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The potential for further control of emissions of fine particulate matter in Europe

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Abstract

This report examines the possible evolution of emissions of primary particulate matter in Europe up to 2020 as a consequence of further economic development and progressing implementation of emission control legislation, in particular of the Protocols that also influence primary emissions of PM. Furthermore, it explores the potential for further PM emission reductions through extensions of the existing protocols (i) to additional countries, (ii) by stricter emission limit values, and (iii) to other sectors.

Based on the implementation of the RAINS model as it was used for the Clean Air For Europe (CAFE) program of the European Commission, the report analyses three emission control cases: (i) the situation in the year 2000, (ii) the current legislation case for 2020, and (iii) a case with further control measures.

Results are presented for three groups of countries: (i) the 15 old Member States of the European Union, Norway and Switzerland, (ii) the 10 new Member States, and (iii) the other countries in Europe including the European area of Russia and Turkey.

The analysis concludes that primary emissions of PM are expected to decline in the future due to current legislation, between 2000 and 2020 by approx. 40-45 percent in the EU-25 and by 8-9 percent in the non-EU countries. Tightened emission limit values in a potential revision of the Heavy Metals and Gothenburg Protocols would have a relatively small effect on total PM emissions in 2020, especially if the protocols would not receive ratifications from additional Parties. In the EU-25, PM2.5 emissions would decline in 2020 at maximum by an additional 7 percent if the most advanced technical measures were implemented.

A significantly larger reduction potential could be harvested through ratification and subsequent implementation of the Heavy Metals and Gothenburg Protocols by additional Parties. This could reduce PM2.5 emissions in the non-EU countries by up to 25 percent in 2020 compared to the current legislation situation.

While the Heavy Metals and Gothenburg Protocols contain obligations for PM emissions from certain emission sources, in 2020 the majority of PM emissions is expected to originate from sources for which these protocols do not specify emission limit values. For the EU-25, about 80 percent of the identified technical potential for further PM reductions emerges from sources that are not covered in the Protocols. In the non-EU countries, more than 60 percent of the technical reduction potential relates to these sources. Approximately two thirds of this technical reduction potential from the non-protocol sectors emerge from small non-industrial combustion sources, especially wood and coal stoves.

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1 Background

Epidemiological studies have worldwide demonstrated consistent associations between increased levels of fine particulate matter in ambient air and increased rates of mortality and morbidity (Pope et al., 2002; WHO, 2003). As a result it is estimated that current levels of fine particulate matter (PM) can shorten the life of European citizens on average by nine months (Amann et al., 2004).

There is clear evidence for the transboundary character of fine particulate matter, especially of the fine fraction. As a consequence, effective reductions of ambient PM concentrations at any given site must involve emission reductions at a large number of sources, including sources in other countries.

The Convention on Long-range Transboundary Air Pollution provides an international policy framework to tackle such pollution problems that require international cooperation. Although the Convention has not yet addressed pollution from particulate matter in an explicit way, several Protocols of the Convention contain obligations for emission reductions that also influence – as a side impact – PM concentrations in ambient air. Protocols require measures to reduce precursor emissions of secondary organic and inorganic aerosols (i.e., emissions of SO_2, NO_x, VOC and NH_3), and prescribe technological standards that limit, in addition to other pollutants, also primary emissions of fine particulate matter. Therefore, while there is no specific obligation for the control of PM, implementation of the existing Protocols is expected to lead to reduced ambient concentrations of PM in Europe.

This report has been prepared as input for meeting of the Expert Group on Particulate Matter of the Convention on Long-range Transboundary Air Pollution, Dessau, March 13-14, 2006.

2 Objective of the study

This report examines the possible evolution of emissions of primary particulate matter in Europe up to 2020 as a consequence of further economic development and progressing implementation of emission control legislation, in particular of the Protocols that also influence primary emissions of PM.

The report provides background material that should assist the Working Group on Particulate Matter (EGPM) established under the Convention in answering the following questions:

- How will PM emissions in Europe develop, given the obligations laid down in the UNECE Heavy Metals and Gothenburg Protocols?
- What is the potential for further PM emission reductions through extensions of the existing protocols?
  - To additional countries?
  - By strengthening existing limit values?
  - To other sectors?

3 Approach

This report attempts to answer these questions using IIASA's Regional Air Pollution Information and Simulation (RAINS) model with the dataset that has been reviewed by numerous Parties in the context of the Clean Air For Europe Programme of the European Commission. In particular, the analysis employs the energy projections used for the CAFE analysis, i.e., the projections developed with the PRIMES energy model in 2004 assuming climate policy measures. Details on this baseline scenario are available from Amann *et al.* (2004) and the on-line version of the RAINS model on the Internet (http://www.iiasa.ac.at/web-apps/apd/RainsWeb/index.html).

While the analysis is carried out for each of the 43 countries in the model domain, results are presented in aggregated form for three groups of countries:

- The 15 old Member States of the European Union (EU15), Norway and Switzerland (EU-15+2),
- the 10 new Member States that joined the European Union in 2004 (EU-10), and the
- non-EU countries in the EMEP region (Albania, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Macedonia, Moldova, Romania, Russia, Serbia-Montenegro, Ukraine, Turkey).

This paper analyzes the resulting emissions of fine particulate matter, distinguishing PM2.5 and PM10 as two size classes.

The report distinguishes emissions from two groups of sources

- Emissions from sectors for which the Heavy Metals and Gothenburg Protocols of the Convention specify binding emission limit values, and
- sectors that are not covered in these protocols.

The RAINS model computes emissions for more than 200 source categories and presents them – broken down into the two above mentioned groups – for the 11 SNAP sectors. Sectors covered by the Protocols are listed in Table 3.1, and Table 3.2 lists the other sectors.

Table 3.1: Sectors for which the Heavy Metals and Gothenburg Protocols specify emission limit values

Sector	SNAP code
Large combustion plants in industry and in the power sector (includes municipal waste burning with heat recovery)	1
Cast iron production	3
Cement production	3
Glass production	3
Metal ores storage and handling, agglomeration and sintering	3
Non-ferrous metals production	3
Iron and steel production	4
Mining of metal ores	4
Road transport	7
Non-road transport	8

Table 3.2: Sectors for which the Heavy Metals and Gothenburg Protocols do not specify emission limit values

Sector	SNAP code
Production of coal briquettes	1
Combustion in residential/commercial sector	2
Lime production	3
Small combustion plants in industry	3
Processes in oil refineries, coke ovens	4
Production of aluminium (primary and secondary), fertilizers, paper pulp	4
Production of carbon black, fertilizers, glass fibre, gypsum, PVC and other products	4
Construction activities	4
Material storage and handling other than metals	4
Small industrial and business facilities	4
Storage and handling of NPK fertilizers and other industrial products	4
Coal mining, storage and handling	5
Flaring in oil and gas industry, open burning of residential waste, residential emissions from meat frying, food preparation, barbeques, cigarette smoking, fireworks	9
Agriculture (animal farming, ploughing, tilling, harvesting, storage and handling of products, open waste burning)	10

3.1 Scenarios

This report presents emission calculations for the following three cases:

- The situation in the year 2000, reflecting recent statistics on energy use, agricultural activities, industrial production, etc., and the control measures that were applied in the various countries in the year 2000.
- The situation that is expected for 2020 for the economic development as anticipated in the activity projections of the CAFE program and assuming for all countries full implementation of the current legislation on emission controls (the "CLE 2020" case). This includes
    - all existing national regulations on emissions as described in the RAINS database, and
    - for the EU Member States the current EU legislation and its transposition into national laws (e.g., the Large Combustion Plant Directive as well as the regulations for mobile sources). This also includes emission and fuel quality standards for mobile sources in the road sector (cars, trucks, motorcycles and mopeds) as well as in the non-road sector (agricultural tractors, construction machinery, railways, inland waterways and national sea traffic).
    - For countries that have ratified the Gothenburg and Heavy Metals Protocols (Table 3.4) the mandatory emission limit values laid down in the Technical Annexes to these protocols, if they are stricter than the emission limit values from other applicable (EU and national) legislation. The Heavy Metals Protocol imposes emission limit values for PM for certain stationary sources, and the Gothenburg Protocol contains binding PM emission limit values for mobile sources.
- An additional "with further measures" case where a set of more efficient technical measures to reduce primary emissions of PM would be implemented in the year 2020. This case assumes implementation of the most efficient measures available in the RAINS databases (see Klimont et al., 2002) subject to the following conditions:
    - No change in projected levels and patterns of fuel consumption/agricultural activities, i.e., no fuel switching, and no lowering of demand through economic instruments, behavioral changes, etc.
    - No premature scrapping of existing infrastructure.
    - Only emission control measures contained in the current RAINS database, excluding, e.g., emerging technologies.
    - For new plants/capacities (i.e., commissioned after 2005) it is assumed that measures required by the "current legislation" can be replaced by the measures with the highest removal efficiency in the RAINS databases, up to the country-specific application limit.
    - For existing plants (i.e., commissioned before 2005) the emission control measures specified in the RAINS "current legislation" scenario are

assumed. This excludes replacement of already installed control equipment (no premature scrapping of existing control equipment) even if more efficient options exist.

- Due to uncertainties in the estimates of the technical potential for further PM reductions from road traffic, this potential is not quantified in this study. However, it should be mentioned that for the current legislation case without further measures the contribution of diesel exhaust emissions from light duty diesel vehicles to total PM2.5 is estimated in the EU-25 at approx. four percent in 2020, and from heavy duty vehicles at 1.2 percent.

Table 3.3 summarizes groups of measures that are typically available to further reduce PM emissions from stationary sources on top of the requirements imposed by the current legislation.

Table 3.3: Types of measures that can be applied to further reduce the emissions from stationary sources

Sector	Measure
Large combustion plants	High efficiency electrostatic precipitators and fabric filters
Small combustion sources in industry	Electrostatic precipitators, filters, good practices
Combustion sources in residential/commercial sector	New boiler types, filters, good practices
Production processes - stack emissions	Electrostatic precipitators, wet scrubbers, fabric filters
Production processes - fugitive emissions	Process hermetisation, filters, good practices
Flaring in oil and gas industry	Good practices
Open burning of waste	Ban
Agricultural production	Good practices

Table 3.4: Applicable legislation and protocol ratifications as of March 2006

	EU	HM	GOT		EU	HM	GOT		EU	HM	GOT
Austria	■	■		Latvia	■	■	■	Belarus			
Belgium	■	■		Lithuania	■	■	■	Bosnia			
Cyprus	■	■		Luxembourg	■	■	■	Bulgaria		■	■
Czech R.	■	■	■	Malta	■			Croatia			
Denmark	■	■	■	Netherlands	■	■	■	Norway		■	■
Estonia	■			Poland	■			R. Moldova		■	
Finland	■	■	■	Portugal	■		■	Romania		■	■
France	■	■		Slovakia	■	■	■	Russia			
Germany	■	■	■	Slovenia	■	■	■	Serbia-M.			
Greece	■			Spain	■		■	Switzerland		■	■
Hungary	■	■		Sweden	■	■	■	FYR Maced.			
Ireland	■			UK	■	■	■	Turkey			
Italy	■			Albania				Ukraine			

4 Results for PM2.5

4.1 Emission projections

4.1.1 EU-15+2

In the year 2000, non-industrial combustion sources (i.e., in the residential and commercial sector) made the largest single contribution to total PM2.5 emissions in the EU-15+2 countries (32 percent). Road transport was responsible for another 21 percent, off-road mobile sources contributed 12 percent and industrial production processes not connected with energy combustion emitted 11 percent (Table 4.1, Figure 4.1). More than 50 percent of these emissions originated from sources for which the Heavy Metals and Gothenburg Protocols specify binding emission limit values.

For 2020, changes in the levels of economic activities combined with the current legislation (including the EU legislation as well as the Protocols) are expected to lead to a decline of PM2.5 emissions in these countries by 42 percent. By then it is expected that more than 57 percent of total primary PM2.5 emissions come from sources that are not included in the two protocols. Non-industrial combustion will remain the largest contributor to total PM2.5 emissions.

Technical measures are available that, if fully implemented along the rules laid out in the preceding section, could in the year 2020 further reduce PM2.5 emission by 36 percent compared to the current legislation case, or by 62 percent compared to 1990. Strengthening the emission limit values of the current protocols could reduce emissions from the already regulated sectors by 16 percent. Emission limit values for sources that are currently not covered in these protocols could reduce their emissions by more than 50 percent compared to the current legislation case. The major technical potential for reductions exists for small non-industrial combustion sources (wood and coal stoves), in addition to non-technical measures that could reduce the overall consumption of firewood and coal in the domestic sector.

Table 4.1: PM2.5 emissions in the EU15+2 (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

SNAP sector	*2000*			*2020 CLE*			*2020 MTFR*		
	Covered	Not covered	Total	Covered	Not covered	Total	Covered	Not covered	Total
1: Energy industries	72.9	3.5	76.4	32.9	0.2	33.1	15.0	0.1	15.1
2: Non-industrial combustion	0.0	439.2	439.2	0.0	248.1	248.1	0.0	95.3	95.3
3: Combustion in industry	103.4	13.8	117.2	68.9	9.3	78.2	59.2	3.7	62.9
4: Production processes	56.2	92.6	148.8	56.8	87.9	144.7	33.0	47.3	80.2
5: Extraction & distribution	0.0	4.1	4.1	0.0	2.0	2.0	0.0	2.0	2.0
6: Solvent use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7: Road transport	295.7	0.0	295.7	113.2	0.0	113.2	113.2	0.0	113.2
8: Other mobile sources	169.7	0.0	169.7	70.3	0.0	70.3	70.3	0.0	70.3
9: Waste	0.0	70.8	70.8	0.0	69.0	69.0	0.0	52.8	52.8
10: Agriculture	0.0	40.1	40.1	0.0	42.0	42.0	0.0	27.8	27.8
Sum	698.0	664.1	1362.1	342.1	458.4	800.5	290.6	228.9	519.6

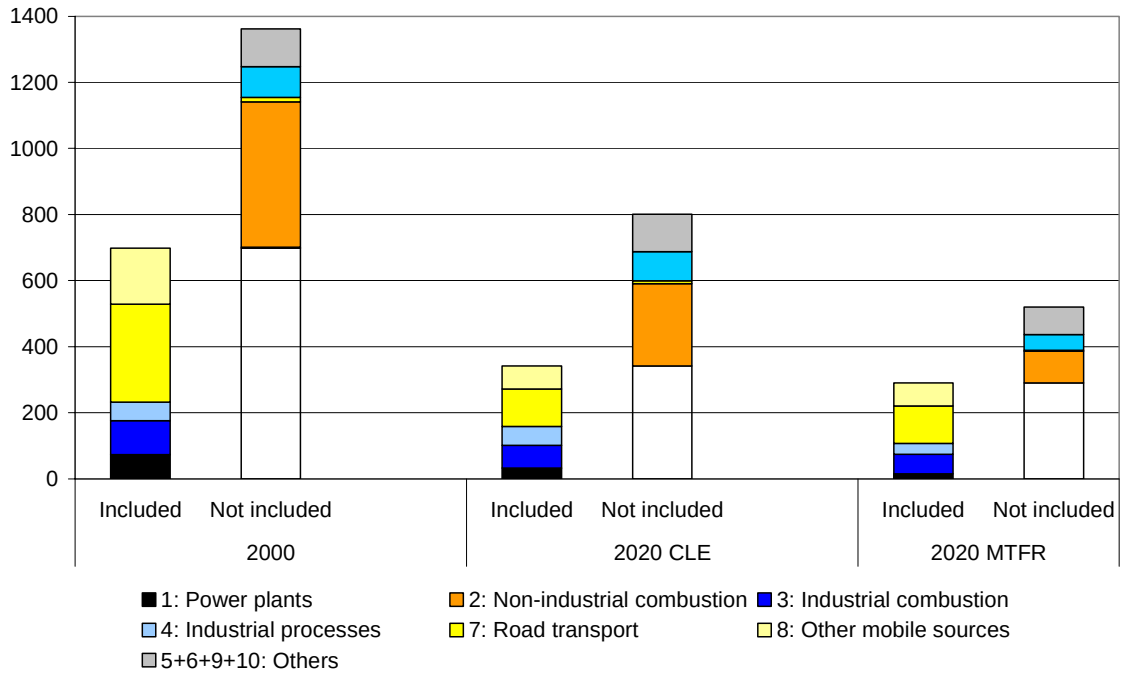

Figure 4.1: PM2.5 emissions in the EU15+2 (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

4.1.2 EU-10

The emission source structure in the New Member States of the European Union is distinctively different to that of the EU-15+2 countries. In the year 2000, non-industrial combustion sources (i.e., in the residential and commercial sector) made by far the largest single contribution to total PM2.5 emissions in the EU-10 countries (45 percent), followed by power generation (19 percent), industrial production processes not connected with energy combustion (9 percent) and road transport (7 percent). Because of the high emissions from small combustion sources more than 60 percent of these emissions originated from sources for which the Heavy Metals and Gothenburg Protocols specify binding emission limit values (Table 4.2, Figure 4.2).

For 2020, changes in the levels of economic activities combined with the progressing implementation of EU legislation are expected to lead to a decline of PM2.5 emissions in these countries by 56 percent. By then it is expected that more than two thirds of total primary PM2.5 emissions will originate from sources which are not included in the two protocols. Non-industrial combustion will remain the largest contributor to total PM2.5 emissions.

Technical measures are available that, if fully implemented along the rules laid out in the preceding section, could in the year 2020 further reduce PM2.5 emission by 55 percent compared to the current legislation case, or by 80 percent compared to 1990. Strengthening the emission limit values of the current protocols could reduce emissions from the already regulated sectors by 30 percent, and introducing emission limit values for sources that are currently not covered in these protocols could reduce their emissions by 66 percent compared to the current legislation case. The major technical potential for reductions exists for small non-industrial combustion sources (wood and coal stoves), in addition to non-technical measures that could reduce the overall consumption of firewood and coal in the domestic sector.

Table 4.2: PM2.5 emissions in the EU10 (New Member States) (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

	2000			*2020 CLE*			*2020 MTFR*		
	Covered	Not covered	Total	Covered	Not covered	Total	Covered	Not covered	Total
1: Energy industries	70.2	9.4	79.6	27.8	0.7	28.5	14.0	0.2	14.2
2: Non-industrial combustion	0.0	192.5	192.5	0.0	75.2	75.2	0.0	21.0	21.0
3: Combustion in industry	23.2	3.5	26.7	12.5	1.8	14.2	9.9	0.4	10.4
4: Production processes	19.5	19.2	38.7	4.8	12.6	17.4	2.8	5.1	7.8
5: Extraction & distribution	0.0	2.9	2.9	0.0	2.0	2.0	0.0	2.0	2.0
6: Solvent use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7: Road transport	29.9	0.0	29.9	10.8	0.0	10.8	10.8	0.0	10.8
8: Other mobile sources	21.7	0.0	21.7	5.7	0.0	5.7	5.7	0.0	5.7
9: Waste	0.0	13.7	13.7	0.0	13.3	13.3	0.0	8.8	8.8
10: Agriculture	0.0	19.0	19.0	0.0	19.8	19.8	0.0	4.8	4.8
Sum	164.5	260.2	424.7	61.6	125.3	186.9	43.3	42.3	85.5

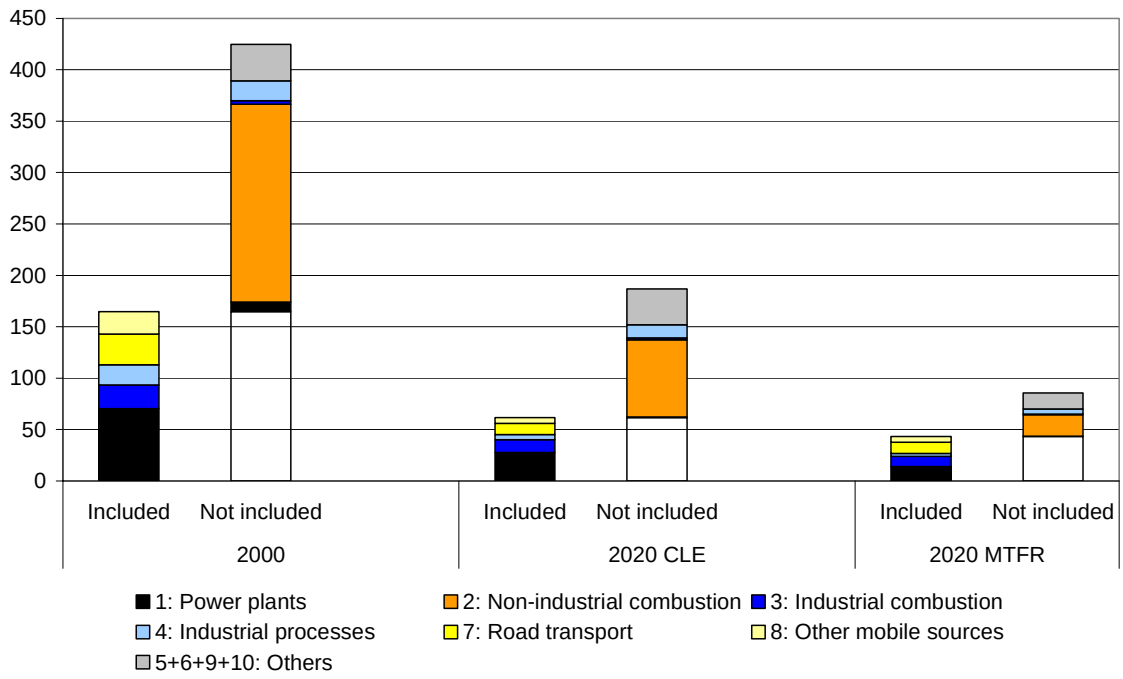

Figure 4.2: PM2.5 emissions in the EU10 (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

4.1.3 Non-EU countries

Compared to the EU countries, PM emissions show a significantly lower degree of control in the countries outside of the European Union.

In the year 2000, the largest contribution to total primary PM2.5 emissions is estimated from industrial production processes not connected with energy combustion (31 percent), followed by small non-industrial combustion sources (30 percent), power generation (10 percent), and agricultural sources (10 percent). 52 percent of these emissions originated from sources to which the Heavy Metals and Gothenburg Protocols applies (Table 4.3, Figure 4.3).

For 2020, PM2.5 emissions are computed to decline by 8 percent, mainly due to changes in the levels of economic activities, while little is known about firm plans to strengthen emission control legislation. Small combustion sources are expected to maintain their current share in total emissions, while emissions from industrial production processes are expected to decline by 25 percent and emissions from road transport to increase by 37 percent. By then it is expected that approximately 55 percent of total primary PM2.5 emissions originate from sources which are not included in the two protocols.

Because of the low level of penetration of control measures, application of the currently available technical measures could substantially reduce emissions of primary PM2.5. With the assumptions laid out in the preceding section, full implementation of the most efficient measures could in the year 2020 reduce PM2.5 emission by almost 70 percent compared to the current legislation case. Ratifications of the Heavy Metals and Gothenburg Protocols, possibly combined with strengthened emission limit values, could reduce emissions from the sectors which are covered in the Protocol by 60 percent. Including emission limit values for sources that are currently not covered in these protocols could reduce their emissions by 77 percent compared to the current legislation case. The major technical potential for reductions exists for industrial production processes (90 percent) and small non-industrial combustion sources (wood and coal stoves), in addition to non-technical measures that could reduce the overall consumption of firewood and coal in the domestic sector.

Table 4.3: PM2.5 emissions in the non-EU countries (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

	2000			*2020 CLE*			*2020 MTFR*		
	Covered	Not covered	Total	Covered	Not covered	Total	Covered	Not covered	Total
1: Energy industries	141.1	13.4	154.4	111.0	1.6	112.6	20.8	0.3	21.1
2: Non-industrial combustion	0.0	466.9	466.9	0.0	450.1	450.1	0.0	103.9	103.9
3: Combustion in industry	92.7	8.8	101.5	103.4	8.4	111.8	23.4	1.1	24.6
4: Production processes	340.5	142.4	482.9	216.6	145.8	362.3	14.8	22.6	37.4
5: Extraction & distribution	0.0	6.0	6.0	0.0	4.9	4.9	0.0	4.9	4.9
6: Solvent use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7: Road transport	86.0	0.0	86.0	118.6	0.0	118.6	118.6	0.0	118.6
8: Other mobile sources	75.7	0.0	75.7	89.3	0.0	89.3	89.3	0.0	89.3
9: Waste	0.0	50.0	50.0	0.0	46.9	46.9	0.0	32.9	32.9
10: Agriculture	0.0	135.9	135.9	0.0	139.2	139.2	0.0	18.2	18.2
Sum	735.9	823.3	1559.2	638.9	796.9	1435.8	267.0	183.8	450.7

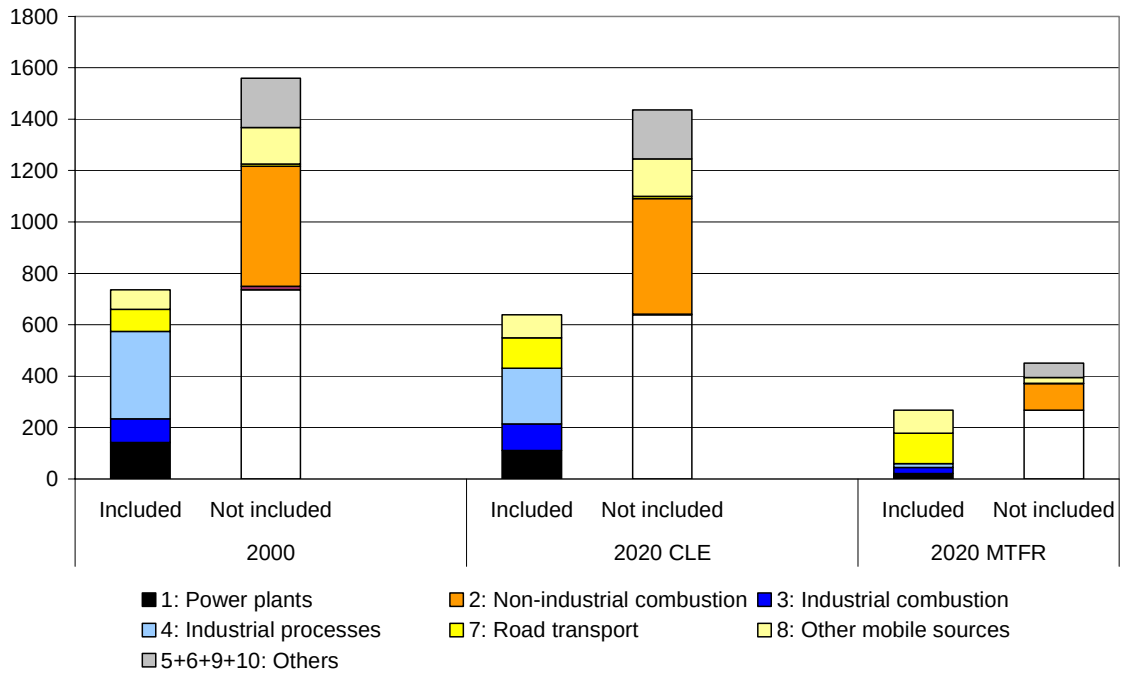

Figure 4.3: PM2.5 emissions in the non-EU countries (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

4.2 Potential for further reductions

A comparison of the differences between the "current legislation" and the "further measures" cases reveals the potential for further emission reductions that could be attained through technical measures on top of the requirements laid down in the current legislations (Table 4.4). For the EU countries, approximately 20 percent of the total reduction potential is identified in sectors for which the Heavy Metals and Gothenburg Protocols specify binding emission limit values, and thus could - at least in principle - be addressed by more stringent emission limit values in revised protocols. In the non-EU countries, about 40 percent of the theoretical potential is linked to these sectors, essentially because most of these countries have not yet ratified the protocols. An enhanced ratification could harness a substantial fraction of these reduction potential (Table 4.4).

In the EU, approx. 55 percent of the potential further emission reductions emerge for small combustion sources (wood and coal stoves), for which the protocols do not prescribe emission limit values. Another 20 percent comes from industrial production processes, two thirds of it from sources which are not subject to the Heavy Metals Protocol. For the non-EU countries, each of these two sectors offer about one third of the potential total emission reductions.

Table 4.4: Technical potentials for further reductions of primary PM2.5 emissions (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

	EU-15+2			*EU-10*			*Non-EU*		
	Covered	Not covered	Total	Covered	Not covered	Total	Covered	Not covered	Total
1: Combustion in energy industries	18	0	18	14	1	14	90	1	91
2: Non-industrial combustion	0	153	153	0	54	54	0	346	346
3: Combustion in industry	10	6	15	3	1	4	80	7	87
4: Production processes	24	41	64	2	8	10	202	123	325
5: Extraction & distribution	0	0	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0	0	0
7: Road transport	0	0	0	0	0	0	0	0	0
8: Other mobile sources	0	0	0	0	0	0	0	0	0
9: Waste	0	16	16	0	5	5	0	14	14
10: Agriculture	0	14	14	0	15	15	0	121	121
Sum	51	230	281	18	83	101	372	613	985

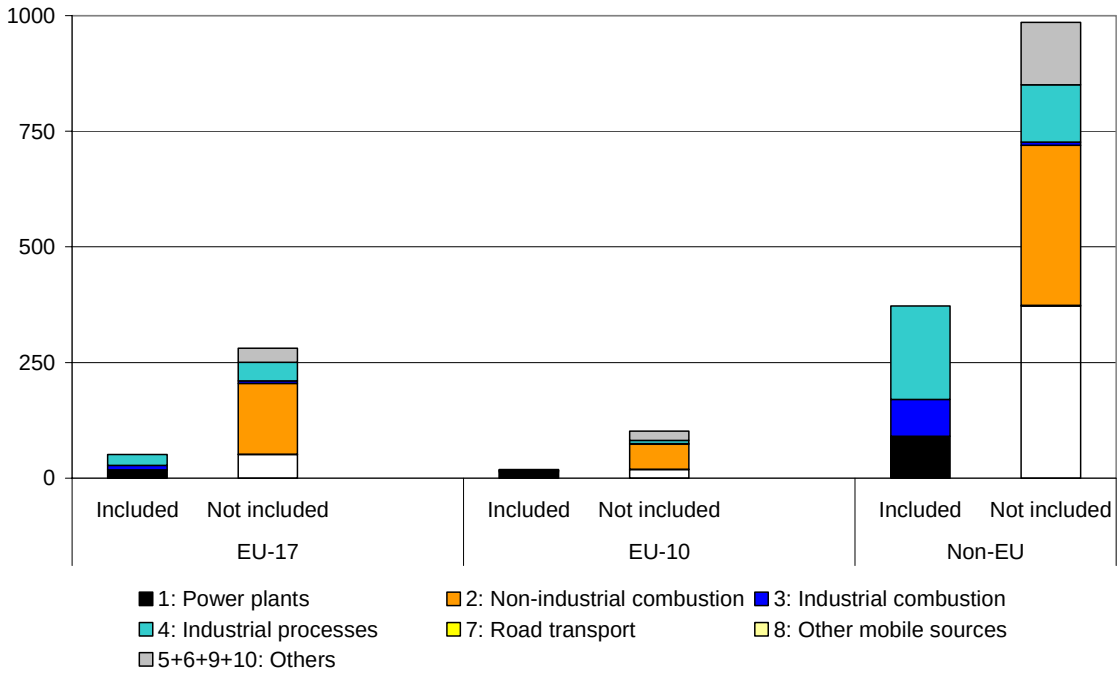

Figure 4.4: Technical potentials for further reductions of PM2.5 in 2020 (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

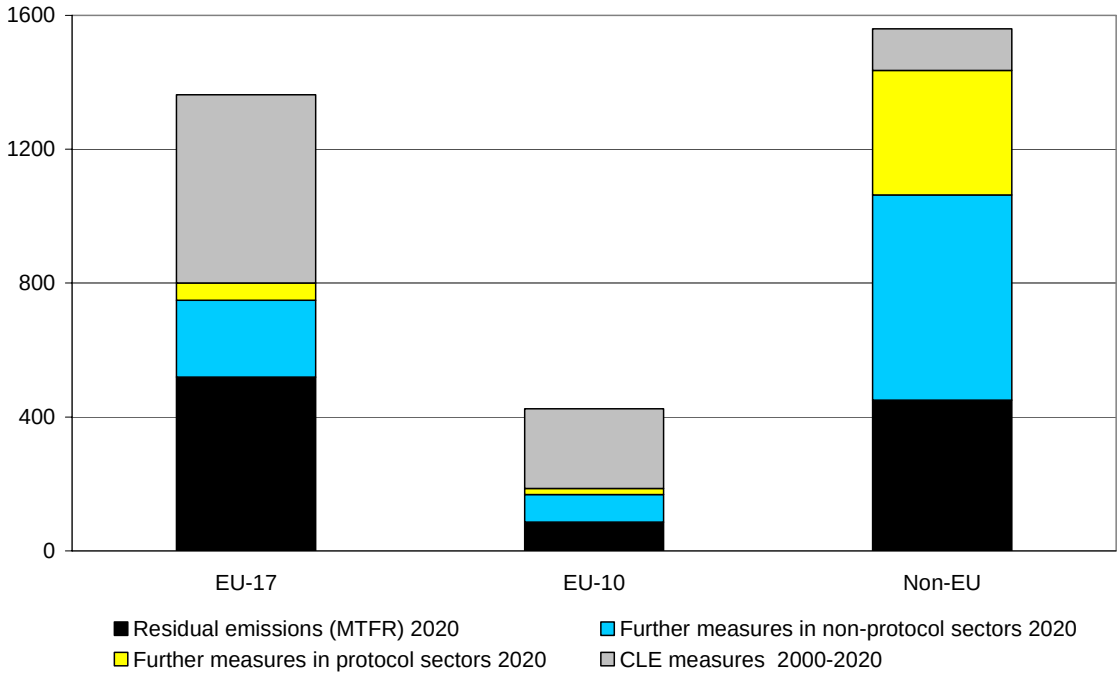

Figure 4.5: Potentials for further PM2.5 emission reductions through existing and potential new protocol agreements

5 Results for PM10

Similar results and conclusions emerge for PM10. The following paragraphs provide tables and graphs for PM10 emissions.

Table 5.1: PM10 emissions in the EU15+2, (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

	2000			*2020 CLE*			*2020 MTFR*		
	Covered	Not covered	Total	Covered	Not covered	Total	Covered	Not covered	Total
1: Energy industries	114.7	6.0	120.7	50.2	0.3	50.5	18.2	0.1	18.3
2: Non-industrial combustion	0.0	481.2	481.2	0.0	259.8	259.8	0.0	99.2	99.2
3: Combustion in industry	144.6	19.6	164.2	89.2	12.4	101.6	72.7	4.5	77.3
4: Production processes	69.9	235.4	305.3	69.2	225.8	295.0	40.5	140.4	180.8
5: Extraction & distribution	0.0	35.1	35.1	0.0	17.5	17.5	0.0	17.5	17.5
6: Solvent use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7: Road transport	356.0	0.0	356.0	194.7	0.0	194.7	194.7	0.0	194.7
8: Other mobile sources	179.7	0.0	179.7	74.3	0.0	74.3	74.3	0.0	74.3
9: Waste	0.0	75.1	75.1	0.0	73.3	73.3	0.0	52.8	52.8
10: Agriculture	0.0	161.3	161.3	0.0	170.9	170.9	0.0	114.8	114.8
Sum	864.8	1013.8	1878.6	477.5	760.0	1237.5	400.3	429.3	829.6

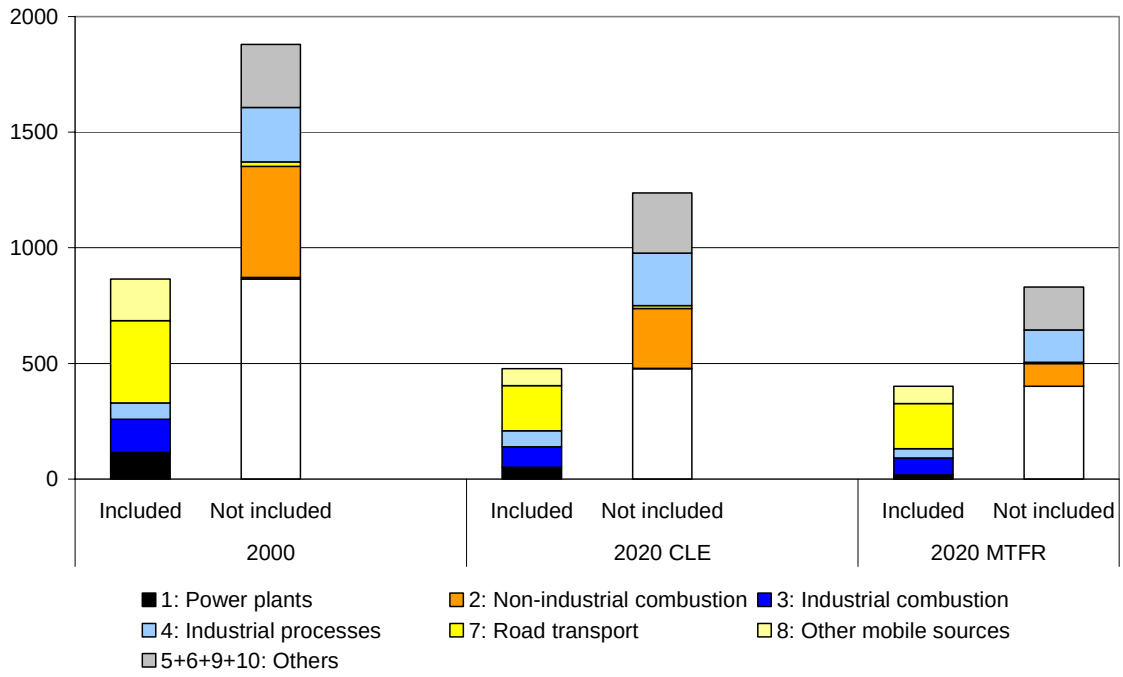

Figure 5.1: PM10 emissions in the EU15+2 (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

Table 5.2: PM10 emissions in the EU10 (New Member States) (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

	2000			*2020 CLE*			*2020 MTFR*		
	Covered	Not covered	Total	Covered	Not covered	Total	Covered	Not covered	Total
1: Energy industries	125.2	15.8	141.0	42.3	1.0	43.3	17.8	0.2	18.0
2: Non-industrial combustion	0.0	231.6	231.6	0.0	83.8	83.8	0.0	22.8	22.8
3: Combustion in industry	39.9	6.5	46.4	16.8	2.8	19.7	11.9	0.5	12.4
4: Production processes	23.4	41.5	65.0	5.7	28.6	34.3	3.3	15.0	18.3
5: Extraction & distribution	0.0	26.4	26.4	0.0	17.5	17.5	0.0	17.5	17.5
6: Solvent use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7: Road transport	35.0	0.0	35.0	19.7	0.0	19.7	19.7	0.0	19.7
8: Other mobile sources	22.9	0.0	22.9	6.1	0.0	6.1	6.1	0.0	6.1
9: Waste	0.0	15.0	15.0	0.0	14.6	14.6	0.0	8.7	8.7
10: Agriculture	0.0	42.0	42.0	0.0	45.8	45.8	0.0	22.1	22.1
Sum	246.4	378.9	625.3	90.7	194.1	284.8	58.7	86.8	145.6

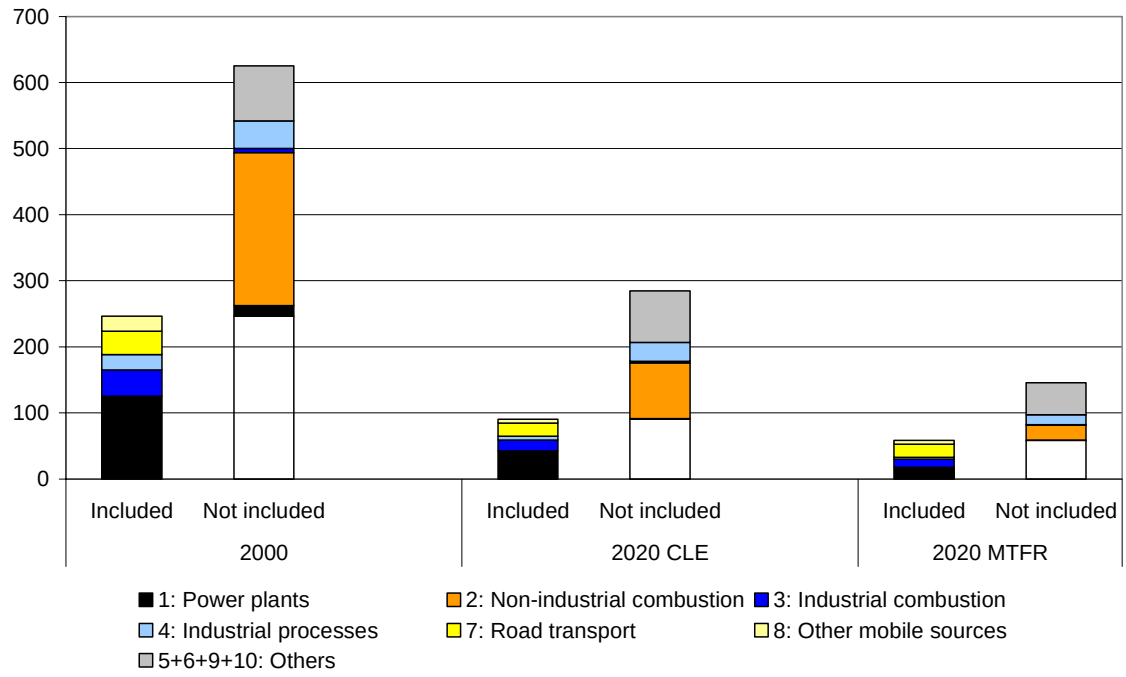

Figure 5.2: PM10 emissions in the EU10 (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

Table 5.3: PM10 emissions in the non-EU countries (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

	2000			*2020 CLE*			*2020 MTFR*		
	Covered	Not covered	Total	Covered	Not covered	Total	Covered	Not covered	Total
1: Energy industries	387.0	32.4	419.4	321.2	4.3	325.5	38.7	0.5	39.2
2: Non-industrial combustion	0.0	941.5	941.5	0.0	877.5	877.5	0.0	155.4	155.4
3: Combustion in industry	221.4	28.6	250.1	252.5	29.9	282.4	50.8	1.6	52.4
4: Production processes	475.9	268.8	744.7	309.7	255.7	565.3	21.4	72.9	94.3
5: Extraction & distribution	0.0	63.4	63.4	0.0	43.5	43.5	0.0	43.5	43.5
6: Solvent use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7: Road transport	117.4	0.0	117.4	157.1	0.0	157.1	157.1	0.0	157.1
8: Other mobile sources	95.7	0.0	95.7	106.4	0.0	106.4	106.4	0.0	106.4
9: Waste	0.0	62.5	62.5	0.0	61.5	61.5	0.0	42.9	42.9
10: Agriculture	0.0	242.2	242.2	0.0	264.1	264.1	0.0	99.7	99.7
Sum	1297.4	1639.5	2936.9	1146.8	1536.5	2683.3	374.3	416.5	790.8

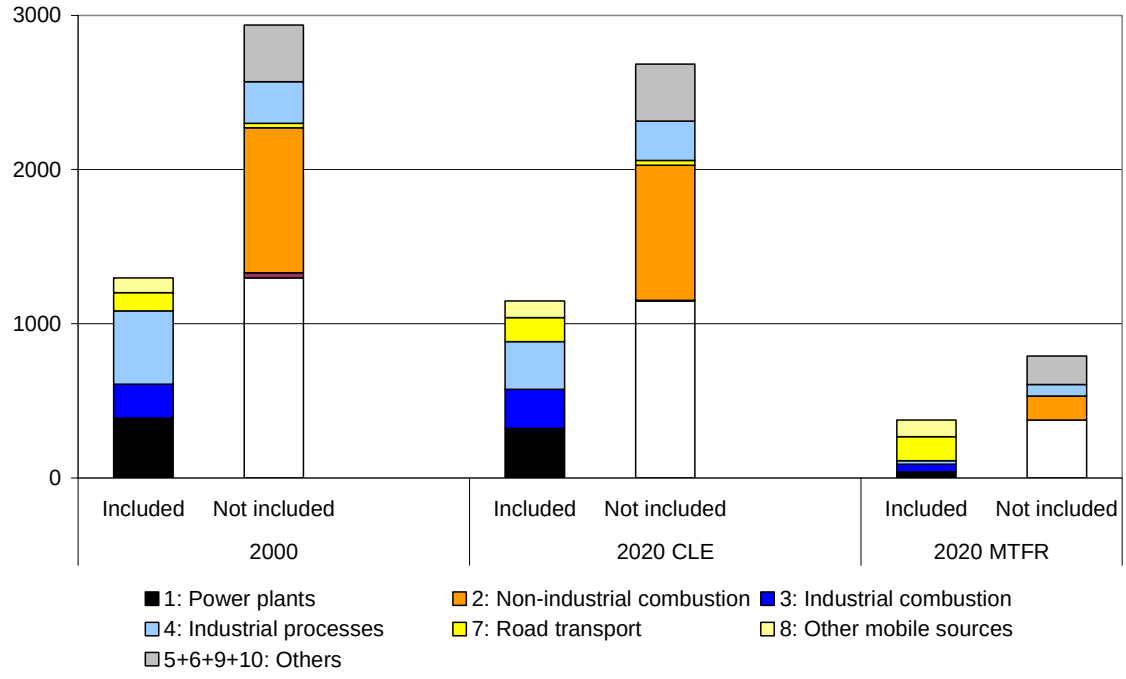

Figure 5.3: PM10 emissions in the non-EU countries (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

Table 5.4: Technical potentials for further emission reductions (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

	EU-15+2			*EU-10*			*Non-EU*		
	Covered	Not covered	Total	Covered	Not covered	Total	Covered	Not covered	Total
1: Energy industries	32.0	0.2	32.2	24.6	0.8	25.3	282.5	3.9	286.3
2: Non-industrial combustion	0.0	160.6	160.6	0.0	61.1	61.1	0.0	722.0	722.0
3: Combustion in industry	16.5	7.9	24.4	5.0	2.3	7.2	201.7	28.3	230.0
4: Production processes	28.7	85.4	114.2	2.4	13.6	16.1	288.3	182.7	471.0
5: Extraction & distribution	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6: Solvent use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7: Road transport	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8: Other mobile sources	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9: Waste	0.0	20.4	20.4	0.0	5.9	5.9	0.0	18.7	18.7
10: Agriculture	0.0	56.0	56.0	0.0	23.7	23.7	0.0	164.4	164.4
Sum	77.2	330.6	407.8	31.9	107.3	139.2	772.5	1120.0	1892.5

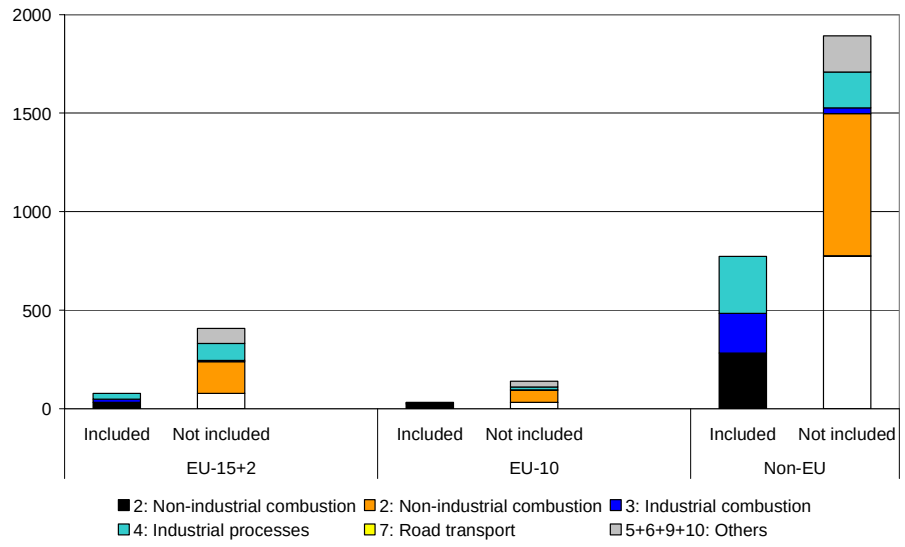

Figure 5.4: Technical potentials for further reductions of PM10 in 2020 (in kt), distinguishing emissions from sources that are covered by the Heavy Metals and Gothenburg Protocols and emissions from other sources.

6 Discussion and conclusions

The analysis of three emission control cases (i.e., the situation in the year 2000, the current legislation case for 2020, and a case with further control measures) leads to the following conclusions:

- Throughout Europe, primary emissions of PM are expected to decline in the future. In the European Union stringent national and community legislation on emission controls will lead to a 45 percent reduction of primary PM2.5 emissions between 2000 and 2020, and to a 40 percent reduction of primary PM10 emissions. However, in the non-EU countries primary PM emissions are expected to only decline by 8-9 percent, because of the absence of stricter emission control regulations.
- Tightening of the current emission limit values of the Heavy Metals and Gothenburg Protocols would have a relatively small effect on total PM emissions in 2020, especially if the protocols would not receive ratifications from additional Parties. In the EU-25, PM2.5 emissions would decline in 2020 at maximum by an additional 7 percent if the most advanced technical measures were implemented.
- Due to important uncertainties in the quantification of the technical potential for further reductions of PM emissions from mobile sources (e.g., through diesel particle filters) this study has not quantified the potential further scope from this sector. However, it should be mentioned that for the current legislation case without further measures the contribution of diesel exhaust emissions from light duty diesel vehicles to total PM2.5 is estimated in the EU-25 at approx. four percent in 2020, and from heavy duty vehicles at 1.2 percent.
- A significantly larger reduction potential could be harvested through ratification and subsequent implementation of the Heavy Metals and Gothenburg Protocols by additional Parties. This could reduce PM2.5 emissions in the non-EU countries by up to 25 percent in 2020 compared to the current legislation situation.
- While the Heavy Metals and Gothenburg Protocols contain obligations for PM emissions from certain emission sources, in 2020 the majority of PM emissions is expected to originate from sources for which these protocols do not specify emission limit values. For the EU-25, about 80 percent of the identified technical potential for further PM reductions emerges from sources that are not covered in the Protocols. In the non-EU countries, more than 60 percent of the technical reduction potential relates to these sources.
- Approximately two thirds of this technical reduction potential from the non-protocol sectors emerge from small non-industrial combustion sources, especially wood and coal stoves. This potential could be realized through advanced technical end-of-pipe measures that are commercially available. However, especially in the new EU Member States and the non-EU countries, the continued use of solid fuels for home heating is linked to the poor social and economic conditions of households, and it is questionable to what extent such advanced technical emission control devices could be realistically applied under such conditions. Obviously, there is a significant and possibly rather cost-effective potential for non-technical measures to phase out the use of solid fuels in

small stoves and replace them by other forms of energy, which however has not been explored in this study.

- The analysis presented in this report is restricted to the implications of the Heavy Metals and Gothenburg Protocols on primary emissions of particulate matter. As pointed out elsewhere, a significant fraction of particulate matter in ambient air consists of secondary aerosols, which are formed in the atmosphere from precursor emissions of sulphur dioxide (SO_2), nitrogen oxides (NOx), ammonia (NH_3) and volatile organic compounds (VOC). Especially the Gothenburg Protocol with its emission ceilings for these pollutants will lead to a significant reduction of such secondary aerosols, and thus to further improvements in ambient PM concentrations in addition to those that result from the expected reductions of primary PM emissions that are identified in this paper.
- Furthermore, it should be mentioned that given reductions of primary PM emissions do not necessarily lead to proportional changes in population exposure, which ultimately determines actual health impacts. There is clear evidence that emissions from low level sources, especially in urban areas, such as domestic combustion and transport, make a larger contribution to population exposure to PM than emissions released from high stacks.
- Due to various uncertainties in these calculations, the exact quantitative estimates presented in this study need to be interpreted with care. Important uncertainties relate to the levels of economic activities projected for 2020, the expected composition of fuel use, emission inventories, especially for small combustion sources and for non-combustion emissions of coarse particulate matter. However, the main conclusions about the relative reduction potentials from different protocol options are considered robust.

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