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Forty years of improvements in European air quality: the role of EU policy–industry interplay

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SI-1 Comparison of reference 2010 emissions and retrospective scenarios

Table SI-1.1 shows the ratios between STAG_FUEL and REF global and European emissions. With the exception of NH_3, global ratios of STAG_FUEL to REF emissions for energy are 0.15-0.36, for industry between 0.49 and 0.70, and for road-transport between 0.14 and 0.33. For Europe these ratios are much higher (energy 0.25-1.18, industry 1.15-3.96, road transport 0.17-0.68), indicating the impact of cleaner fuels (e.g. for SO_2) on pollutant emissions. Similarly to Table SI-1.1, Table SI-1.2 reports the STAG_TECH to REF emission ratios for global and European scale. These ratios range from 1.06 to 2.40 for the energy and industrial sectors at global scale, corresponding to a change in technology and implementation of abatement measures; a much higher ratio of 8.5 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. Without considering 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 paragraphs 3.2, 3.3 and 3.4 of the manuscript.

Table SI-1.1: Effect of fuel consumption stagnation at year 1970 on 2010 pollutant emissions at global and European scales. The ratio between STAG_FUEL 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_FUEL to REF (2010) – Globe (EU27)								
	SO_2	NOx	CO	NMVOC	NH_3	PM_{10}	$PM_{2.5}$	BC	OC
Energy	0.36 (1.18)	0.28 (0.86)	0.25 (0.37)	0.24 (0.25)	0.96 (0.60)	0.17 (0.82)	0.15 (0.74)	0.22 (1.03)	0.17 (0.82)
Industry	0.64 (3.96)	0.70 (2.65)	0.44 (1.90)	0.52 (1.83)	1.17 (0.46)	0.48 (2.23)	0.51 (2.25)	0.47 (3.27)	0.45 (1.53)
Road Transport	0.16 (0.51)	0.21 (0.24)	0.33 (0.68)	0.30 (0.68)	0.77 (0.52)	0.14 (0.20)	0.14 (0.20)	0.14 (0.17)	0.16 (0.22)

Table SI-1.2: 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
Energy	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)

SI-2 Scenarios overview: emissions comparison (2010)

In this section, from Table SI-2.1 to Table SI-2.9 2010 pollutant emissions are reported for the three scenarios, in decreasing order of magnitude of STAG_FUEL for 24 world regions. All emission sectors are considered, with the exception of 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_FUEL scenario, due to their high consumption. In addition to China and India, also Africa contributes significantly to actual global PM emissions, while industrialized countries as 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 SI-2.1 Comparison of SO_2 emission scenarios per world region (year 2010). Emissions are expressed in Tg SO_2/yr and include all emission sectors.

SO2 - 2010	STAG_FUEL	STAG_TECH	REF_2010
China +	10.2	37.8	31.6
USA	7.8	20.8	10.1
OECD Europe	5.8	8.7	3.2
Russia +	5.1	4.2	2.7
India +	3.0	11.5	10.9
Central Europe	3.0	5.5	3.0
Ukraine +	2.6	1.3	1.2
Asia-Stan	1.7	1.9	1.8
Rest South America	1.7	2.5	2.2
Japan	1.6	1.7	1.1
Southern Africa	1.4	2.8	2.7
Middle East	1.3	8.3	7.5
Southeastern Asia	1.1	2.8	2.5
Korea	1.0	1.8	1.6
Brazil	0.9	1.6	1.2
Canada	0.7	1.3	1.0
Rest Central America	0.7	1.4	1.3
Oceania	0.7	1.6	1.1
Mexico	0.6	1.6	1.3
Turkey	0.6	1.6	1.5
Indonesia +	0.5	2.2	2.0
Northern Africa	0.5	1.7	1.5
Western Africa	0.3	0.6	0.5
Eastern Africa	0.2	0.4	0.4
Globe	53.0	125.6	93.7

Table SI-2.2 Comparison of NOx emission scenarios per world region (year 2010). Emissions are expressed in Tg NOx/yr and include all emission sectors.

NOx - 2010	STAG_FUEL	STAG_TECH	REF_2010
USA	9.7	13.4	12.5
China +	7.2	27.2	25.1
OECD Europe	6.2	13.0	7.2
India +	3.1	10.3	9.9
Russia +	3.0	4.9	3.9
Central Europe	2.1	3.2	2.3
Japan	2.0	3.8	2.2
Brazil	1.5	3.6	3.1
Rest South America	1.4	3.1	2.9
Southeastern Asia	1.4	4.1	3.3
Ukraine +	1.2	1.1	0.9
Canada	1.1	1.7	1.7
Asia-Stan	1.0	1.1	0.9
Southern Africa	0.9	2.2	1.8
Middle East	0.9	8.2	6.1
Indonesia +	0.8	2.5	2.2
Oceania	0.7	2.1	1.4
Western Africa	0.7	1.5	1.3
Korea	0.5	1.7	1.7
Mexico	0.5	2.2	2.1
Rest Central America	0.5	1.1	1.1
Eastern Africa	0.4	0.8	0.7
Turkey	0.3	1.1	0.9
Northern Africa	0.3	1.9	1.5
Globe	47.5	115.7	96.9

Table SI-2.3 Comparison of CO emission scenarios per world region (year 2010). Emissions are expressed in Tg CO/yr and include all emission sectors.

CO - 2010	STAG_FUEL	STAG_TECH	REF_2010
China +	132.1	218.5	165.5
India +	75.3	108.1	96.2
Southeastern Asia	38.3	59.4	48.3
USA	36.4	48.2	47.7
Western Africa	33.3	55.6	38.2
Brazil	23.9	30.7	27.8
Indonesia +	21.8	47.0	36.2
Eastern Africa	19.5	24.0	20.5
Rest South America	16.6	27.5	25.8
Southern Africa	16.2	23.5	17.5
OECD Europe	14.2	42.6	15.4
Central Europe	7.6	11.2	7.7
Russia +	7.0	14.2	9.0
Rest Central America	6.0	8.7	8.0
Japan	3.7	21.7	5.4
Canada	3.6	5.2	5.1
Mexico	3.6	9.8	9.6
Turkey	3.5	4.8	4.4
Ukraine +	3.3	3.8	3.0
Korea	3.2	5.4	4.9
Oceania	2.7	7.3	3.2
Middle East	2.7	25.2	15.3
Asia-Stan	2.6	3.1	2.2
Northern Africa	1.6	6.0	3.3
Globe	478.8	811.6	620.0

Table SI-2.4 Comparison of NMVOC emission scenarios per world region (year 2010). Emissions are expressed in Tg NMVOC/yr and include all emission sectors.

NMVOC - 2010	STAG_FUEL	STAG_TECH	REF_2010
China +	19.3	27.1	24.2
India +	12.4	15.5	15.0
Western Africa	10.5	11.5	11.5
Southeastern Asia	9.0	11.0	10.3
Middle East	7.8	13.5	11.1
Eastern Africa	7.6	7.8	7.8
Southern Africa	7.5	8.2	7.8
USA	7.1	8.2	7.9
Brazil	4.4	6.2	5.4
OECD Europe	4.3	8.7	4.5
Rest South America	3.8	5.5	5.0
Indonesia +	3.3	5.1	4.7
Russia +	3.2	5.3	4.1
Korea	1.9	2.2	2.1
Rest Central America	1.7	2.1	2.0
Northern Africa	1.6	2.4	2.1
Central Europe	1.5	2.1	1.5
Japan	1.2	2.1	1.5
Canada	1.1	1.3	1.2
Mexico	1.0	2.1	2.1
Asia-Stan	0.9	1.0	0.9
Ukraine +	0.7	0.8	0.7
Oceania	0.7	1.3	0.8
Turkey	0.5	0.7	0.6
Globe	112.7	151.7	134.8

Table SI-2.5 Comparison of NH_3 emission scenarios per world region (year 2010). Emissions are expressed in Tg NH_3/yr and include all emission sectors.

NH3 - 2010	STAG_FUEL	STAG_TECH	REF_2010
China +	14.1	14.1	14.1
India +	8.5	8.6	8.6
OECD Europe	4.2	4.3	4.2
USA	3.8	4.0	3.9
Southeastern Asia	2.8	2.8	2.8
Brazil	2.8	2.9	2.9
Rest South America	2.1	2.2	2.2
Indonesia +	1.9	1.9	1.9
Western Africa	1.8	1.8	1.8
Eastern Africa	1.6	1.7	1.7
Central Europe	1.4	1.4	1.4
Russia +	1.1	1.1	1.1
Southern Africa	1.0	1.0	1.0
Middle East	1.0	1.0	1.0
Oceania	0.9	0.9	0.9
Mexico	0.9	0.9	0.9
Turkey	0.8	0.8	0.8
Northern Africa	0.8	0.8	0.8
Canada	0.7	0.7	0.7
Rest Central America	0.6	0.6	0.6
Ukraine +	0.5	0.5	0.5
Asia-Stan	0.5	0.5	0.5
Japan	0.4	0.4	0.4
Korea	0.3	0.3	0.3
Globe	54.2	54.8	54.8

Table SI-2.6 Comparison of PM_{10} emission scenarios per world region (year 2010). Emissions are expressed in Tg PM_{10}/yr and include all emission sectors.

PM_{10} - 2010	STAG_FUEL	STAG_TECH	REF_2010
China +	14.11	19.96	19.37
India +	9.55	12.12	11.72
Western Africa	5.04	5.33	5.20
Southeastern Asia	4.50	5.03	4.86
Eastern Africa	2.91	2.99	2.96
Indonesia +	2.81	3.15	3.06
Brazil	2.77	3.31	3.25
Southern Africa	2.37	2.57	2.50
USA	2.30	2.32	2.16
OECD Europe	1.57	2.43	1.45
Rest South America	1.19	1.40	1.36
Central Europe	1.10	1.51	1.05
Russia +	0.75	0.64	0.61
Rest Central America	0.60	0.62	0.61
Turkey	0.42	0.52	0.50
Mexico	0.39	0.44	0.43
Canada	0.33	0.43	0.37
Korea	0.31	0.53	0.48
Ukraine +	0.30	0.28	0.26
Oceania	0.30	0.37	0.32
Japan	0.29	0.47	0.26
Asia-Stan	0.28	0.24	0.22
Middle East	0.25	0.46	0.41
Northern Africa	0.22	0.31	0.28
Globe	54.7	67.4	63.7

Table SI-2.7 Comparison of $PM_{2.5}$ emission scenarios per world region (year 2010). Emissions are expressed in Tg $PM_{2.5}$/yr and include all emission sectors.

$PM_{2.5}$ - 2010	STAG_FUEL	STAG_TECH	REF_2010
China +	9.17	13.65	13.18
India +	6.24	8.21	7.98
Southeastern Asia	3.1	3.51	3.4
Western Africa	2.47	2.67	2.62
Brazil	2.1	2.57	2.38
Indonesia +	1.92	2.19	2.14
USA	1.66	1.4	1.32
Eastern Africa	1.37	1.42	1.41
Southern Africa	1.14	1.27	1.23
OECD Europe	1.04	1.69	0.93
Rest South America	0.82	1.00	0.95
Central Europe	0.67	0.94	0.63
Russia +	0.46	0.4	0.38
Rest Central America	0.31	0.34	0.32
Turkey	0.31	0.38	0.37
Oceania	0.24	0.28	0.24
Mexico	0.23	0.27	0.26
Canada	0.22	0.28	0.25
Asia-Stan	0.22	0.17	0.16
Ukraine +	0.21	0.18	0.17
Korea	0.19	0.35	0.32
Japan	0.18	0.33	0.15
Middle East	0.15	0.32	0.27
Northern Africa	0.11	0.19	0.16
Globe	34.7	44.1	41.4

Table SI-2.8 Comparison of BC emission scenarios per world region (year 2010). Emissions are expressed in Tg BC/yr and include all emission sectors.

BC - 2010	STAG_FUEL	STAG_TECH	REF_2010
China +	1.26	1.72	1.59
India +	0.65	1.01	0.89
Western Africa	0.31	0.37	0.36
Southeastern Asia	0.21	0.32	0.27
Eastern Africa	0.17	0.19	0.19
USA	0.15	0.2	0.15
Southern Africa	0.14	0.17	0.15
Indonesia +	0.13	0.2	0.18
OECD Europe	0.12	0.52	0.16
Brazil	0.11	0.27	0.17
Rest South America	0.06	0.12	0.09
Central Europe	0.05	0.12	0.07
Rest Central America	0.03	0.05	0.04
Russia +	0.03	0.04	0.03
Japan	0.02	0.06	0.03
Asia-Stan	0.02	0.02	0.02
Canada	0.02	0.05	0.03
Ukraine +	0.02	0.01	0.01
Turkey	0.02	0.04	0.03
Mexico	0.01	0.03	0.03
Oceania	0.01	0.04	0.02
Korea	0.01	0.04	0.04
Northern Africa	0.01	0.05	0.03
Middle East	0.01	0.09	0.06
Globe	3.7	5.9	4.7

Table SI-2.9 Comparison of OC emission scenarios per world region (year 2010). Emissions are expressed in Tg OC/yr and include all emission sectors.

OC - 2010	STAG_FUEL	STAG_TECH	REF_2010
China +	3.16	4.00	3.91
India +	2.58	2.84	2.82
Southeastern Asia	1.10	1.21	1.17
Western Africa	1.05	1.09	1.09
Indonesia +	0.67	0.76	0.74
Brazil	0.59	0.69	0.65
Eastern Africa	0.58	0.59	0.59
Southern Africa	0.43	0.45	0.45
USA	0.43	0.30	0.28
Rest South America	0.25	0.29	0.28
OECD Europe	0.22	0.47	0.25
Central Europe	0.19	0.24	0.20
Turkey	0.12	0.14	0.13
Rest Central America	0.11	0.11	0.11
Russia +	0.09	0.09	0.09
Mexico	0.07	0.09	0.08
Oceania	0.06	0.08	0.06
Korea	0.04	0.06	0.05
Ukraine +	0.04	0.04	0.04
Canada	0.04	0.05	0.04
Asia-Stan	0.04	0.04	0.03
Middle East	0.03	0.07	0.06
Northern Africa	0.03	0.06	0.05
Japan	0.01	0.05	0.02
Globe	11.9	13.8	13.2

SI-3 Comparison of STAG_FUEL scenario and the reference case outside Europe

Figure SI 3.1 shows the impact of fuel consumption and fuel mix stagnating at 1970 levels outside Europe (STAG_FUEL scenario), thus complementing results shown in Figs. 3 and 4 where the global and European trends are represented. USA reflects the trend of industrialized countries, characterized by lower emissions moving from 1970 to 2010 due to use of cleaner technologies and fuels, while increasing trend is observed for China, representative of emerging countries, due to enhanced consumptions and activities. Interestingly, USA decreased its industrial emissions by a factor of 4 in 2010 compared to STAG_FUEL for SO_2 and by 2-3 times for NOx, CO and PM_{10} due to the shift to cleaner fuels and shift of some industrial activities to emerging countries. Conversely, Chinese industrial emissions drastically increased due to the enhanced activities compared to 1970. This increase couples both the Chinese economic growth and the shift of manufacturing production of industrialized countries to the developing ones (e.g. to China, Southeastern Asia, etc.).

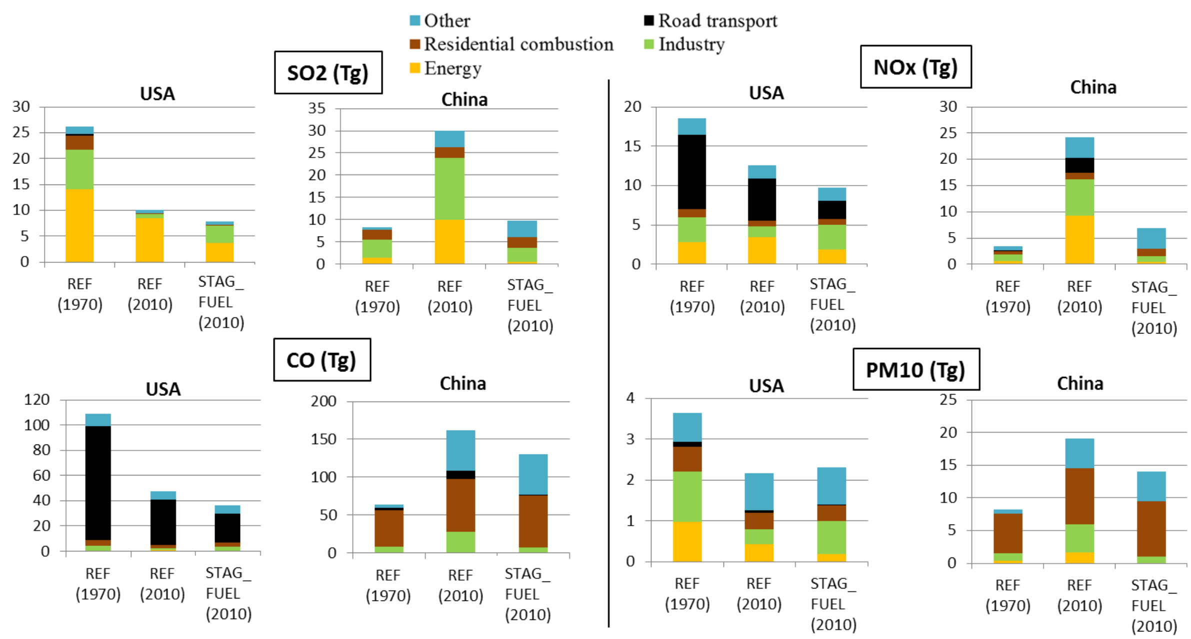

Figure SI 3.1 – Impact of stagnant fuel consumption and mix as in 1970 outside Europe (STAG_FUEL scenario).

SI-4 Impact of EU policy and EoP technologies on the energy and road transport sector

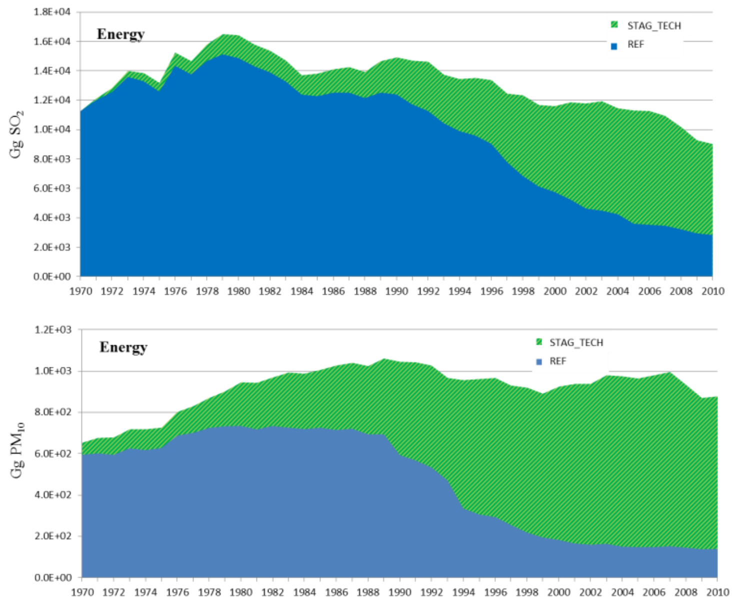

Figure SI 4.1 – Effect of the implementation of European legislation and of keeping emission factors constant (STAG_TECH) since 1970 on power generation emissions (EU27). SO_2 (upper panel) and PM_{10} (lower panel) annual emissions time series are presented.

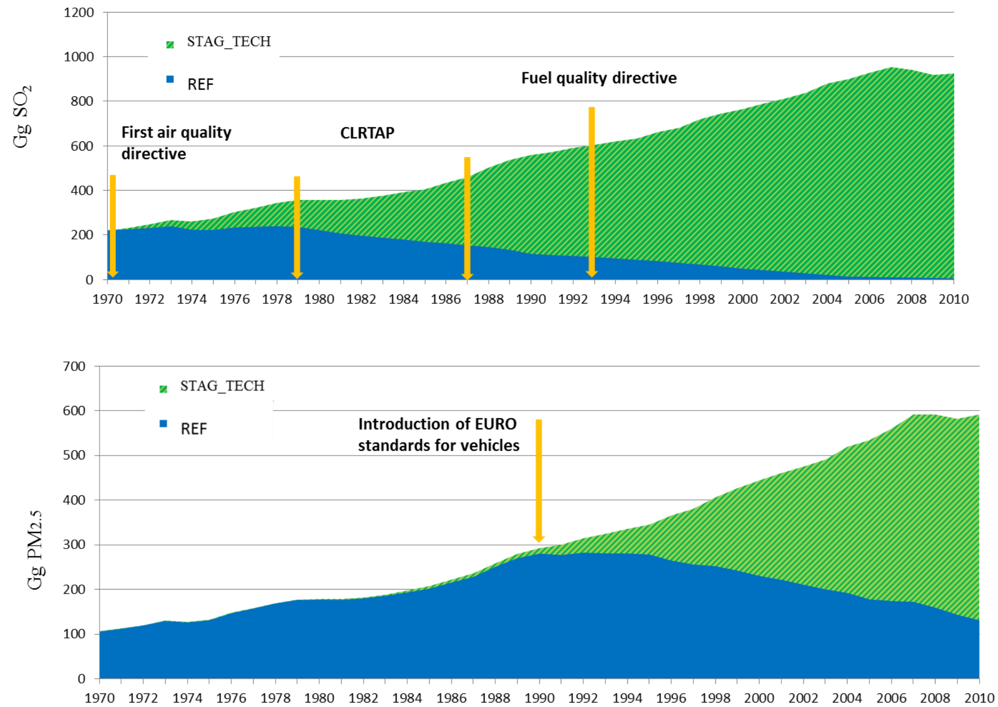

Figure SI 4.2 – Effect of the implementation of European legislation and of keeping emission factors constant since 1970 (STAG_TECH) on road transport emissions (EU27). SO_2 (upper panel) and PM_{10} (lower panel) annual emissions time series are presented.

SI-5 Comparison of EDGAR4.3 reference emission scenario with other reported emissions

In order to evaluate the consistency of the EDGARv4.3 reference scenario, a comparison with other official and science based national/regional emission inventories and regional databases is performed (see Figs. SI-5.1 and SI-5.2). In the following, we show the good agreement obtained for SO_2 and BC, but similar results can be extended for all gaseous and particulate matter pollutants. Here we represent the comparison at regional level, although this was performed at sector level for specific regions of interest. Considering Europe, USA, China and India, the agreement of regional emissions between EDGARv4.3 and HTAP_v2 is quite good. Differences between EDGARv4.3 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 they range from -53% to 14% for PM (including its components).

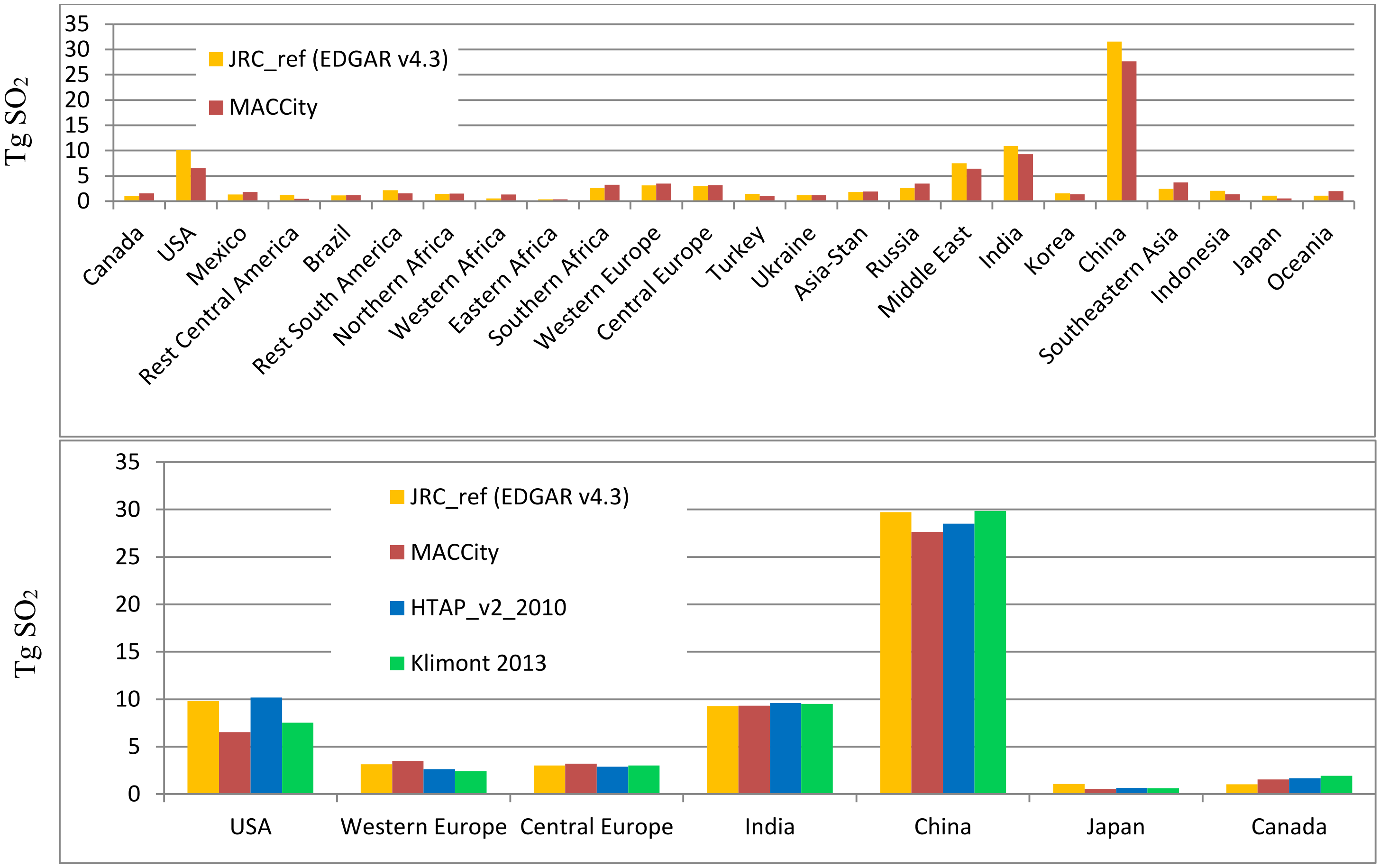

Figure SI 5.1 – Comparison of 2010 SO_2 emission data from EDGAR v4.3, HTAP_v2, MACCity and literature works at regional level.

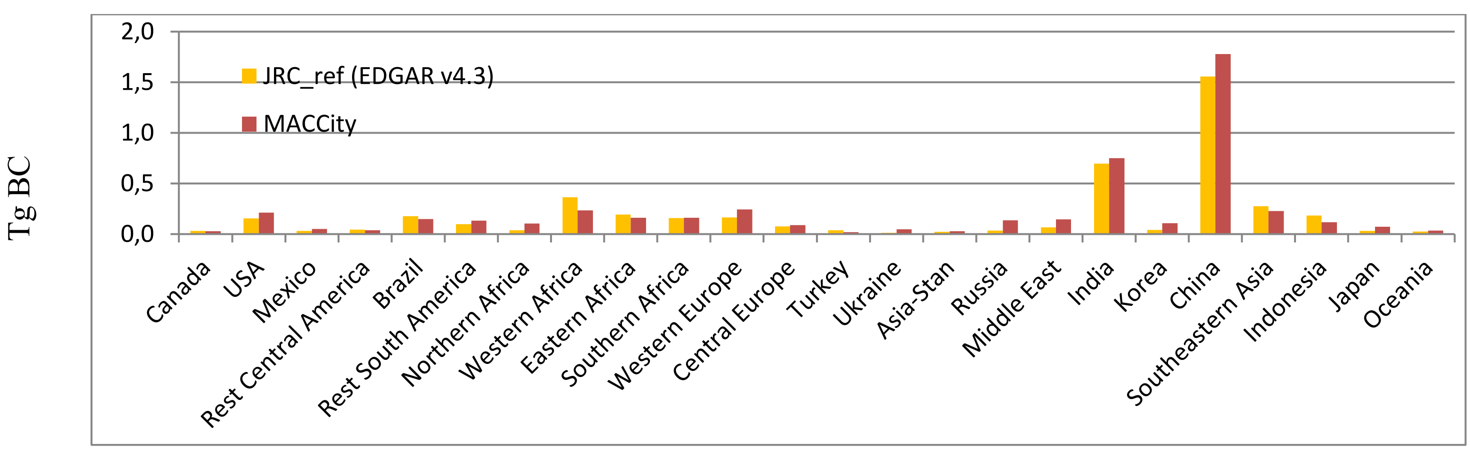

Figure SI 5.2 – Comparison of 2010 BC emission data from EDGAR v4.3 and MACCity at regional level.

Figures SI-5.3, SI-5.4 and SI-5.5 show the comparison of the emission time series for selected pollutants (SO_2, NOx, CO, BC and OC) provided by the EDGARv4.3 and MACCity databases for groups of regions. The relative difference between these two inventories is calculated for each year as VAR = (EDGARv4.3-MACCity)/MACCity and then averaged over time. Table SI-5.1 summarizes the averaged relative difference (VAR) between the emissions estimated by MACCity and EDGARv4.3 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 have a similar trend 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. (submitted) using the HTAP_v2.2 database, where they estimate an uncertainty of 8% for SO_2, 4-5% for NOx and CO and larger values for BC (29%).

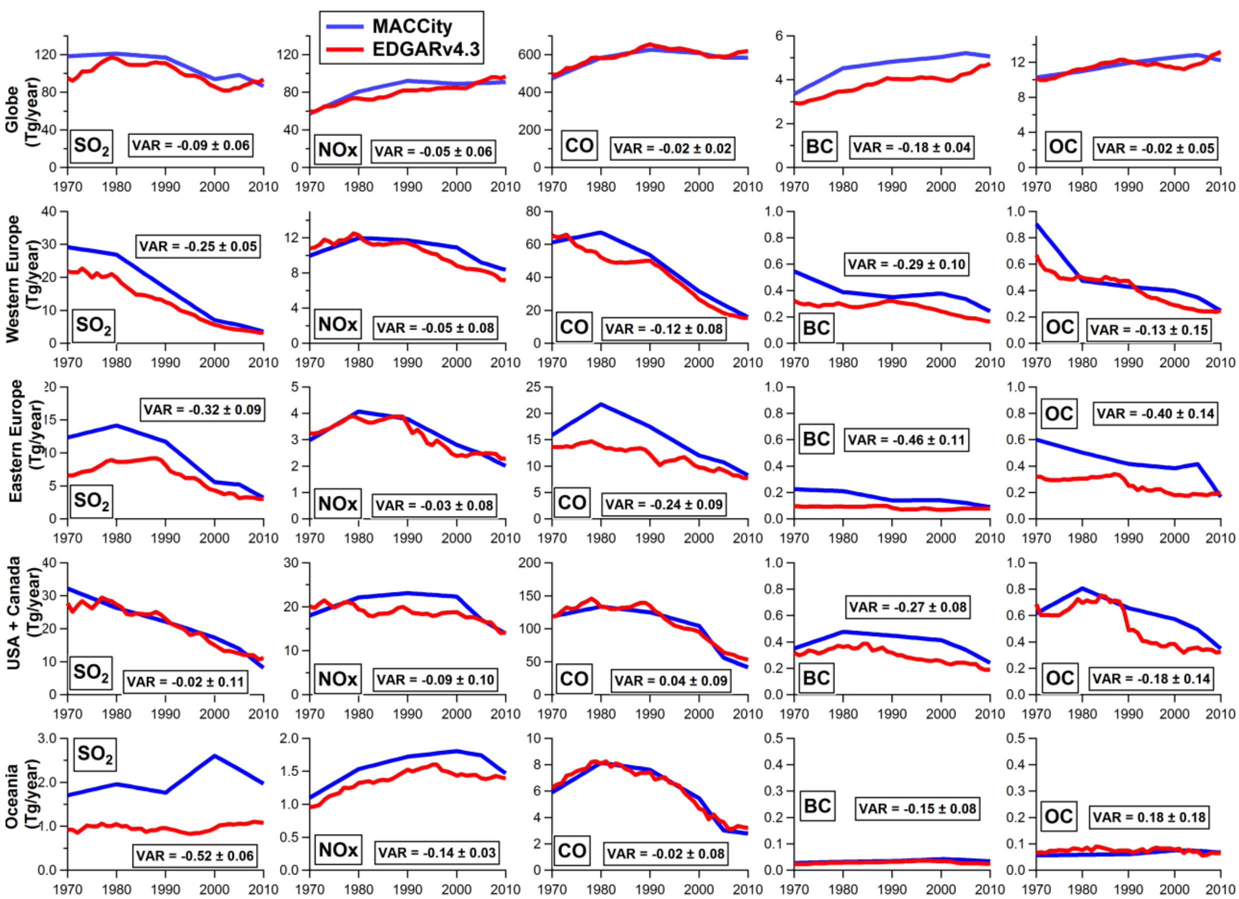

Figure SI 5.3 – MACCity vs EDGARv4.3 time series comparison (industrialized countries).

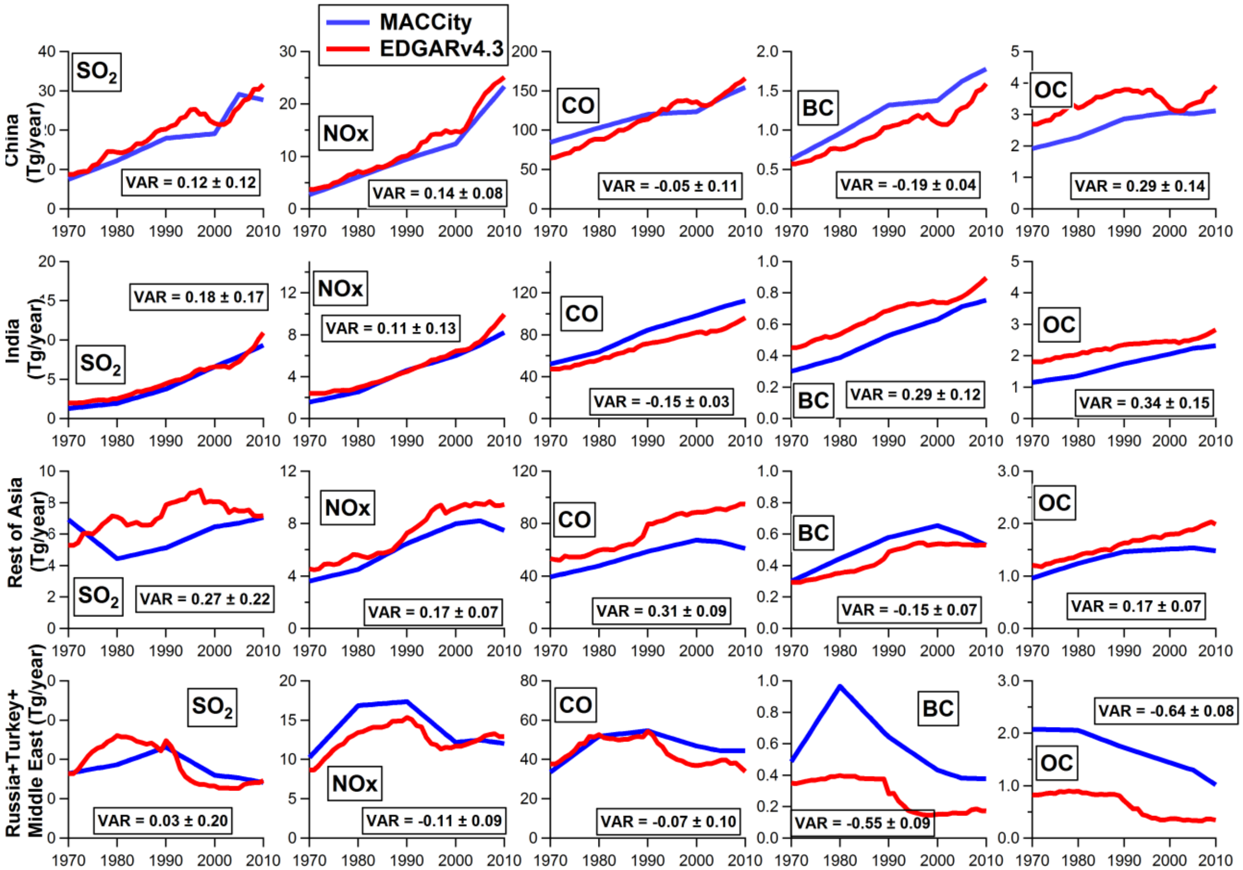

Figure SI 5.4 – MACCity vs EDGARv4.3 time series comparison (emerging countries).

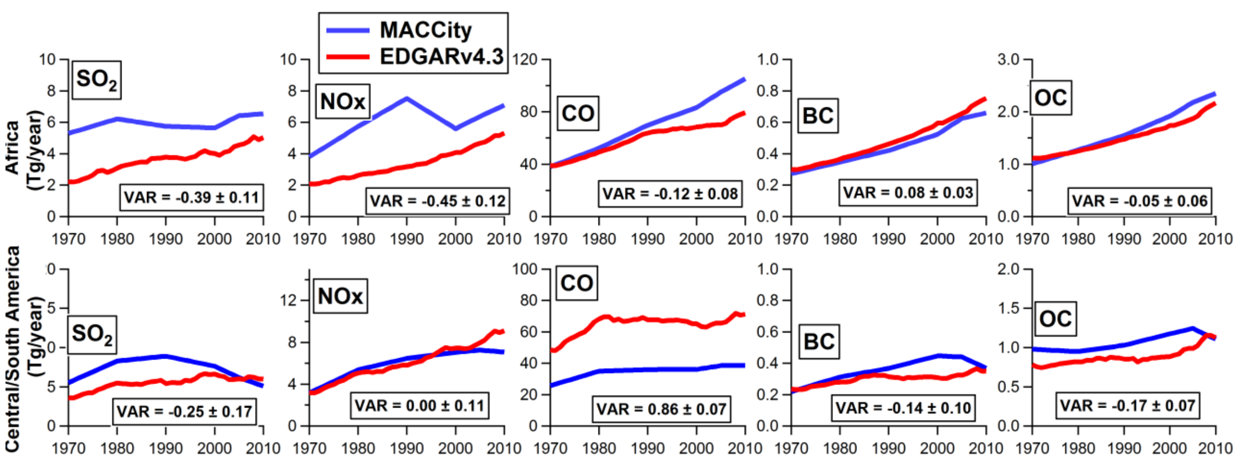

Figure SI 5.5 – MACCity vs EDGARv4.3 time series comparison (developing countries).

Table SI-5.1 – Relative difference between MACCity and EDGARv4.3 time series for groups of regions (industrialized, emerging and developing countries).

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 %**

SI-6 EDGARv4.3 emitting sector specifications and regions classification

In this section some details about the EDGARv4.3 database are provided, focusing on the three emission sectors included in our scenarios (energy, industry and road transport).

SI-6.1: Power generation (ENE)

Table SI-6.1.1 summarizes the processes and technologies considered in the power generation sector by the EDGARv4.3 database, while from Table SI-6.1.2.1 to Table SI-6.1.2.3 pollutant specific abatement measures are reported. Numerical codes reported in Figs. SI-6.1.1 and SI-6.1.2 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 S1-6.1.1: 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

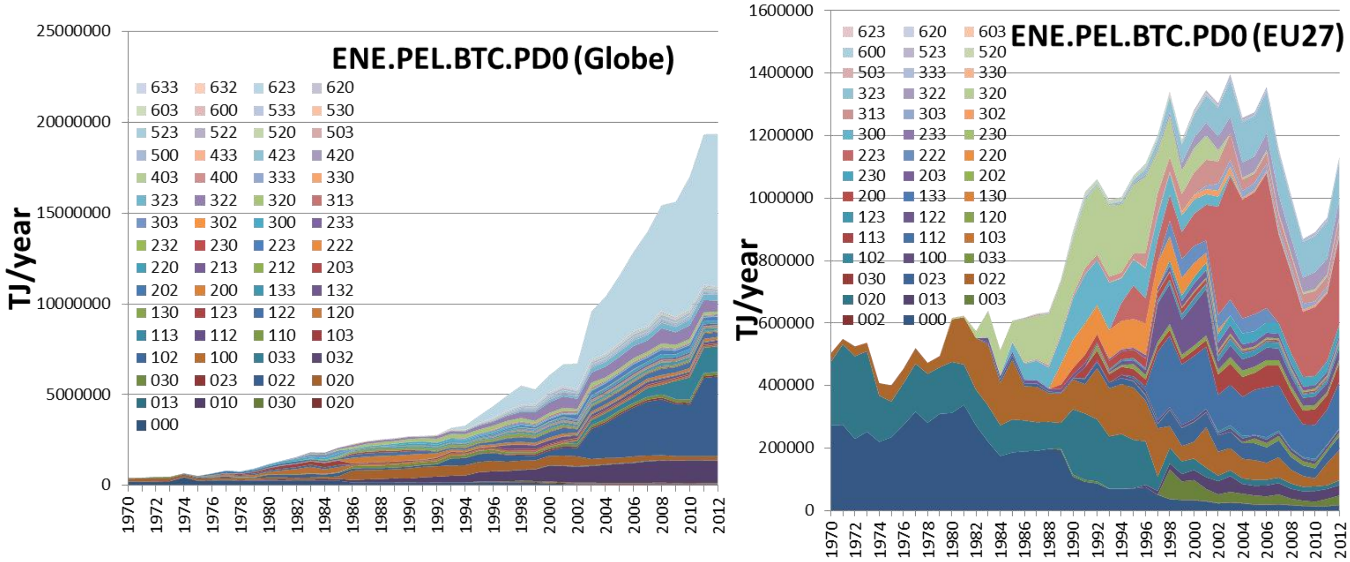

Figure SI 6.1.1 – Penetration of technologies applied to the energy sector (e.g. public electricity production with bituminous coal = ENE.PEL.BTC.PD0) at global and European scales.

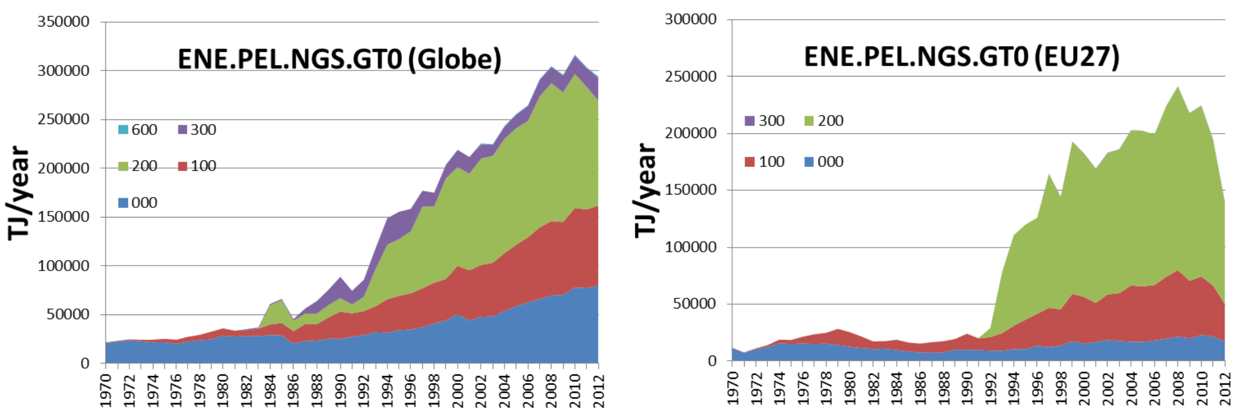

Figure SI 6.1.2 – Penetration of technologies applied to the energy sector (e.g. public electricity production with natural gas = ENE.PEL.NGS.GT0) at global and European scales.

Table SI-6.1.2: 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 SI-6.1.3: SOx abatements

SOx abatement measures have no impact on other component emissions (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 %

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 %

SI-6.2: Manufacturing industry and construction (IND)

Table SI-6.2.1 summarizes the processes and technologies considered in the industrial sector of the EDAGRv4.3 database.

Table SI-6.2.1: 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

SI-6.3: Road transport (TRO.ROA)

In this section details concerning the road transport sector as implemented in the EDGARv4.3 database are reported (refer to Table SI-6.3.1 for the processes and technologies and Table SI-6.3.2 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 SI-6.3.1: Processes and technologies

Road transport (TRO.ROA)			
Process	**Description**	**Technology**	**Description**
TRO.ROA.AVG	Aviation Gasoline	**BS0**	Buses
TRO.ROA.BDS	Biodiesel	**HD0**	Heavy Duty vehicles
TRO.ROA.BGL	Biogasoline	**LD0**	Light Duty vehicles
TRO.ROA.DIE	Gas/Diesel Oil	**PC0**	Passenger cars
TRO.ROA.OKE	Kerosene	**MC0**	Motorcycles
TRO.ROA.LPG	Liquefied Petroleum Gases (LPG)	**MP0**	Mopeds (Scooters)
TRO.ROA.MOG	Motor Gasoline		
TRO.ROA.NGS	Natural Gas		
TRO.ROA.OPR	Non-specified Petroleum Products		

TRO.ROA.OLB	Other liquid biofuels		
TRO.ROA.SBI	Primary Solid Biomass		
TRO.ROA.HFO	Residual Fuel Oil		

Table SI-6.3.2: 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 buses 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. SI-6.3.1 and SI-6.3.2, 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).

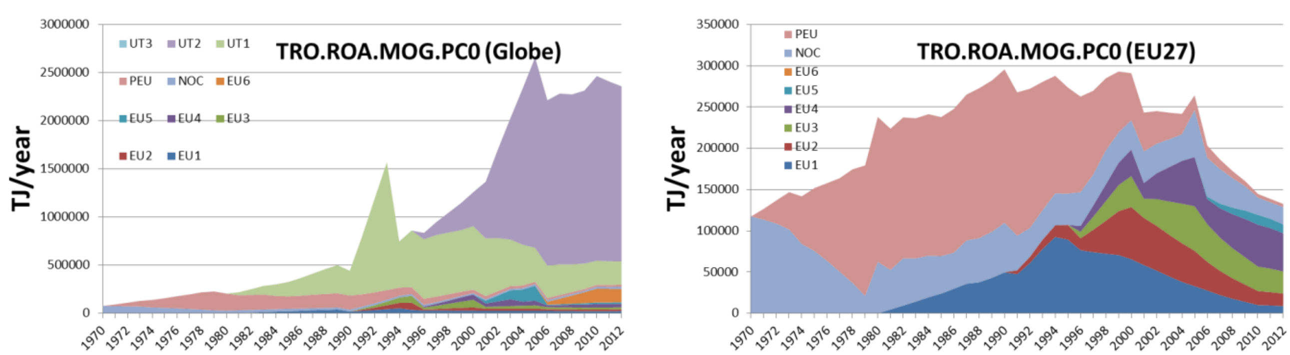

Figure SI 6.3.1 – Penetration of technologies applied to the road sector (e.g. motor gasoline for passenger cars = TRO.ROA.MOG.PC0) at global and European scales.

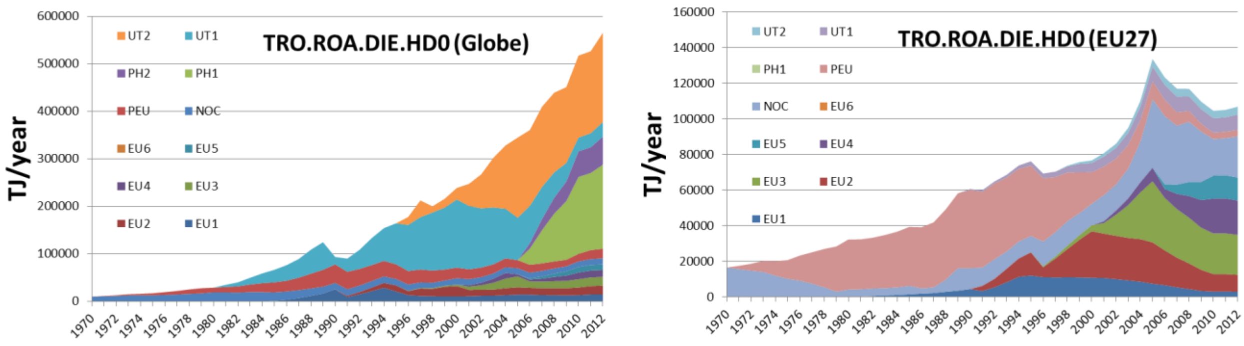

Figure SI 6.3.2 – Penetration of technologies applied to the road sector (e.g. diesel for heavy duty vehicles = TRO.ROA.DIE.HD0) at global and European scales.

SI-6.4: Regions classification in EDGARv4.3

In the present work emission data are often grouped by 24 emission regions, 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.).

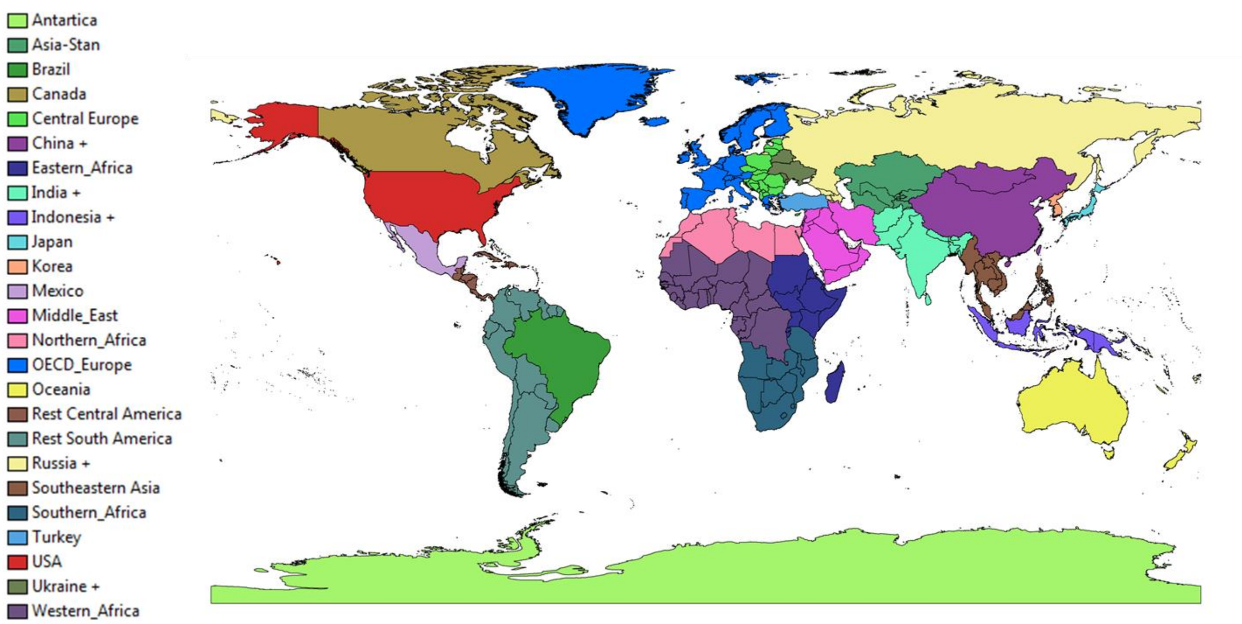

Figure SI 6.4.1 – Classification of world regions in the EDGARv4.3 database.

SI-7 European legislation

Table SI-7.1 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 COM(2005)446-447	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 (large combustion plants)	x	x	x	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 or.

Table SI-7.2 Implementation of European standards on vehicle emissions with PM limits (mg/km) over time.

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

SI-8 TM5-FASST results: impacts on concentrations, health and crops

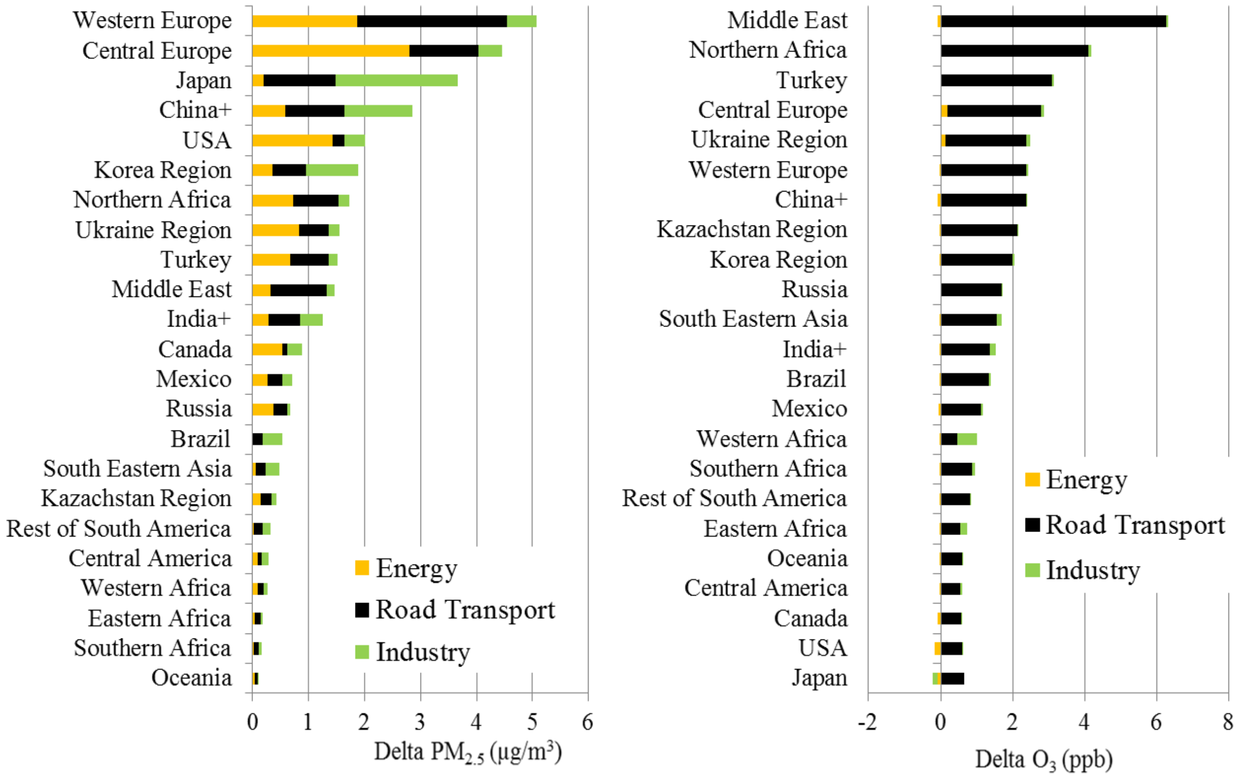

Figure SI-8.1 Change in $PM_{2.5}$ and O_3 modeled concentrations comparing STAG_TECH with the reference scenario (REF) for the year 2010.

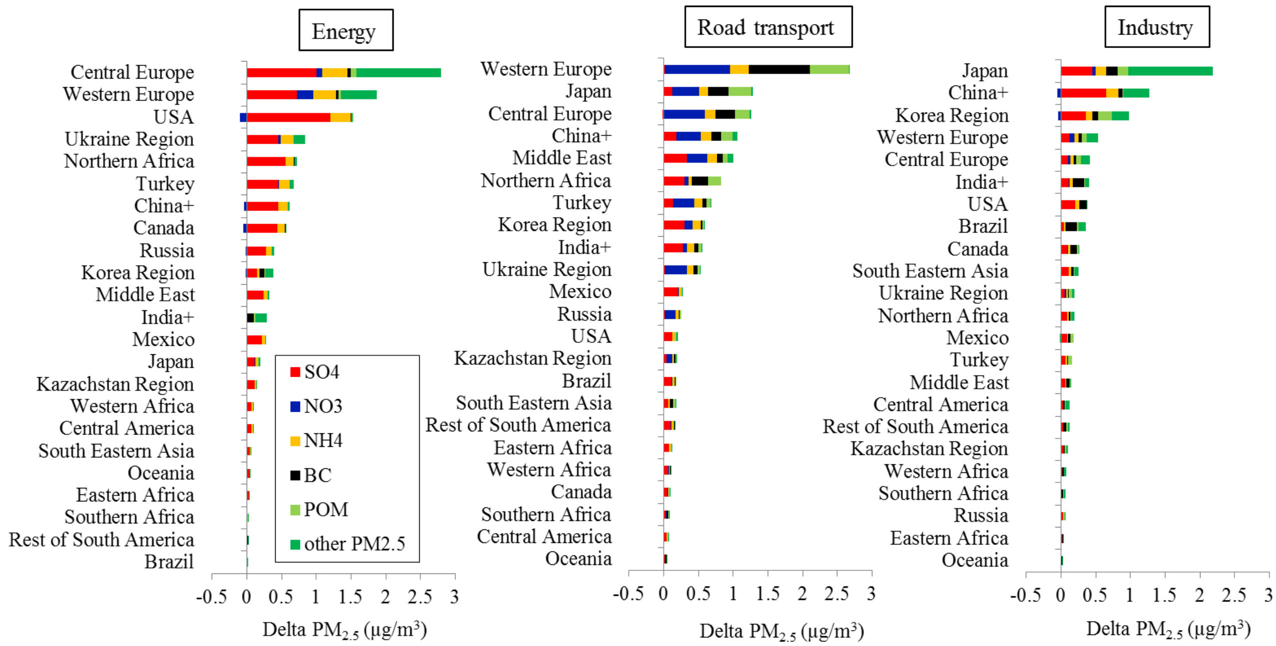

Figure SI-8.2 Change in regional $PM_{2.5}$ chemical composition and concentration comparing STAG_TECH and REF scenarios. The comparison between the power generation, road transport and manufacturing industry sectors is reported for the year 2010.

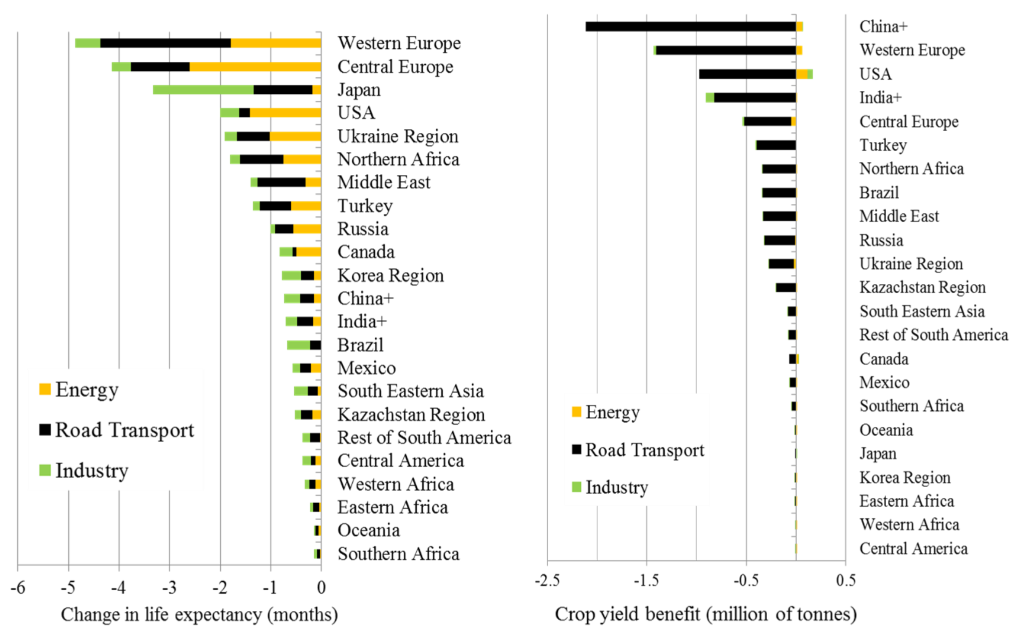

Figure SI-8.3 Impacts of $PM_{2.5}$ and O_3 concentrations on human health and crop yields. Changes in life expectancy and crop yield are obtained comparing the STAG_TECH scenario and the reference case (REF) for the year 2010.

References

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., acp-2015-214, submitted.