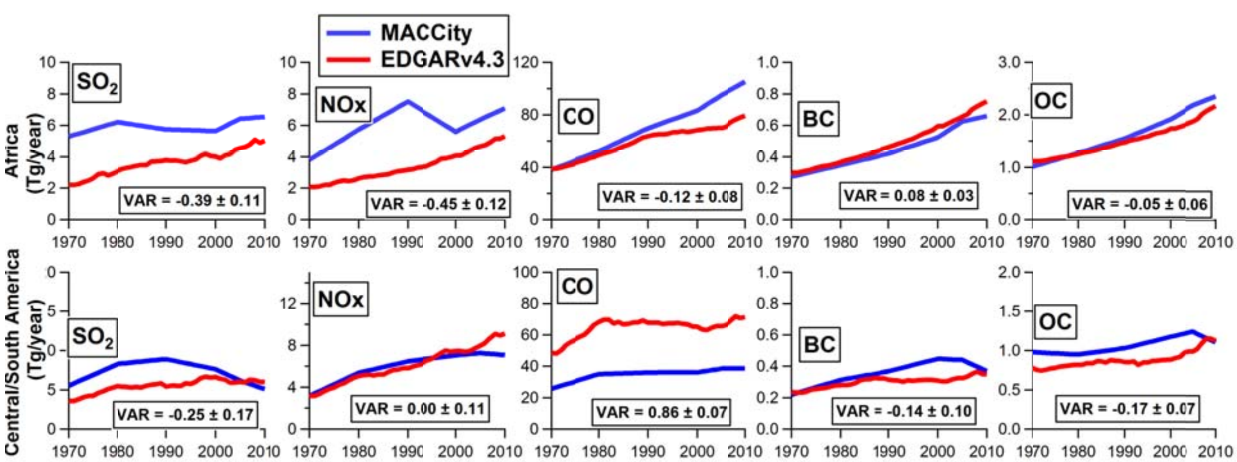

Figure S3.5 – MACCity vs EDGARv4.3.1 time series comparison (developing countries).

Table S3.1 – Relative difference between MACCity and EDGARv4.3.1 time series for groups of regions (industrialized, emerging and developing countries). +/- 1 standard deviation based on deviations of 30 years of regionally aggregated differences.

VAR %	SO_2	NOx	CO	BC	OC
Globe	-8.5 ± 6.0 %	-5.2 ± 6.0 %	1.8 ± 2.0 %	-18.1 ± 4.0 %	-1.6 ± 5.0 %
Industrialized	-27.8 ± 20.6 %	-7.9 ± 4.9 %	-7.6 ± 13.0 %	-29.3 ± 12.8 %	-13.4 ± 23.9 %
Emerging	14.7 ± 10.0 %	7.7 ± 13.0 %	0.8 ± 20.4 %	-15.2 ± 34.6 %	3.9 ± 46.0 %
Developing	-31.9 ± 10.2 %	-22.3 ± 31.4%	36.8 ± 69.3 %	-3.1 ± 16.1 %	-10.9 ± 8.7 %

S4 EDGARv4.3.1 emitting sector specifications and regions classification

In this section some details about the EDGARv4.3.1 database are provided, focusing on the three emission sectors included in our scenarios (power, industry and road transport).

S4.1: Power generation (ENE)

Table S4.1.1 summarizes the processes and technologies considered in the power generation sector by the EDGARv4.3.1 database, while pollutant specific abatement measures are reported in Tables S4.1.2, 4.1.3 and 4.1.4. Numerical codes reported in Figs. S4.1.1 and S4.1.2 refer to applied abatement measures for NOx, PM and SO_2 (e.g. 000 means that no abatements are applied for the three pollutants, while increasing numbers correspond to more advanced abatement measures).

Table S4.1.1: Processes and technologies

Power industry (ENE)			
Process	**Description**	**Technology**	**Description**
ENE.PEL	Public electricity production	**NSF**	Non-specified technology
ENE.CHP	Public cogeneration of heat and electricity	**GF0**	Grate firing
ENE.DHE	Public district heating	**PW0**	Pulverized coal wet bottom
ENE.AEL	Autoproduced electricity	**PD0**	Pulverized coal dry bottom
ENE.AHP	Autoproduced cogeneration of heat and electricity	**FB0**	Fluidized bed
ENE.AHE	Autoproducer heat plants	**BO0**	Boiler for gas/liquids
ENE.POW	Own of electricity and heat (no emission)	**IC0**	Internal combustion engine
ENE.PUM	pumped storage of electricity (no emission)	**GT0**	Gas turbine

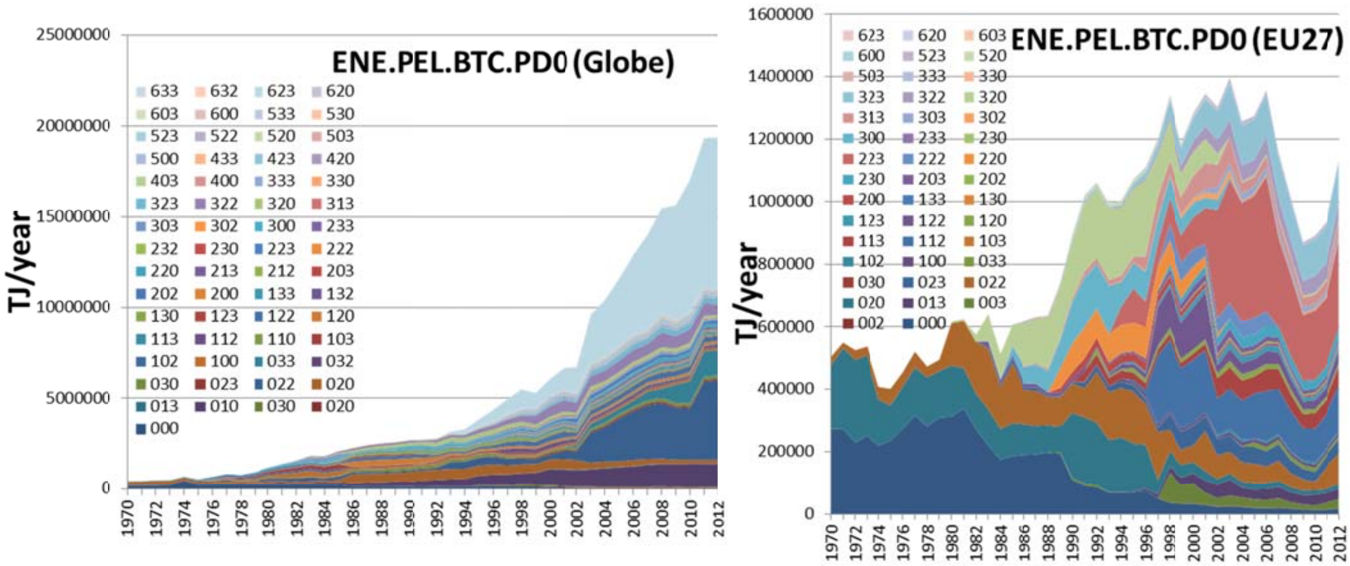

Figure S4.1.1 – Penetration of technologies applied to the power generation sector (e.g. public electricity production with bituminous coal and the technology of pulverized coal dry bottom boiler = ENE.PEL.BTC.PD0) at global and European scales.

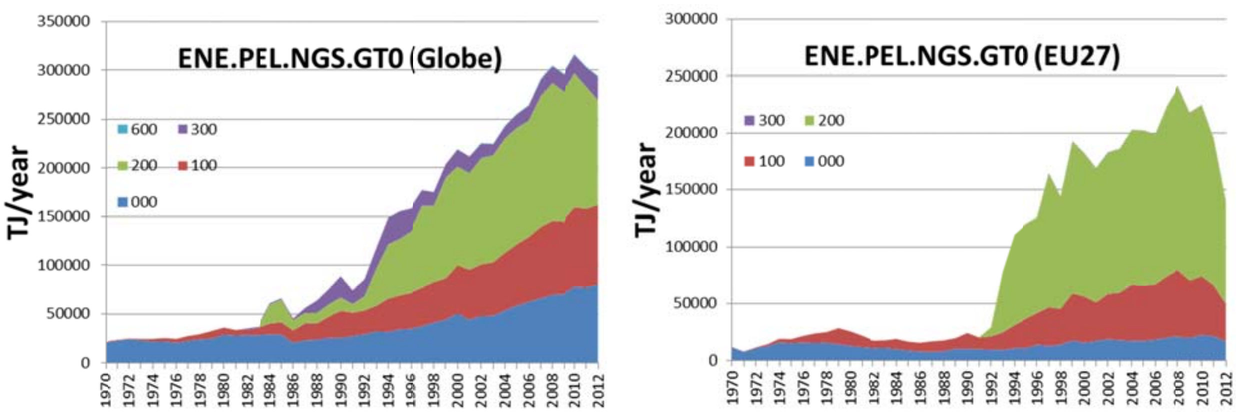

Figure S4.1.2 – Penetration of technologies applied to the power sector (e.g. public electricity production with natural gas with gas turbines = ENE.PEL.NGS.GT0) at global and European scales.

Table S4.1.2: NOx abatements

NOx abatement measures also influences NH_3 emissions, increasing them by a factor of 5.5 and 11.2 for SC1/SC2 and SN1/SN2, respectively.

Abbrev.	Description	Reduction	EOP_code EDGARv4	Emission reduction
CLN	Combustion modification: low nox burners	30 %	NO1	30%
CL0	Combustion modification: low excess air	20 %	NO1	30%
CAF	Combustion modification: air staging in furnace	20 %	NO1	30%
CFF	Combustion modification: flue gas recirculation - in furnace	40 %	NO1	30%
CR0	Combustion modification: reduced air preheat	20 %	NO1	30%
CSF	Combustion modification: fuel staging (burn or low nox	30 %	NO1	30%
SC1	Secondary: selective catalytic reduction	70 %	NO2	60%
SC2	Secondary: selective catalytic reduction+ combustion modification	90 %	NO3	90%
SN1	Secondary: selective non-catalytic reduction	30 %	NO4	30%
SN2	Secondary: selective non-catalytic reduction+ combustion modification	50 %	NO5	60%
NSN	SOxNOx combined measures	95 %	NO6	90%
NSF	Non-specified	0 %	NO0	0 %
NOC	No control	0 %	NO0	0 %

Table S4.1.3: SOx abatements

SOx abatement measures have no impact on other emission components (e.g. NOx, NH_3, and primary PM).

Abbrev.	Description	Reduction	EOP_code EDGARv4	Emission reduction
SND	Non-regenerative-dry (dry FGD)	50 %	SO2	50%
SNS	Non-regenerative semidry	90 %	SO3	90%
SNW	Non-regenerative wet (wet FGD)	90 %	SO3	90%
SRN	Regenerative	95 %	SO3	90%
NSN	SOxNOx	95 %	SO3	90%
NSF	Non-specified	0 %	SO0	0 %
NOC	No control	0 %	SO0	0 %

Table S4.1.4: PM abatements

Reduction measures of $PM_{2.5}$ are derived from the PM_{10} ones, while for BC and OC they are assumed equal to the $PM_{2.5}$ ones.

Abbrev.	Description	Reduction PM10	Reduction PM2.5
ESP	Electrostatic precipitator	99.95 %	98.30 %
FBF	Fabric filter	99.95 %	99.60 %
CYC	Cyclone	90 %	0 %
SCR	Wet scrubber	99.90 %	99.50 %
COM	Combination of measures	99.95 %	98.30 %
NSF	Non specified	0 %	0 %
NOC	No control	0 %	0 %

S4.2: Manufacturing industry and construction (IND)

Table S4.2.1 summarizes the processes and technologies considered in the industrial sector of the EDAGRv4.3 database.

Table S4.2.1: Processes and technologies

Manufacturing industries and construction (IND)	
Process	**Description**
CHE	chemical
CON	construction
FOO	food and tobacco
IRO	iron and steel
MAC	machinery
MIN	mining
NFE	non-ferrous metals
NMM	non-metallic minerals
PAP	paper, pulp, print
TEQ	transport equipment
TEX	textiles
WOO	wood and wood products
INO	non-specified industry

S4.3: Road transport (TRO.ROA)

In this section details concerning the road transport sector as implemented in the EDGARv4.3.1 database are reported (refer to Table S4.3.1 for the processes and technologies and Table S4.3.2 for the abatement measures). In our work we only consider exhaust emissions, while break wear and re-suspension of road-dust are not taken into account.

Table S4.3.1: Processes and technologies

Road transport (TRO.ROA)			
Fuel	**Description**	**Technology**	**Description**
AVG	Aviation Gasoline	**BS0**	Busses
BDS	Biodiesel	**HD0**	Heavy Duty vehicles
BGL	Biogasoline	**LD0**	Light Duty vehicles
DIE	Gas/Diesel Oil	**PC0**	Passenger cars
OKE	Kerosene	**MC0**	Motorcycles
LPG	Liquefied Petroleum Gases (LPG)	**MP0**	Mopeds (Scooters)
MOG	Motor Gasoline		
NGS	Natural Gas		
OPR	Non-specified Petroleum Products		
OLB	Other liquid biofuels		
SBI	Primary Solid Biomass		
HFO	Residual Fuel Oil		

Table S4.3.2: Abatement measures

Abatement measures (EU)	Description
NOC	Non controlled or conventional
PEU	Pre Euro standards (combined impact of EU technologies before 1990)
EU1	Euro standard 1
EU2	Euro standard 2
EU3	Euro standard 3
EU4	Euro standard 4
EU5	Euro standard 5
EU6	Euro standard 6
For busses using natural gas (globally)	
PEU	Pre Euro standards
EU1	Euro standard 1
EU2	Euro standard 2
EU3	Euro standard 3
EEV	Standard for Enhanced Environmental Vehicles

American standards for passenger cars are also reported in Figs. S4.3.1 and S4.3.2, like UT1, UT2, UT3 (US Tier1-Tier3). Analogous standards are also available for heavy duty vehicles (PH1 and PH2, US Phase Tier 1 and 2 used for HDV).

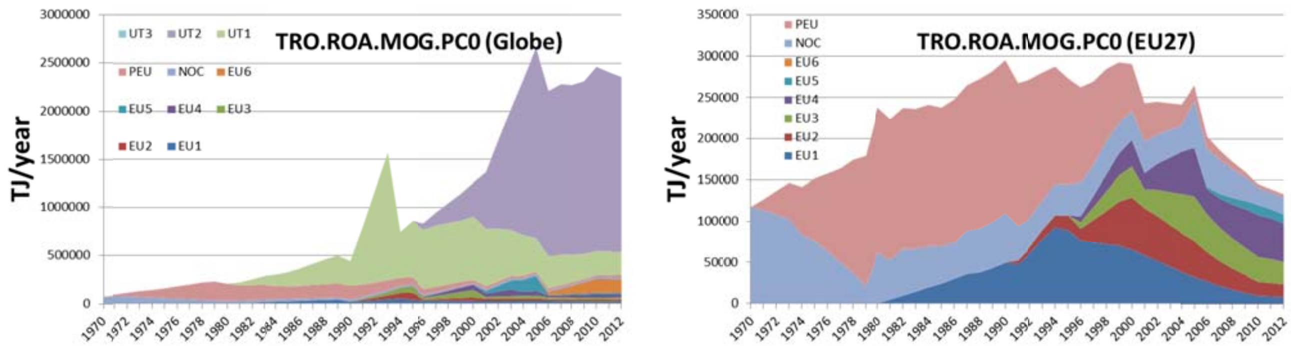

Figure S4.3.1 – Penetration of technologies applied to the road sector (e.g. motor gasoline for passenger cars = TRO.ROA.MOG.PC0) at global and European scales.

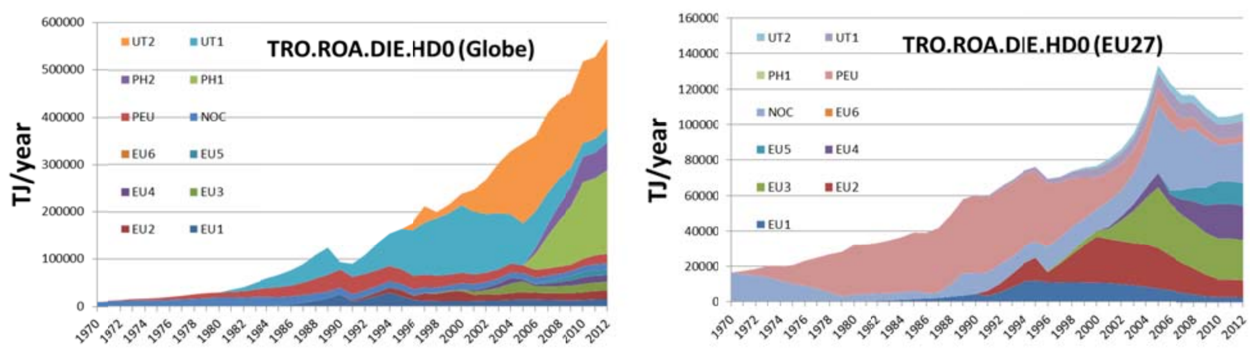

Figure S4.3.2 – Penetration of technologies applied to the road sector (e.g. diesel for heavy duty vehicles = TRO.ROA.DIE.HD0) at global and European scales.

S4.4: Regions classification in EDGARv4.3.1

In the present work emission data are often grouped by 24 emission regions (excluding Antartica), representing single geographical or political entities. However, in some cases, emissions from small countries have been added to bigger countries, like for Ukraine+ (including also Moldova and Belarus), Indonesia+ (including also Papua New Guinea), China+ (including also Hong Kong, Taiwan, Macao, Mongolia), Russia+ (including also Armenia, Georgia, Arzebaijan), India+ (including also Afghanistan, Nepal, Pakistan, etc.), Asia-Stan (including Uzbekistan, Turkmenistan, Tajikistan, Kirghizistan and Kazakhstan).

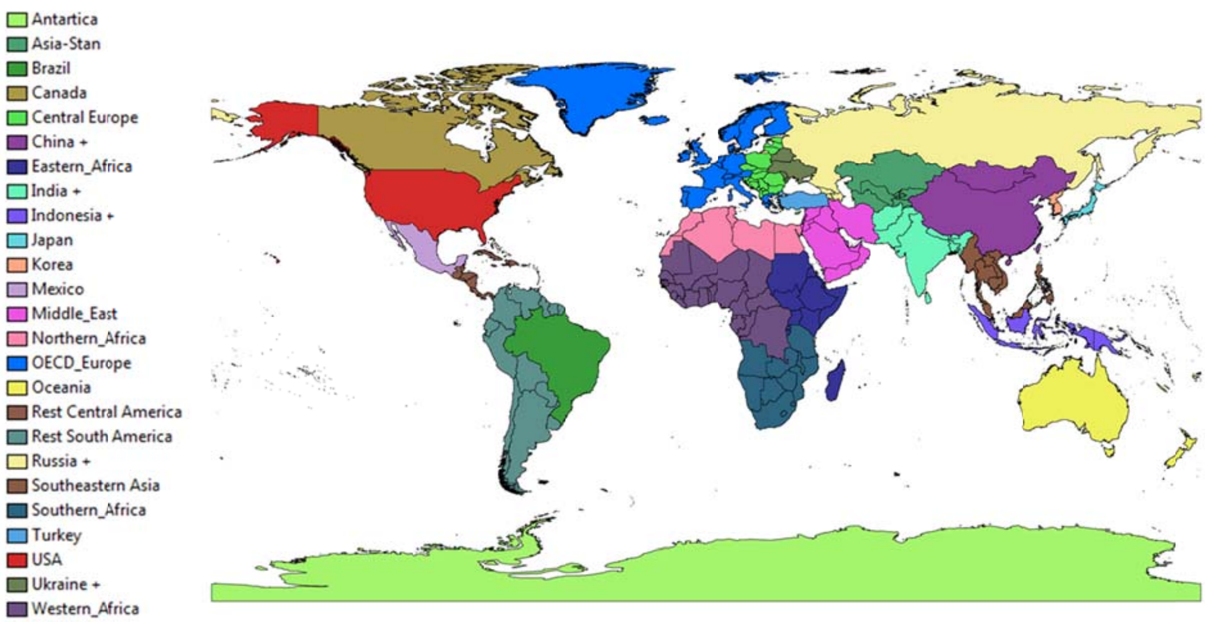

Figure S4.4.1 – Classification of world regions in the EDGARv4.3.1 database.

S5 European legislation

The European Union (EU), as well as the extended UNECE/CLTRAP/EMEP region (http://www.ceip.at/ms/ceip_home1/ceip_home/ceip_unece/), which also includes North American and Eastern European countries, have introduced several air quality related protocols and legislation to reduce pollutant emissions in the atmosphere from anthropogenic activities (combustion processes, energy production, transportation, etc.). Table S5.1 gives an overview of historical European and international legislation pertaining to the European domain from the 1970s to 2012. European policies are classified into “air quality directives” when regulating pollutant concentrations in the air, “directives regulating air pollutants emissions from anthropogenic activities” when dealing with emission limits for specific activities, “EU standards on road vehicle emissions” and “fuel quality directives”. A broader air quality regulation framework is given by international conventions which were created to promote the improvement of global air quality, like the Convention on Long-range Transboundary Air Pollution (CLRTAP) created in 1979 and later extended by several protocols such as the Gothenburg Protocol (GP) of 1999, most recently revised in 2012.

Table S5.1 Overview of historical European legislations regulating air pollutant emissions

	Policy/Pollutant	PM	SOx	NOx	CO	heavy metals	VOCs
Air quality directives	70/220/EEC	x	x	x			
	80/779/EEC	x	x	x			
	85/203/EEC	x	x	x			
	96/62/EC	x	x	x	x	x	x
	1999/30/EC	x	x	x		x	
	99/13/EC						x
	2004/107/EC					x	
	CAFE directive	x	x	x			x
	2008/50/EC	x	x	x	x	x	x
Directives regulating air pollutant emissions from anthropogenic activities	2000/76/EC (waste incineration)	x	x	x			x
	2001/81/EC and 2010 revision (national emission ceilings)		x	x			x
	2010/75/EU (industry)	x	x	x	x		x
EU standards on road vehicle emissions	94/63/EC	x		x	x		x
	1999/13/EC	x		x	x		x
	2009/126/EC	x		x	x		x
Fuel quality directives	93/12/EC		x				
	98/70/EC		x				
	1999/32/EC		x				
	2003/17/EC		x			x	x
	2009/30/EC		x				
International conventions	CLRTAP (1979, 1987/94 and 1997/98)	x	x	x	x	x	x
	Gothenburg protocol (1999 and 2012)	x		x	x		x
	IPPC directive (2008/1/EC)	x					

Depending on the considered regulation, emission limits can be defined as sector specific annual emissions for selected pollutants, as total annual emissions per country (refer to 2010/75 EU), and as concentrations at the stack or in ambient air.

Table S5.2 Implementation of European standards on vehicle emissions with PM limits (mg/km) over time. PEU refers to prior-to-Euro norms. Numerical values represent the limit value in [mg/km]. Note that Mopeds and motorcycles, using petrol, are not subject to PM limits.

Standard PM limit in mg/km	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Busses	PEU	PEU	EU1	EU1	EU1	EU1	EU2	EU2	EU2	EU2	EU3	EU3	EU3	EU3	EU3	EU4	EU4	EU4	EU4	EU5	EU5
			250	250	250	250	170	170	170	170	100	100	100	100	100	60	60	60	60	5	5
Heavy duty	PEU	PEU	EU1	EU1	EU1	EU1	EU2	EU2	EU2	EU2	EU3	EU3	EU3	EU3	EU3	EU4	EU4	EU4	EU4	EU5	EU5
			250	250	250	250	170	170	170	170	100	100	100	100	100	60	60	60	60	5	5
Light duty	PEU	PEU	EU1	EU1	EU1	EU1	EU2	EU2	EU2	EU2	EU3	EU3	EU3	EU3	EU3	EU4	EU4	EU4	EU4	EU5	EU5
			190	190	190	190	120	120	120	120	70	70	70	70	70	40	40	40	40	5	5
Passenger car	PEU	PEU	EU1	EU1	EU1	EU1	EU2	EU2	EU2	EU3	EU3	EU3	EU3	EU3	EU3	EU4	EU4	EU4	EU4	EU5	EU5
			140	140	140	140	80	80	80	50	50	50	50	50	50	25	25	25	25	5	5
Moped/ Motorcycle	PEU	PEU	PEU	PEU	PEU	PEU	PEU	PEU	PEU	EU1	EU1	EU1	EU2	EU2	EU2	EU2	EU3	EU3	EU3	EU3	EU3

S6 TM5-FASST results: impacts on concentrations, health and crops

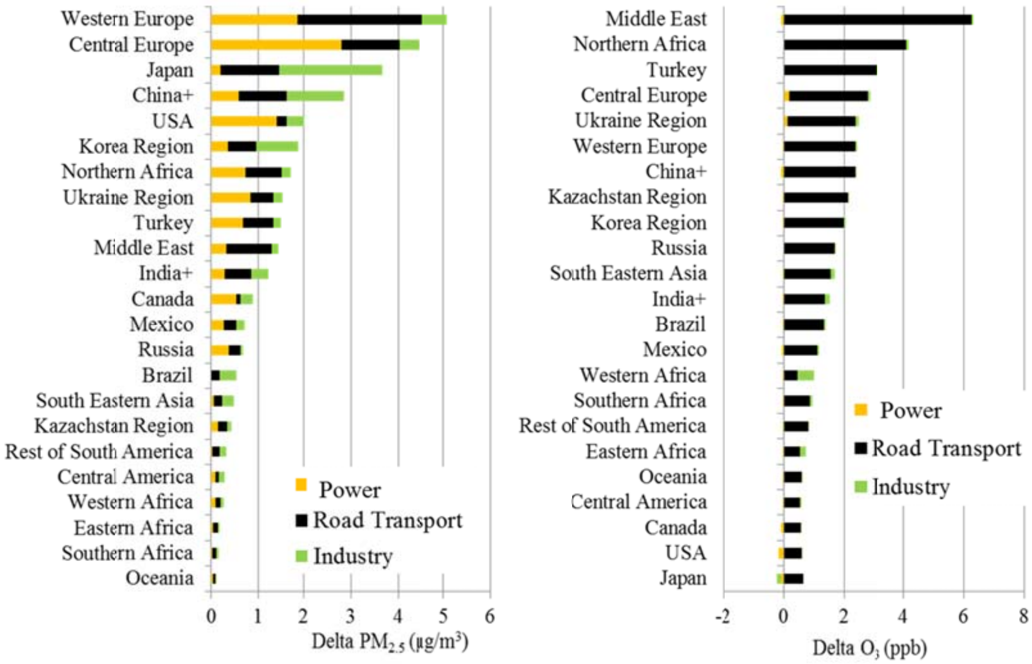

Figure S6.1 Change in $PM_{2.5}$ and O_3 modeled concentrations comparing STAG_TECH with the reference scenario (REF) for the year 2010.

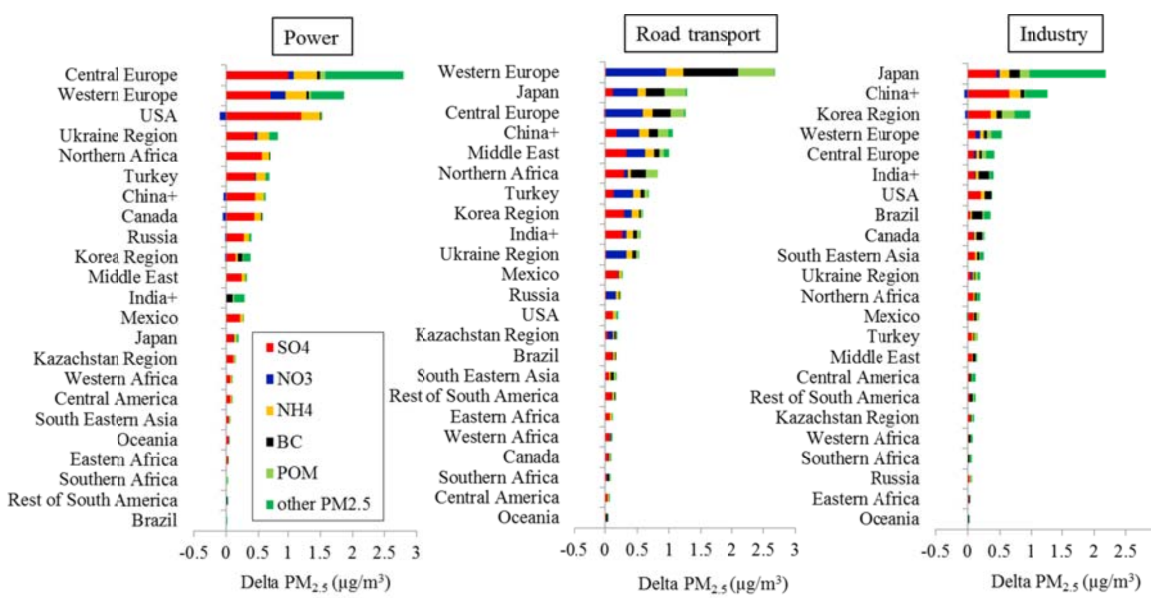

Figure S6.2 Change in regional $PM_{2.5}$ chemical composition and concentration comparing STAG_TECH and REF scenarios. The comparison between the power generation, road transport and manufacturing industry sectors is reported for the year 2010.

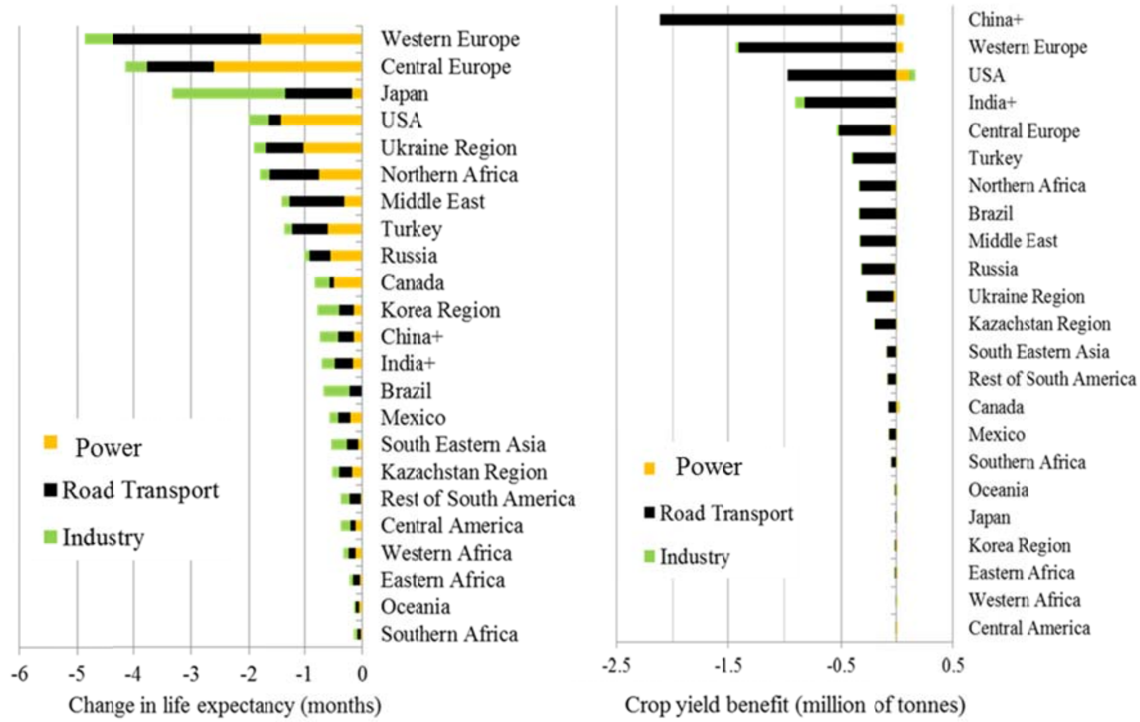

Figure S6.3 Impacts of $PM_{2.5}$ and O_3 concentrations on human health and crop yields. Changes in life expectancy and crop yield are obtained comparing the STAG_TECH scenario and the reference case (REF) for the year 2010.

References

70/220/EEC: Council Directive of 20 March 1970 on the approximation of the laws of the Member States relating to measures to be taken against air pollution by gases from positive ignition engines of motor vehicles, 1970.

80/779/EEC: Council Directive 80/779/EEC of 15 July 1980 on air quality limit values and guide values for sulfur dioxide and suspended particulates, as last amended by Directive 89/427/EEC, 1980.

85/203/EEC: Council Directive 85/203/EEC of 07 March 1985 on air quality standards for nitrogen dioxide, as last amended by Council Directive 85/580/EEC, 1985.

93/12/EEC: Council Directive 93/12/EEC of 23 March 1993 relating to the sulfur content of certain liquid fuels, 1993.

96/62/EC: Council Directive 96/62/EC on ambient air quality assessment and management (Air Quality Framework Directive), 1996.

98/70/EC: Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC, 1998.

1999/13/EC: Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations, 1999.

99/30/EC: Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulfur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air, 1999.

1999/32/EC: Directive 1999/32/EC on reduction of sulfur content of certain liquid fuels, 1999.

2000/76/EC: Directive 2000/76/EC of the European Parliament and of the Council of 04 December 2000 on the incineration of waste, 2000.

2001/80/EC: Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from Large Combustion Plants, 2001.

2001/81/EC: Directive 2001/81/EC on national emissions ceilings for certain atmospheric pollutants, 2001.

2003/17/EC: Directive 2003/17/EC of the European Parliament and of the Council of 03 March 2003 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels, 2003.

2004/107/EC: Directive 2004/107/EC of the European Parliament and of the Council relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (Fourth Daughter Directive), 2004.

2008/50/EC: Directive 2008/50/EC on ambient air quality and cleaner air for Europe, 2008.

2009/30/EC: Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gasoil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive, 2009.

2010/75/EU: Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control), 2010.

Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Dentener, F., Muntean, M., Pouliot, G., Keating, T., Zhang, Q., Kurokawa, J., Wankmüller, R., Denier van der Gon, H., Klimont, Z., and and Frost, G.: HTAP_v2: a mosaic of regional and global emission gridmaps for 2008 and 2010 to study hemispheric transport of air pollution, Atmos. Chem. Phys., 15, 1–21, 2015.