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Draft guidance document on prioritizing reductions of particulate matter so to also achieve reduction of black carbon

Prepared by the Task Force on Integrated Assessment Modelling in cooperation with the Task Force on Techno-economic Issues

I. Summary for policymakers

1. This guidance document presents guidance on measures to reduce emissions of PM2.5 that are also effective in reducing emissions of black carbon (BC). The guidance is based on previously reported emission scenarios available in the GAINS model developed by the centre for integrated assessment modelling (Stohl et al. 2015, Klimont et al. 2017, Amann et al. 2018) The results of the scenario comparison is aggregated for three regions. The first region includes the countries Belarus, Moldova, Russia, and the Ukraine, the four EECCA countries available for analysis with the European online version of the GAINS model. The second region includes Albania, Bosnia-Herzegovina, Kosovo, North-Macedonia, Montenegro, Serbia and Turkey (non-EU Balkan + Turkey). The third group consists of the EU countries, Norway, Switzerland and the United Kingdom.

2. The baseline emission scenarios supporting this guideline are not for all regions aligned with officially reported emission inventories but given data limitations the scenarios still constitute the best available information for the question at hand. It is also worth highlighting that BC emission factors still are uncertain, and future research might come to change our results slightly.

3. The baseline scenario results for the EECCA region countries indicate that between 2020 and 2030 implementation of emission control measures in industry would abate 7 ktonne of PM2.5 emissions, but almost no BC emission abatement is anticipated. By 2030 it is technically feasible to apply other measures that would combine PM-reduction with reduction of BC emissions, inter alia increased control of agricultural waste burning and replacement of older wood-fuelled stoves. A comparison of the baseline scenario with technically feasible emission levels suggest a technical potential to further control 2030 PM2.5 emissions with more than 300 ktonne PM2.5 whilst still ensuring large co-benefits with BC emission control.

4. The baseline scenario results for the non-EU Balkan countries and Turkey indicate that 22 ktonne PM2.5 emissions will be abated between 2020-2030 through controlling emissions from cement production, without much BC emission abatement. Technically available measures by 2030 that also ensures effective BC emission abatement include cleaner coal-fuelled heating stoves and bans on trash burning provide. All in all, between 2020 and 2030 the scenarios suggest a technical potential to further control 128 ktonne PM2.5 emissions whilst still ensuring large co-benefits with BC emission control.

5. The scenario results for the EU-countries, Norway, Switzerland and the United Kingdom suggest that current legislation to a large extent enables co-benefits between PM2.5 and BC emission reduction. However, 49 ktonne of the PM2.5 emission reduction does not imply any noticeable change in BC emissions for the period 2020-2030. There is a large remaining technical potential for measures ensuring co-benefits between PM2.5 and BC. A full-scale effective ban on agricultural waste burning and increased utilization of new wood-fuelled stoves and pellet stoves can be highlighted as high-potential measures.

II. Black carbon abatement - a win-win for human health and climate change

6. Black carbon – carbonaceous particulate matter that absorb light – is composed of small particles which are considered a component of PM2.5 and are therefore linked to severe effects on human health such as respiratory disease and reduced life expectancy. Although the final numbers vary between studies and methods, a ballpark assessment is that human exposure to PM2.5 around 2010 was linked to ~3-4 million preterm fatalities each year, and in Europe ~400 – 500 000 (World Health Organization 2014, European environment Agency 2015, Lelieveld et al. 2015). There are even indications that black carbon might be more toxic than other PM2.5 components (Janssen et al. 2011, WHO 2012, Grahame et al. 2014).

7. In adopting the Paris Agreement, to "limit warming to well below 2°C above pre-industrial levels …", the Parties to the UNFCCC recognized that reductions in the emission of carbon dioxide are the backbone of any meaningful effort to mitigate climate forcing. But in order to slow the pace of warming over the next two to three decades, both globally and in the Arctic, countries must also reduce emissions of short-lived climate forcers (SLCFs) such as black carbon and methane as a complement to reductions of carbon dioxide and other long-lived greenhouse gas emissions.

8. Black carbon emissions originate mainly from combustion of fuel. But even though black carbon is within the PM2.5 size fraction, it is not certain that all PM2.5 emission abatement will have co-beneficial effects between human health and climate change. The reason for this is partly that the share of black carbon in PM2.5 emissions varies between emission source sectors and fuels combusted (Figure 1). Correspondingly, reduction of PM2.5 emissions in sectors with low shares of black carbon risk leading to trade-off between human health and climate change since the co-emitted organic carbons, and non-carbonaceous PM as well as coarser PM-fractions, all are cooling forcers. Reduction of these will warm the climate, thereby partly or fully counteracting the cooling effect of black carbon emission reduction.

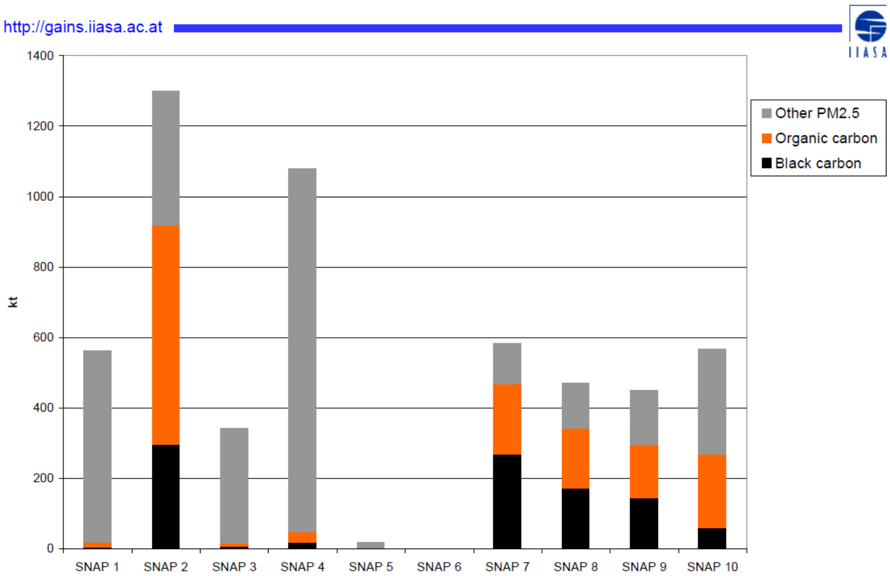

Figure 1: Modelled emissions of PM2.5/BC/OC in the UNECE area in 2005 (Klimont 2011). **SNAP 1: combustion in energy and transformation industries, SNAP 2: non industrial combustion plants, SNAP 3: combustion in manufacturing industries, SNAP 4: production processes, SNAP 5: extraction and distribution of fossil fuels and geothermal energy, SNAP 6: solvent and other product use, SNAP 7: road transport, SNAP 8: other mobile sources and machinery, SNAP 9: waste treatment and disposal, SNAP 10: agriculture**

9. Given the potential for co-benefits between human health and climate change, and the variability of BC-fractions in PM2.5 emissions it is necessary to give guidance to Air Convention parties on which specific sectors and abatement measures that gives largest opportunities to capture these co-benefits.

III. The purpose and approach of this Guidance document

A. Purpose of the Guidance document

10. The present Guidance document is meant to clarify in which sectors parties to the Convention can focus their efforts to reduce PM2.5 emissions so that they also enable co-benefits with black carbon abatement. The ambition is that awareness among the parties to the Air Convention will increase with respect to the fact that PM2.5 emission abatement can have various effects on BC emissions. More specifically, the Guidance document strives to answer the following questions:

a. Has PM2.5 emission abatement since 2010 ensured co-benefits with BC abatement?

b. Given current air quality policies: will co-benefits between PM2.5 and BC emission abatement be ensured in the future?

c. Is there a potential to increase co-benefits between PM2.5 and BC emission abatement? If so, which sectors and control measures are most important?

B. Approach of the Guidance document

11. The work leading to this Guidance document has been made possible by using the detailed data presented in the openly available GAINS model[1] scenarios CEP_post2014_CLE_v.Dec.2018, CEP_MTFR, ECLIPSE_v5a_CLE_base and ECLIPSE v5a_MTFR_base. The CEP scenario set was used for the EU, Norway, Switzerland and the United Kingdom as baseline (CEP_post2014_CLE_v.Dec.2018) and maximum technically feasible reduction, MTFR (CEP_MTFR) scenarios. The ECLIPSE scenario set was used for the other regions since the CEP scenario set didn't include any MTFR-estimates for regions outside the EU-region (baseline: ECLIPSE v5a_MTFR_base, MTFR: ECLIPSE_MTFR). All these scenarios have been previously presented in Amann et al. (2018), Stohl et al. (2015) and Klimont et al. (2017). It has not been possible to collect information on relevant data supporting the emission trends and scenarios reported by the parties, so the guidance given in this document might not exactly match the parties' own estimation of their emission trends and scenarios. The applicability of the guidelines thereby needs to be estimated by the parties themselves.

12. Through the focus on emission control measures available in the GAINS model database this Guidance document omits the possibility to reduce PM2.5 and BC emissions by structural changes of for example the energy and transport system. The quantities presented are thereby understatements of total potential for co-benefits between PM2.5 and BC. Harvesting this total potential would however likely require improved integration of climate change and air quality policies.

13. Constrained by data and scenario availability, the UNECE parties in focus for this Guidance document are those on the European continent and represented in the GAINS model, and the time horizon is 2010-2030. Given that the model emission trends and scenarios were made publicly available by 2018 the effect on 2020 emissions of the ongoing COVID-19 pandemic are not included. This Guidance document considers 2020 as an 'historical' year since 2020 is the GAINS model year that lies closest to the last reported historical year (2018).

14. An update of the EU Clean Air Outlook report (Amann et al. 2018) is anticipated during autumn 2020. Should the model scenarios developed in support to this update be made publicly available it is anticipated that these would be utilised in a revised version of this Guidance document.

IV. Methodological overview and terminology

A. Methods used to provide guidance

15. The overarching method used to support the guidance was to compare sector specific PM2.5 and BC emission trends and scenarios for different policy scenarios available in the GAINS model (a baseline scenario and an MTFR scenario). The comparison considered trends and scenarios for: emissions; emission control and relationship between PM2.5 and BC. The separation between emission scenarios and emission control scenarios is needed to decompose the modus with which emissions have been-, and is expected to, change. The analysis was grouped geographically in three regions. The first region consists of the parties commonly grouped as Eastern Europe, Caucasus and Central Asia (EECCA), in this document represented by Belarus, the European part of the Russian Federation, the Republic

[1] https://gains.iiasa.ac.at/gains/EUN/index.login?logout=1&switch_version=v0

of Moldova and Ukraine since these four are represented in the GAINS model. The second region consists of the non-EU Balkan countries and Turkey. The third region consists of the Air Convention parties that have already ratified the amended Gothenburg Protocol and have emission reduction commitments for PM2.5 for 2020 and beyond (EU-27 + Norway, Switzerland and the United Kingdom).

16. The relationship between PM2.5 and BC emissions are irregular over sectors but also over emission control measures. It is therefore not enough to only identify sectors with high shares of BC in their PM2.5 emissions. When comparing emission trends and scenarios we identified whether emissions were driven by changes in fuel activities or use of measures. When changes were driven by changes in use of measures, we continued to identify whether the measures were characterised by relatively large or small removal of BC per unit PM2.5 abated. We also identified whether the measure in absolute terms was/would be important for emission abatement of PM2.5 and BC (total kilo-tonnes emission abatement). The residual, i.e. measures that did have small or no co-beneficial character, were quantified with respect to its' total effect on PM2.5 emissions.

17. The support for prioritization could then compiled by comparing how much of the PM2.5 emission abatement from 2010 that has been characterised by also implying emission abatement of BC; how much of the planned PM2.5 emission abatement that implies strong BC emission abatement; and how many of the remaining technically available control measures that are BC-intensive . The quantitative results present per region which sectors that should be advocated or discouraged to promote prioritization of PM2.5 emission control whilst effectively controlling BC emissions. The results are also characterised by presenting which control measures that are most important for results.

B. Terminology used in the guidance document

18. This Guidance document use some terms adapted for the question at hand:

a) The term **Activity data** refers to fuel use, transport use or production quantities: i.e. the basic cause of emissions. Changes in emissions due to changes in the Activity data was identified by applying emission factors for the starting year of the period studied also on the Activity data for the last year of the same period and re-calculating emissions as 'frozen' emission factor emissions. The difference between starting year emissions and 'frozen' emission factor emissions is thus due to changes in Activity data. The residual difference between the 'frozen' emission factor emissions and the original scenario emissions is thus due to changes in the use of control measures.

b) Co-benefits is a general concept and is in this document referring to a situation when PM2.5 emission reduction also implies 'large' BC emission reductions. In this document, 'large' has two interpretations and these are specified as follows:

i) if the BC emission reductions are 'large' in relative terms (the change in implied emission factor of BC correspond to at least 50% of the change in implied emission factors of PM2.5), the term **Relative co-benefits** is used. Relative co-benefits were identified through two steps:

1. For each sector and fuel: subtract PM2.5 and BC target year emissions in the 'frozen' Activity data emission calculation from the emissions in the starting year of the period to find emission reductions due to changes in use of control measures.
2. For each sector and fuel: calculate the BC/PM2.5 emission reduction ratio. If the BC/PM2.5 reduction ratio is higher than 0.5, the emission reduction is considered 'large' in relative terms.

ii) if the BC emission reductions are 'large' in absolute terms (ktonne emissions reduced), the term **Absolute co-benefits** is used. Sectors with Absolute co-benefits were identified by first sorting the sectors with respect to the size of PM2.5 emission reductions over the period. Second, identifying which sectors that have

BC/PM2.5 emission reduction ratios over 0.1. Third, from the top-ranked PM2.5-sectors with BC/PM2.5 ratios over 0.1, selecting the five sectors with largest BC emission reductions.

c) Unless classified as Absolute co-benefits: Sectors with a BC/PM2.5 emission reduction ratio over 0.5 are classified as **Relative co-benefits** sectors.

d) Unless classified as Absolute co-benefits: If the BC/PM2.5 emission reduction ratio is lower than 0.5 but higher than 0.1 the sector is classified as **Neutral**.

e) If the BC/PM2.5 ratio is lower than 0.1 the sector is classified as a **Trade-off** sector, because this is the approximate ratio where one unit of PM2.5 emission shifts between being cooling or warming for European emissions (BC/PM2.5-ratio above 0.1 implies warming) when using common climate metrics for particulate matter and BC presented by the IPCC (Myhre et al. 2013)). The 0.5 ratio is arbitrarily picked by the authors.

V. Guidance to decisions makers

19. This guidance document gives at hand some indicative strategies on how to prioritize PM2.5 emission control so as to also reduce BC emissions. In general measures to reduce PM2.5-emissions from domestic wood burning and agricultural waste burning are the most effective measures to also reduce BC. Here we present the quantitative support to the strategies and first establish the support behind the strategies. The quantitative support starts with presenting results for the EECCA region, followed by the Balkan + Turkey region and finally the EU + Norway, Switzerland and the United Kingdom. For all regions we first present the overall picture, followed by detailed description of the modelled development for the period 2010-2020, the planned emission reductions 2020-2030, and the potential for further emission reductions by 2030. The quantitative support allows identification of whether BC emission reduction comes autonomously from PM2.5 emission reduction. It also highlights the measures still available to ensure co-benefits between PM2.5 and BC emission reductions.

BC-Prioritization of PM2.5 control in EECCA region

20. For the countries representing the EECCA region in this Guidance document, the guidance baseline ECLIPSE_v5a_CLE_base scenario assumes that both PM2.5 and BC emissions increase due to structural changes 2010-2020, a tendency that continues until 2030. Correspondingly there remains a large PM2.5 emission reduction potential in 2030 if implementing all available control measures (Table 1 and Figure 2). Detailed scenario information on the use of measures in the baseline and ECLIPSE_MTFR_base (MTFR) scenario is available in Appendix A.

Table 1: Decomposed PM2.5 and BC emission reductions from 2010 to 2020 for Belarus, the Russian Federation, the Republic of Moldova and the Ukraine, planned emission reductions between 2020 and 2030, and remaining technically available emission reduction potential in 2030 based on the GAINS model scenarios ECLIPSE v5a_base and ECLIPSE_MTFR_base. Negative values imply an increase in total emissions.

Emission reductions by source, kt	Activity data	Absolute co-benefits	Relative co-benefits	Neutral	Trade-off	TOTAL
Historical reductions (2010-2020)						
PM2.5	-195	23	0.2	3	25	-144
BC	-21	12	0.1	1	0.4	-7
Planned reductions (2020-2030) with measures according to current legislation						
PM2.5	-204	8	1	1	12	-182
BC	-9	3	1	0	0.5	-4

Potential extra reductions by 2030 with additional emission reduction measures beyond current legislation						
PM2.5	n.a.	350	4	43	820	1217
BC	n.a.	68	3	11	3	85

21. Despite the 182 ktonne PM2.5 and 4 ktonne BC emission increase up until 2030 assumed in the baseline scenario there remains an even larger technical potential to reduce emissions, to well below the 2010 emission levels. Although most of this potential is constituted of control measures that implies Trade-offs between air quality and climate change, the potential for emission reduction with measures implying Absolute co-benefits is still higher than the assumed scenario emission increase between 2010 and 2030.

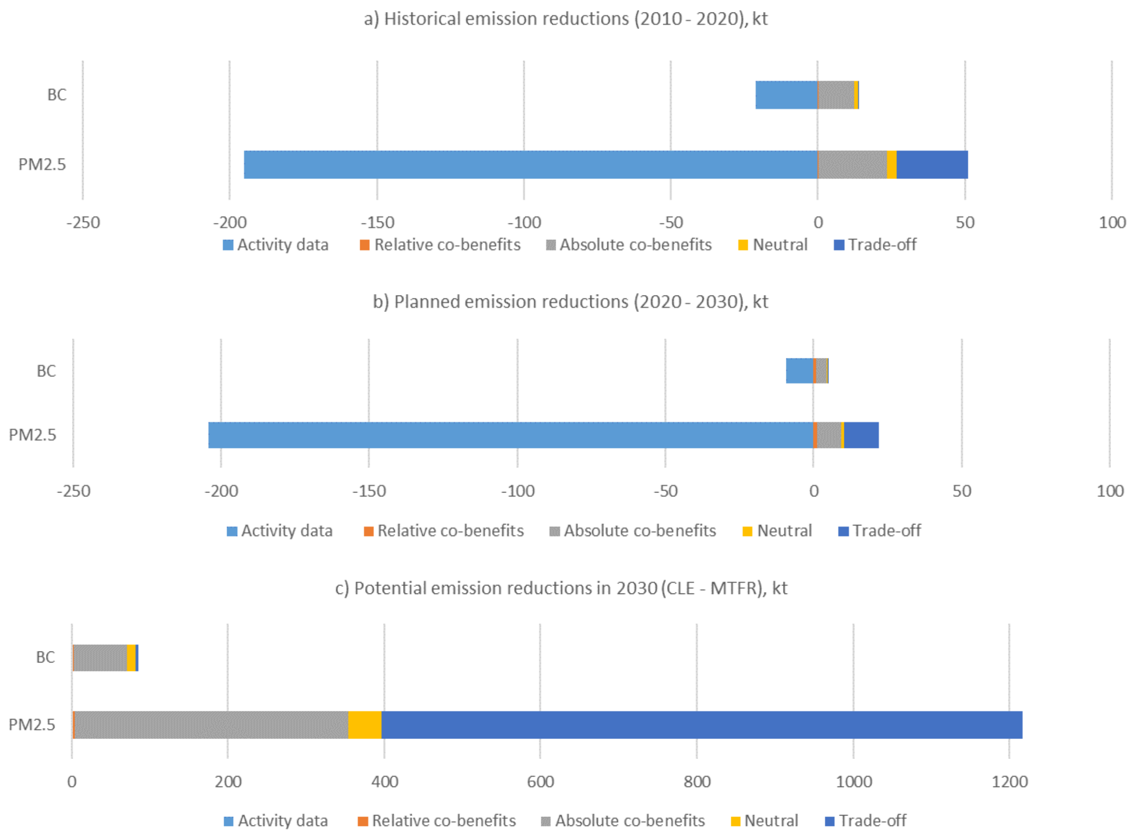

Figure 2a) Graphical illustration of emission changes 2010-2020 decomposed into changes in Activity data, measures that imply Relative Co-benefits between PM2.5 and BC emission control, Absolute co-benefit measures, as well as Neutral and Trade-off measures. 2b) Graphical illustration of the emission scenario representing planned emission legislation. 2c) Graphical illustration of the remaining technical potential for further emission reductions. Notice the difference in scale in 2c. The figures are based on the GAINS model scenarios ECLIPSE v5a_base and ECLIPSE_MTFR_base scenarios

22. The detailed analysis of the baseline scenario shows that although increased economic Activity drive up actual emissions, the control measures with highest effect on PM2.5 and BC emissions 2010-2020 are stricter emission control (Euro-standards) in diesel-fuelled road and rail transport (trucks, cars, buses, and trains). 46% of the PM2.5 emission reductions in 2010-2020 is realised using Absolute co-benefit measures (86% of BC emission reductions). 0.3% of the emission reductions comes from measures having Relative Co-benefit measure. The Neutral and Trade-off measures are those used to reduce PM2.5 emissions from new hard-coal fuelled power plants.

23. Increased economic Activity is in the baseline scenario continuing to drive up PM2.5 emissions for many emitting sectors during 2020-2030. But 36% of the drive towards reduced PM2.5 emissions (64% of BC) is induced by the use of control measures with Absolute co-benefits. More specifically, continued rejuvenation of diesel-fuelled heavy-duty vehicles, trains and agricultural machineries are the most important of these measures. Also, the use of cyclones and one-field electrostatic precipitators to reduce PM2.5 emissions from black liquor combustion in the paper & pulp industry is characterised as having Absolute co-

benefits. Emission reductions via Relative co-benefit measures are rejuvenation of diesel-fuelled buses and light-duty vehicles. The measures with Neutral or Trade-off characteristics are mainly measures used to reduce PM2.5 emissions from biomass fuel combustion in chemical- and paper & pulp industries, and renewal of fuelwood household heating stoves. 1 ktonne of PM2.5 emission reductions is in the baseline scenario expected to take place with Neutral and 12 with Trade-off measures. The above-mentioned measures account for 9 of these ktonne. All in all, the baseline scenario shows that most of the expected PM2.5 emission abatement until 2030 can be expected to be with Trade-off measures, and thereby miss opportunities for effective BC abatement.

24. The MTFR scenario indicate a large technical potential by 2030 to further the reduction in emissions of PM2.5 and BC. The Absolute co-benefit control measures still available for implementation in 2030 are found in the control of emissions from agricultural waste burning, small scale household wood burning, iron & steel coke ovens, oil refinery gas flaring and from non-road mobile machineries. Measures with Absolute co-benefits constitute 29% of the technical potential for PM2.5 emission reduction and 80% of the BC emission reduction potential. A full implementation and enforcement of a ban on open burning of agricultural has the largest Absolute co-benefit potential for the four EECCA countries. The second highest potential comes from a quicker introduction and use of pellets stoves and rejuvenation of other wood-fuelled household stoves. Other important control measures are increased use of high-efficiency dedusters to reduce emissions from coke oven processes, good flaring practices in oil and gas industries as well as rejuvenation of gas-fuelled non-road mobile machinery engines and emission control for gas pipeline compressors. Remaining control measures with Relative co-benefits only constitutes 0.3% and 3% of the remaining potential for PM2.5 and BC emission reduction, respectively. The largest part (70%) of the remaining potential is however characterised by Trade-off measures, such as those available to reduce PM2.5 emissions from steel production and cement production.

25. When comparing the baseline and MTFR scenarios, it is shown that even if the EECCA region in the baseline scenario can be expected to implement mostly Trade-off measures, the remaining potential with Absolute co-benefit measures is much higher. All the in 2030 still available Absolute co-benefit measures presented above have PM2.5 emission reduction potentials larger than the 12 ktonne emission abatement expected with Trade-off measures in the baseline scenario.

BC-Prioritization of PM2.5 control in the non-EU Balkan + Turkey region

26. For the non-EU Balkan + Turkey the guidance baseline scenario suggests that PM2.5 emissions for the entire period 2010-2030 are driven up by increased use of coal-fired power plants. For the period 2010-2020, this emission driver is counteracted by increased emission control, resulting in a net reduction in emissions. But for 2020-2030, the increase in emission control is not enough to reduce PM2.5 emissions. For BC emissions the situation is different, where changes in Activity data as well as implementation of control measures both help reduce emissions for the entire period 2010-2030 (Table 2, Figure 3). Detailed scenario information on the use of control measures in the baseline and MTFR scenario is available in Appendix B.

Table 2: Decomposed PM2.5 and BC emission reductions from 2010 to 2020 for the non-EU Balkan + Turkey, planned emission reductions between 2020 and 2030, and remaining technically available emission reduction potential in 2030 based on the GAINS model scenarios ECLIPSE v5a_base and ECLIPSE_MTFR_base. Negative values imply an increase in total emissions.

Emission reductions by source, kt	**Activity data**	**Absolute co-benefits**	**Relative co-benefits**	**Neutral**	**Trade-off**	**TOTAL**
Historical reductions (2010-2020)						
PM2.5	-41	15	0.5	0.5	49	24
BC	18	8	0.4	0.2	1.4	28
Planned reductions (2020-2030) with measures according to current legislation						
PM2.5	-95	15	0.3	0.5	22	-57
BC	1	4	0.2	0.2	0.1	6
Potential extra reductions by 2030 with additional emission reduction measures beyond current legislation						
PM2.5	-	121	0.4	12	304	438
BC	-	28	0.3	3	2	34

27. For the non-EU Balkan countries and Turkey, the baseline scenario indicates that even though increased fuel use activity drives PM2.5 and BC emissions up, the countervailing increased use of control measures ensures an emission reduction between 2010-2020. For the decade between 2020-2030 though, current legislation as represented in the baseline scenario shows that PM2.5 emissions will increase due to increased fuel use Activity. The same is not the case for BC. As was the case for the countries representing the EECCA region, the remaining technical potential for control measures that reduce PM2.5 emissions is substantially larger than the emission reduction achieved with measures expected to be implemented 2020-2030.

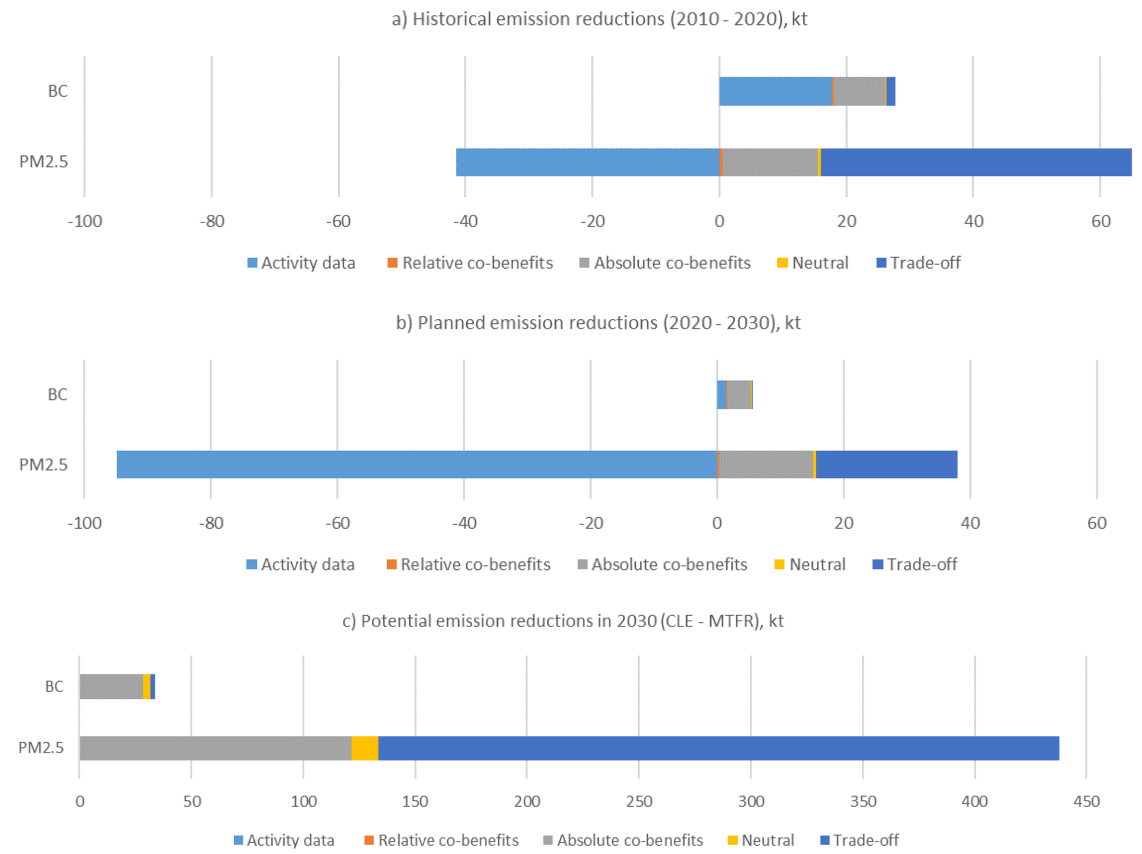

Figure 3a) Graphical illustration of emission changes 2010-2020 decomposed into changes in Activity data, measures that imply Relative Co-benefits between PM2.5 and BC emission control, Absolute co-benefit measures, as well as Neutral and Trade-off measures. 3b) Graphical illustration of the emission scenario representing planned emission legislation. 3c) Graphical illustration of the remaining technical potential for further emission reductions. Notice the difference in scale in 3c. The figures are based on the GAINS model scenarios ECLIPSE v5a_base and ECLIPSE_MTFR_base scenarios

28. During 2010-2020, Absolute co-benefit measures ensure 23% and 80% respectively of PM2.5 and BC emission reductions induced using control measures in the baseline scenario, again with the outcome on emissions affected by the varying change in fuel use activities. The most important technologies for the period are rejuvenation of the diesel vehicle and mobile machinery fleets and the corresponding introduction of advanced emission control technologies. Also important is the implementation of newer and improved installation of wood-fuelled household boilers. Relative co-benefit measures are responsible for 2% and 1.2% of PM2.5 and BC emission reductions. The most important Trade-off measures are measures used to reduce PM2.5 emissions from brown coal-fuelled power plants, cement production and newer and improved household heating stoves on fuelwood.

29. For 2020-2030 in the baseline scenario, the most important Absolute co-benefit measures are the same as for the period 2010-2020, with the addition that new and improved wood-fuelled stoves in single households contributes. This group of measures will be achieving 39% and 87% of the PM2.5 and BC emission reductions respectively over the period. The Relative co-benefit measures are having small impacts on emissions.

30. For the period 2020-2030, the most important Trade-off measures are the ones used to reduce PM2.5 emissions from cement production.

31. When studying the technically remaining potential for emission reductions by 2030 and the potential for co-benefits by comparing the baseline and MTFR scenarios there are several technically available Absolute co-benefit measures. An introduction of wood pellets stoves in combination with increased replacement rate of existing installations for newer ones would have the largest effect on BC emissions, followed by an effective implementation of

a ban on the burning of agricultural waste. Other high-impact measures include the use of briquette stoves and increased replacement rate of existing installation for newer ones for coal-fired heating stoves and rejuvenation of diesel-fuelled machinery used in agriculture. These measures constitute 28% and 84% of the remaining technical potential to reduce PM2.5 and BC emissions, respectively. Again, the measures with Relative co-benefits ensures only a small proportion of the remaining technical emission reduction potential. The most important Trade-off measures are the ones used to reduce PM2.5 emissions from cement production, from steel production, and from coal-powered power plants.

32. In summary, the scenarios suggest that most of the past and expected PM2.5 emission abatement in the non-EU Balkan + Turkey region has been and will be implemented with Trade-off measures. However, there is large technical potential to implement Absolute co-benefit measures on top of current legislation, large enough to offset the entire expected emission increase between 2020 and 2030.

BC-Prioritization of PM2.5 control in the EU + Norway, Switzerland, United Kingdom

33. For the western European countries, represented by the EU countries and Norway, Switzerland and the United Kingdom, both PM2.5 and BC emissions have decreased since 2010 and are expected to continue decreasing until 2030. The decrease in emissions is driven by reduced fuel use activities as well as by direct implementation of control measures, mainly Absolute co-benefit measures. By 2030, the remaining technical potential is also dominated by Absolute co-benefit measures (Table 3, Figure 4). Detailed scenario information on the use of measures in each scenario is available in Appendix C.

Table 3: Decomposed PM2.5 and BC emission reductions from 2010 to 2020 for the EU, Norway, Switzerland and the United Kingdom, planned emission reductions between 2020 and 2030, and remaining technically available emission reduction potential in 2030 based on the GAINS model scenarios CEP_post2014_CLE_v.Dec.2018 and CEP_MTFR. Negative values imply an increase in total emissions.

Emission reductions by source, kt	Activity data	Absolute co-benefits	Relative co-benefits	Neutral	Trade-off	TOTAL
Historical reductions (2010-2020)						
PM2.5	13	226	17	31	64	351
BC	-1	101	9	7	1	117
Planned reductions (2020-2030) with measures according to current legislation						
PM2.5	246	236	7	30	49	568
BC	61	64	6	9	2	142
Potential extra reductions by 2030 with additional emission reduction measures beyond current legislation						
PM2.5	n.a.	172	1	17	103	294
BC	n.a.	38	0.8	4	1	44

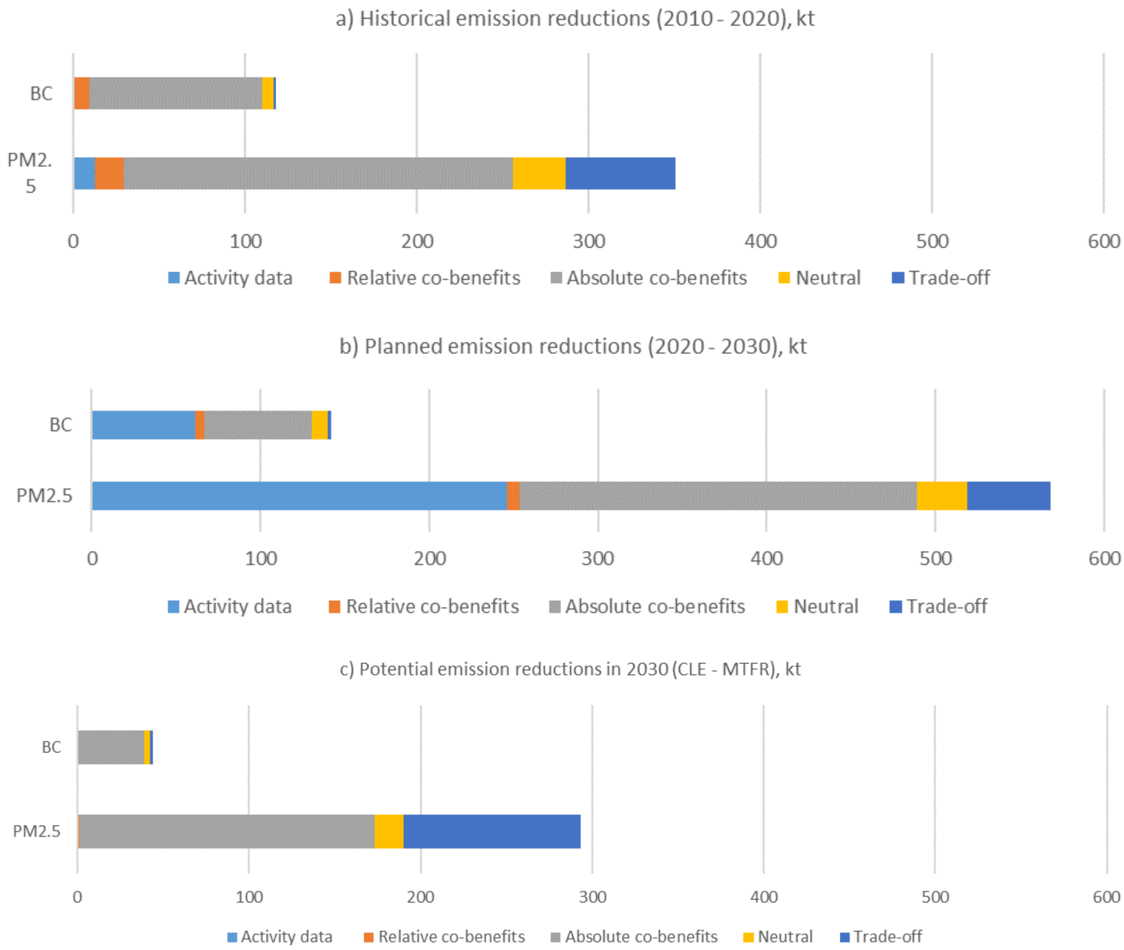

Figure 4a) Graphical illustration of emission changes 2010-2020 decomposed into changes in Activity data, measures that imply Relative Co-benefits between PM2.5 and BC emission control, Absolute co-benefit measures, as well as Neutral and Trade-off measures. 4b) Graphical illustration of the emission scenario representing planned emission legislation. 4c) Graphical illustration of the remaining technical potential for further emission reductions. The figures are based on the GAINS model scenarios CEP_post2014_CLE_v.Dec.2018 and CEP_MTFR.

34. For 2010-2020 67% of the PM2.5 emission reduction and 85% of the BC reduction comes from Absolute co-benefit control measures. As for the other regions, the emission reductions come mainly from introduction of new and improved wood-fuelled stoves in households (including pellets stoves) as well as from newer vehicle fleets in diesel-driven road and non-road mobile machinery. BC emissions from household stoves is increasing though due to increased use of wood fuels. Relative co-benefit measures constitute 5% and 3% of PM2.5 and BC emission reductions. These measures are mainly newer types of engine exhaust control on diesel-driven machinery and buses. The Trade-off measures are those controlling emissions from cement production and from household fireplaces.

35. According to the baseline scenario, PM2.5 and BC emissions measures decrease with 73% and 79% between 2020 and 2030 through the use of Absolute co-benefit measures. Again, it is the introduction of new installations (including pellet stoves) to control emissions from household stoves and boilers that are inducing largest emission reductions. The improved engine exhaust measures in diesel-fuelled vehicles and machinery are also important in this category. Relative co-benefit measures contribute with 2% of the emission reduction for both PM2.5 and BC. Most important in this category are engine exhaust measures in diesel engines and high-grade coal in stoves. The most important Trade-off measure for this period is newer installations in household fireplaces.

36. On top of current legislation there are still several control measures that could be utilised more to reduce emissions further by 2030. Absolute co-benefit measures ensure 59%

and 87% of the PM2.5 and BC emission reduction potential. In this category, emissions from wood fuels used in household stoves and boilers can be reduced more through increased introduction of newer installations and pellets stoves. Ensuring a 100% effectiveness of bans on open burning, using briquette stoves and newer installations in households using coal stoves, and installation of kitchen filters to reduce emissions from coking/BBQ are other measures in this category. Measures with Relative co-benefits have relatively small potential, whilst measures to reduce PM2.5 emissions from industrial processes, fireplaces, and from biomass combustion in industrial furnaces are the most important Trade-off measures.

37. In contrast to the other regions, PM2.5 emission reductions in EU + Norway, Switzerland, United Kingdom is driven both be changes in activity data as well as by Absolute co-benefit measures. A large majority of PM2.5 emission reductions 2010-2020 is achieved by Absolute co-benefit measures, and for the period 2020-2030 changes in Activity data and Absolute co-benefit measures are responsible for the large majority of emission reductions. Still, almost two thirds of the remaining technical potential by 2030 are Absolute co-benefit measures. The technical potential for measures with Absolute co-benefits is 172 ktonne by 2030. Just ensuring effective ban of agricultural waste burning would reduce PM2.5 emissions with 47 ktonne whilst also ensuring 6 ktonne BC emission reductions. If just half of the technical potential to increase the use of new wood-fuelled stoves and pellets stoves would be ensured, PM2.5 emissions would be reduced with 50 ktonne PM2.5 and 13 ktonne BC.

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APPENDIX A: MOST IMPORTANT MEASURES IMPLEMENTED IN EECCA-SCENARIOS

Historical development (2010 -2020)

Key sectors and measures with large Absolute co-benefit potential of BC and PM2.5 emission control:

- (1) Diesel-fuelled heavy-duty vehicles; Historical emission abatement due to introduced control measures is 9.8 kt PM2.5 and 5.3 kt BC – there is large relative co-benefit in this sector as well (0.54 BC per 1 PM2.5). Control measures:
    - Belarus*: EURO II* (~62% reduction efficiency for PM2.5, ~50% for BC) – increased implementation rates from 10% in 2010 to 80% in 2020.
    - Moldova*: EURO V* (~93% reduction efficiency for PM2.5, ~90% for BC) – increased implementation rates from 0% in 2010 to 10% in 2020; increase of EURO II, III and IV as well.
    - Russia*: EURO V* (~93% reduction efficiency for PM2.5, ~90% for BC) – increased implementation rates from 0% in 2010 to 44% in 2020; increase of EURO IV as well.
    - Ukraine: *EURO III* (~66% reduction efficiency for PM2.5, ~52% for BC) – increased implementation rates from 20% in 2010 to 90% in 2020.

  Actual emission reduction is lower due to increased activity data – 5.6 kt for PM2.5 and 2.8 kt – for BC.
- (2) Diesel-fuelled cars; Historical emission abatement due to introduced control measures is 7.7 kt PM2.5 and 3.7 kt BC. Control measures:
    - Belarus*: Euro 2* (~76% reduction efficiency for PM2.5, ~66% for BC) – increased implementation rates from 10% in 2010 to 80% in 2020.
    - Moldova*: Euro 4* (~82% reduction efficiency for PM2.5, ~71% for BC) – increased implementation rates from 0% in 2010 to 10% in 2020; increase of Euro 1, 2, 3 as well.
    - Russia*: Euro 4* (~81% reduction efficiency for PM2.5, ~71% for BC) – increased implementation rates from 0% in 2010 to 44% in 2020; increase of Euro 3 as well.
    - Ukraine*: Euro3* (~82% reduction efficiency for PM2.5, ~72% for BC) – increased implementation rates from 20% in 2010 to 90% in 2020.

  Actual emission trend is ascending – PM2.5 emissions increased by 0.1 kt and BC emissions – by 0.8 kt, due to increased activity data.
- (3) Diesel-fuelled light duty vehicles; Historical emission abatement due to introduced control measures is 2.2 kt PM2.5 and 1.3 kt BC – there is large relative co-benefit in this sector as well (0.57 BC in PM2.5). Control measures:
    - Belarus*: Euro 2* (~63% reduction efficiency for PM2.5, ~45% for BC) – increased implementation rates from 10% in 2010 to 80% in 2020.
    - Moldova*: Euro 5* (~99.1% reduction efficiency for PM2.5, ~99.7% for BC) – increased implementation rates from 0% in 2010 to 10% in 2020; increase of Euro 2, 3, 4 as well.
    - Russia*: Euro 5* (~99.1% reduction efficiency for PM2.5, ~99.7% for BC) – increased implementation rates from 0% in 2010 to 44% in 2020; increase of Euro 2, 3, 4 as well.
    - Ukraine*: Euro 3* (72% reduction efficiency for PM2.5, ~57% for BC) – increased implementation rates from 20% in 2010 to 90% in 2020.

  Actual emission reduction is lower due to increased activity data – 1.4 kt for PM2.5 and 0.7 kt – for BC.
- (4) Diesel-fuelled heavy-duty buses; Historical emission abatement due to introduced control measures is 2.1 kt PM2.5 and 1.1 kt BC – there is large relative co-benefit in this sector as well (0.54 BC in PM2.5). Control measures:
    - Belarus*: EURO II* (~62% reduction efficiency for PM2.5, ~50% for BC) – increased implementation rates from 10% in 2010 to 80% in 2020.
    - Moldova*: EURO V* (~93% reduction efficiency for PM2.5, ~90% for BC) – increased implementation rates from 0% in 2010 to 10% in 2020; increase of EURO II, III and IV as well.
    - Russia*: EURO V* (~93% reduction efficiency for PM2.5, ~90% for BC) – increased implementation rates from 0% in 2010 to 44% in 2020; increase of EURO IV as well.

    - Ukraine: *EURO III* (~66% reduction efficiency for PM2.5, ~44% for BC) – increased implementation rates from 20% in 2010 to 90% in 2020.

  Actual emission reduction is lower due to increased activity data – 1.9 kt for PM2.5 and 1.0 kt – for BC.

- (5) Diesel-fuelled railway; Historical emission abatement due to introduced control measures is 1.6 kt PM2.5 and 0.7 kt BC. Control measures:
    - Belarus, Russia: *Control Stage 1* (33.3% reduction efficiency for both PM2.5 and BC) – increased implementation rates from 34% in 2010 to 68% in 2020.
    - Moldova*: Control Stage 1* (33.3% reduction efficiency for both PM2.5 and BC) – increased implementation rates from 17% in 2010 to 51% in 2020.
    - Ukraine*:* No changes in the measure application rates.

  Actual emission trend is ascending – PM2.5 emissions increased by 7.1 kt and BC emissions – by 3.2 kt, due to increased activity data.

The emission control measures in five key sectors with largest Absolute co-benefits account for 46% of the reduction of PM2.5 and 86% of the reduction of BC in EECCA in 2010-2020 – these reductions due to control measures are further affected by activity data development so that the actual emissions can be either higher or lower, depending on the sector. In some cases, total emissions increased.

Additional input in emission reductions from control measures with Relative co-benefits is 0.3% for both PM2.5 and BC. This sector is carbon black production (0.99 BC in PM2.5).

The most important sectors with Neutral and Trade-off measures between 2010 and 2020:

- Hard coal combustion at new large power plants (9 kt PM2.5, 0.1 kt BC)
- Hard coal combustion at existing large power plants (3 kt PM2.5, 0.02 kt BC)
- Fuelwood in domestic heating stoves (3 kt PM2.5, 0.2 kt BC)

Planned emission reductions (2020 -2030, current legislation)

Key sectors and measures with large Absolute co-benefit potential of BC and PM2.5 emission control:

- (1) Diesel-fuelled heavy-duty vehicles; Planned emission abatement due to control measures is 2.2 kt PM2.5 and 1.4 kt BC – there is large relative co-benefit in this sector as well (0.63 BC in PM2.5). Control measures:
    - Belarus*: EURO II* (~62% reduction efficiency for PM2.5, ~50% for BC) – increased implementation rates from 80% in 2020 to 100% assumed in 2030.
    - Moldova*: EURO V* (~93% reduction efficiency for PM2.5, ~90% for BC) – increased implementation rates from 10% in 2020 to 78% assumed in 2030.
    - Russia*: EURO V* (~93% reduction efficiency for PM2.5, ~90% for BC) – increased implementation rates from 44% in 2020 to 100% assumed in 2030.
    - Ukraine: *EURO III* (~66% reduction efficiency for PM2.5, ~52% for BC) – increased implementation rates from 90% in 2020 to 100% assumed in 2030.

  Actual emission reduction is expected to be lower due to increased activity data – 1.7 kt for PM2.5 and 1.0 kt – for BC.

- (2) Black liquor combustion in pulp-and-paper industry boilers; Planned emission abatement due to control measures is 2.0 kt PM2.5 and 0.3 kt BC. Control measures:
    - *Cyclones* (30% reduction efficiency for PM2.5, 11% for BC) – increased implementation rates from 0% in 2020 to 30% assumed in 2030.
    - *One-field electrostatic precipitators ESP1* (93% reduction efficiency for PM2.5, 91% for BC) – increased implementation rates from 0% in 2020 to 70% assumed in 2030

  Actual emission reduction is expected to be lower due to increased activity data – 1.2 kt for PM2.5 and 0.2 kt – for BC.

- (3) Diesel-fuelled railway; Planned emission reduction due to control measures is 1.5 kt PM2.5 and 0.7 kt BC. Control measures:
    - Belarus, Russia*: Control Stage 1* (33.3% reduction efficiency for both PM2.5 and BC) – increased implementation rates from 68% in 2020 to 100% assumed in 2030.

- Moldova*: Control Stage 1* (33.3% reduction efficiency for both PM2.5 and BC) – increased implementation rates from 51% in 2020 to 85% assumed in 2030.
    - Ukraine*:* No changes in the measure application rates.

  Actual emission reduction of is expected to be higher due to decreased activity data – 1.7 kt for PM2.5 and 0.8 kt – for BC.
- (4) Diesel-fuelled vehicles in agriculture; Planned emission reduction due to control measures is 1.2 kt PM2.5 and 0.5 kt BC. Control measures:
    - Belarus, Russia: *Control Stage 1* (43.4% reduction efficiency for both PM2.5 and BC) – increased implementation rates from 68% in 2020 to 100% assumed in 2030.
    - Moldova: *Control Stage 1* (43.4% reduction efficiency for both PM2.5 and BC) – increased implementation rates from 51% in 2020 to 85% assumed in 2030.
    - Ukraine*:* No changes in the measure application rates.

  Actual emission reduction is expected to be higher due to decreased activity data – 1.6 kt for PM2.5 and 0.7 kt – for BC.
- (5) Diesel-fuelled cars; Planned emission abatement due to control measures is 1 kt PM2.5 and 0.5 kt BC. Control measures:
    - Belarus: *Euro 2* (76% reduction efficiency for both PM2.5, 66% for BC) – increased implementation rates from 80% in 2020 to 100% assumed in 2030.
    - Moldova: *Euro 4* (83% reduction efficiency for both PM2.5, 73% for BC) – increased implementation rates 10% in 2020 to 78% assumed in 2030.
    - Russia: *Euro* 4 (81% reduction efficiency for both PM2.5, 71% for BC) – increased implementation rates from 44% in 2020 to 100% assumed in 2030.
    - Ukraine*: Euro* 3 (82% reduction efficiency for both PM2.5, 72% for BC) – increased implementation rates from 90% in 2020 to 100% assumed in 2030.

  Actual emission reduction is expected to be lower due to increased activity data – 0.4 kt for PM2.5. For BC, actual emissions are expected to increase by 0.02 kt.

Control measures in 5 key sectors with largest Absolute co-benefits account for 36% of expected emission reduction of PM2.5 and 64% of expected reductions of BC in EECCA in 2020-2030 – these reductions due to technical control measures are further affected by activity data development so that the actual emissions can be either higher or lower, depending on the sector.

Additional input in emission reductions from control measures in sectors with large Relative co-benefits is 6% for PM2.5 and 4% for BC. These sectors include diesel-fuelled heavy-duty buses (0.63 BC in PM2.5), and diesel-fuelled light duty vehicles (0.79 BC in PM2.5).

The most important sectors with Neutral and Trade-off measures between 2020 and 2030:

- Biomass fuel combustion in chemical industry boilers (4 kt PM2.5, 0.2 kt BC)
- Wood fuels in household heating stoves (3.4 kt PM2.5, 0.2 kt BC)
- Biomass fuel combustion in pulp and paper industry boilers (1.5 kt PM2.5, 0.07 kt BC)

Potential emission reductions (MTFR-CLE)

Key sectors and measures with large Absolute co-benefit potential of BC and PM2.5 emission control:

- (1) Agricultural waste burning; Emission reduction potential is 199 kt PM2.5 and 26 kt BC. Control measures:
    - *Effective ban on open burning* (100% reduction efficiency for both PM2.5 and BC).
- (2) Wood fuels in household heating stoves; Emission reduction potential is 66 kt PM2.5 and 12 kt BC. Control measures:
    - *Pellets stoves* (95% reduction efficiency for PM2.5, 96% for BC) – increased implementation rates from 0% assumed in current legislation scenario to 65% as implied in MTFR;
    - *New installations* (80% reduction efficiency for PM2.5, 72% for BC) – increased implementation rates from 0-20% assumed in current legislation scenario to 35% as implied in MTFR;

- (3) Coke oven processes; Emission reduction potential is 51 kt PM2.5 and 15 kt BC. Control measures:
  - *High efficiency dedusters* (>99% reduction efficiency for PM2.5 and BC) – increased implementation rate from % assumed in current legislation scenario to 99% implementation rate as in MTFR.
- (4) Flaring in refineries; Emission reduction potential is 18 kt PM2.5 and 14 kt BC. Control measures:
  - *Good practice in oil and gas industry* (93% reduction efficiency for both PM2.5 and BC) – 100% implementation rate;
- (5) Gas-fuelled non-road 4-stroke engine machinery (small household and forestry machines, military vehicles, motorboats) and pipeline compressors; Emission reduction potential is 16 kt PM2.5 and 1.8 kt BC. Control measures:
  - *EURO 6* (84% reduction efficiency for both PM2.5 and BC) – increased implementation rates from 0% to 50% as in MTFR.

Control measures in 5 key sectors with largest absolute potential account for 29% of the total potential reduction of PM2.5 and 80% of the total potential reduction of BC in EECCA in 2030. Additional input from control measures in sectors with large Relative co-benefits is 0.3% for PM2.5 and 3% for BC. These sectors include diesel-fuelled heavy duty vehicles (0.74 BC in PM2.5), diesel-fuelled heavy duty buses (0.74 BC in PM2.5), diesel-fuelled light duty vehicles (0.82 BC in PM2.5), diesel-fuelled cars (0.91 BC in PM2.5), diesel-fuelled non-road 4-strike engine machinery (0.51 BC in PM2.5), and carbon black production (0.99 BC in PM2.5).

The most important sectors with Neutral and Trade-off measures with high emission reduction potentials for PM2.5:

- Steel production in basic oxygen furnaces (reduction potentials – 442 kt PM2.5, no BC)
- Steel production in electric arc furnaces (reduction potentials – 109 kt PM2.5, no BC)
- Cement production (53 kt PM2.5, 0.3 kt BC).

APPENDIX B: MOST IMPORTANT MEASURES IMPLEMENTED IN BALKAN + TURKEY-SCENARIOS

Historical development (2010 -2020)

Key sectors and measures with large Absolute co-benefit potential of BC and PM2.5 emission control:

- (1) Diesel-fuelled heavy-duty vehicles; Historical emission abatement due to introduced control measures is 7.2 kt PM2.5 and 3.9 kt BC – there is large relative co-benefit in this sector as well (0.55 BC in PM2.5).
  Control measures:
  Balkan:
  - *EURO IV* (92.17% reduction efficiency for PM2.5, 88.25% for BC) – increased implementation rates from 0% in 2010 to 23% in 2020.
  - *EURO III* (65% reduction efficiency for PM2.5, 51.33% for BC) – increased implementation rates from 25% in 2010 to 28% in 2020.

  Turkey:
  - *EURO VI* (99.59% reduction efficiency for PM2.5, 99.88% for BC) – increased implementation rates from 0% in 2010 to 52% in 2020.
  - *EURO V* (91.89% reduction efficiency for PM2.5, 87.84% for BC) – increased implementation rates from 12% in 2010 to ~20% in 2020.

  Actual emission reduction is lower due to increased activity data – 4.7 kt for PM2.5 and 2.5 kt – for BC.
- (2) Diesel-fuelled vehicles used in agriculture; Historical emission abatement due to introduced control measures is 4.6 kt PM2.5 and 1.9 kt BC. Control measures:
  Balkan:
  - *Control Stage 3A* (97.45% reduction efficiency for PM2.5, 74.45% for BC) – increased implementation rates from ~0% in 2010 to 10% in 2020. 11
  - *Control Stage 2* (74.45% reduction efficiency for both PM2.5 and BC) – increased implementation rates from ~0% in 2010 to 7% in 2020.
  - *Control Stage 1* (43.4% reduction efficiency for both PM2.5 and BC) – increased implementation rates from ~0% in 2010 to 1% in 2020.

  Turkey:
  - *Control Stage 2* (74.45% reduction efficiency for both PM2.5, 74.45% for BC) – increased implementation rates from 7% in 2010 to 41% in 2020.

  Actual emission reduction is lower due to increased activity data – 2.3 kt for PM2.5 and 0.9 kt – for BC.
- (3) Diesel-fuelled light duty vehicles; Historical emission abatement due to introduced control measures is 2.1 kt PM2.5 and 1.7 kt BC – there is large relative co-benefit in this sector as well (0.83 BC in PM2.5). Control measures:
  Balkan:
  - *EURO 5* (98.97% reduction efficiency for PM2.5, 99.62% for BC) – increased implementation rates from 0% in 2010 to 43% in 2020.
  - *EURO 4* (~82.52% reduction efficiency for PM2.5, ~72.35% for BC) – increased implementation rates from 0% in 2010 to 23% in 2020.

  Turkey:
  - *EURO 6* (98.96% reduction efficiency for PM2.5, 99.62% for BC) – increased implementation rates from 0% in 2010 to 45% in 2020.
  - *EURO 5* (98.97% reduction efficiency for PM2.5, 99.62% for BC) – increased implementation rates from 0% in 2010 to 47% in 2020.

  Actual emission reduction is lower due to increased activity data – 1.6 kt for PM2.5 and 1.3 kt – for BC.
  (4) Diesel-fuelled heavy-duty buses; Historical emission reduction due to introduced control measures is 0.6 kt PM2.5 and 0.36 kt BC – there is large relative co-benefit in this sector as well (0.59 BC in PM2.5). Control measures:
  Balkan:

- *EURO V* (92.81% reduction efficiency for PM2.5, 89.22% for BC) – increased implementation rates from 0% in 2010 to 23% in 2020.
- *EURO IV* (92.94% reduction efficiency for PM2.5, 89.41% for BC) – increased implementation rates from 0% in 2010 to 23% in 2020.
- *EURO III* (71.70% reduction efficiency for PM2.5, 60.38% for BC) – increased implementation rates from 25% in 2010 to 28% in 2020.

Turkey:

- *EURO VI* (99.63% reduction efficiency for PM2.5, 99.89% for BC) – increased implementation rates from 0% in 2010 to 43% in 2020.
- *EURO V* (92.81% reduction efficiency for PM2.5, 89.22% for BC) – increased implementation rates from 11% in 2010 to 21% in 2020.

Actual emission reduction is higher due to decreased activity data – 0.7 kt for PM2.5 and 0.41 kt – for BC.

- (5) Wood fuels in single house boilers; Historical emission reduction due to introduced control measures is 0.5 kt PM2.5 and 0.1 kt BC. Control measures:
  - *New installations* (80% reduction efficiency for PM2.5, 83% for BC) – increased implementation rates from 1-3% in 2010 to 5-7% in 2020.
  - *Improved installations* (60% reduction efficiency for PM2.5, 50% for BC) – increased implementation rates from 10-25% in 2010 to 20-35% in 2020.

  Actual emission reduction of is higher due to decreased activity data – 0.8 kt for PM2.5 and 0.2 kt – for BC.

Control measures in 5 key sectors with largest Absolute co-benefits account for 23% of the reduction of PM2.5 and 80% of the reduction of BC in Balkan countries in 2010-2020 – these reductions due to technical control measures are further affected by activity data development so that the actual emissions can be either higher or lower, depending on the sector.

Additional input in emission reductions from control measures in sectors with large Relative co-benefits is 2% for PM2.5 and 1.2% for BC. These sectors include diesel-fuelled cars (0.74 BC in PM2.5), diesel-fuelled heavy-duty buses (0.59 BC in PM2.5), and carbon black production process (0.99 BC in PM2.5).

The most important sectors with Neutral and Trade-off measures between 2010 and 2020:

- Cement production process (20 kt PM2.5, 0.1 kt BC)
- Wood fuels in household heating stoves (14 kt PM2.5, 1.3 kt BC)
- Brown coal combustion at existing large power plants (6.3 kt PM2.5, no BC)

Planned emission reductions (2020 -2030, current legislation)

Key sectors and measures with large Absolute co-benefit potential of BC and PM2.5 emission control:

- (1) Wood fuels in household heating stoves; Planned emission reduction due to control measures is 11.2 kt PM2.5 and 1.4 kt BC. Control measures:
  - *New installations* (80% reduction efficiency for PM2.5, 72% for BC) – increased implementation rates from ~10% in 2020 to 20% assumed in 2030.
  - *Improved installations* (63% reduction efficiency for PM2.5, 5% for BC) – increased implementation rates from 45% in 2020 to 50% assumed in 2030.

  Actual emission reduction is expected to be higher due to decreased activity data – 20.8 kt for PM2.5 and 3.8 kt for BC.
- (2) Diesel-fuelled heavy-duty vehicles; Planned emission abatement due to control measures is 2.8 kt PM2.5 and 1.8 kt BC – there is large relative co-benefit in this sector as well (0.64 BC in PM2.5). Control measures:

  Balkan:
  - *EURO V* (91.89% reduction efficiency for PM2.5, 87.84 % for BC) – increased implementation rates from 23% in 2020 to 80% assumed in 2030.

  Turkey:
  - *EURO VI* (99.59% reduction efficiency for PM2.5, 99.88 % for BC) – increased implementation rates from 52% in 2020 to 85% assumed in 2030.

Actual emission reduction of is expected to be lower due to increased activity data – 2.4 kt for PM2.5 and 1.5 kt – for BC.

- (3) Wood fuels in single house boilers; Planned emission abatement due to control measures is 0.4 kt PM2.5 and 0.13 kt BC. Control measures:
    - *New installations* (80% reduction efficiency for PM2.5, 83% for BC) – increased implementation rates from 5-7% in 2020 to 10-15% assumed in 2030.
    - *Improved installations* (60% reduction efficiency for PM2.5, 50% for BC) – increased implementation rates from 20% in 2020 to 30% assumed in 2030.

  Actual emission reduction of is expected to be lower due to increased activity data – 0.3 kt for PM2.5 and 0.08 kt – for BC.
- (4) Diesel-fuelled heavy-duty buses; Planned emission reduction due to control measures is 0.22 kt PM2.5 and 0.15 kt BC – there is large relative co-benefit in this sector as well (0.69 BC in PM2.5). Control measures:

  Balkan:
    - *EURO V* (92.81% reduction efficiency for PM2.5, 89.22% for BC) – increased implementation rates from 23% in 2020 to 80% assumed in 2030.

  Turkey:
    - *EURO VI* (99.63% reduction efficiency for PM2.5, 99.89% for BC) – increased implementation rates from 43% in 2020 to 90% assumed in 2030.

  Actual emission reduction of is expected to be higher due to decreased activity data – 0.26 kt for PM2.5 and 0.18 kt – for BC.
- (5) Diesel-fuelled light duty vehicles; Planned emission reduction due to control measures is 0.19 kt PM2.5 and 0.17 kt BC – there is large relative co-benefit in this sector as well (0.88 BC in PM2.5). Control measures:

  Balkan:
    - *EURO 5* (98.97% reduction efficiency for PM2.5, 99.62% for BC) – increased implementation rates from 43% in 2020 to 100% assumed in 2030.

  Turkey:
    - *EURO 6* (98.96% reduction efficiency for PM2.5, 99.62% for BC) – increased implementation rates from 45% in 2020 to 96% assumed in 2030.

  Actual emission reduction of is expected to be the same (no significant activity data changes).

Control measures in 5 key sectors with largest Absolute co-benefits account for 39% of expected reduction of PM2.5 and 87% of expected reductions of BC in Balkan countries in 2020-2030 – these reductions due to technical control measures are further affected by activity data development so that the actual emissions can be either higher or lower, depending on the sector.

Additional input in emission reductions from control measures in sectors with large Relative co-benefits is 0.9% for PM2.5 and 0.6% for BC. These sectors include diesel-fuelled cars (0.88 BC in PM2.5), and diesel-fuelled construction machinery (0.51 BC in PM2.5).

The most important sectors with Neutral and Trade-off measures between 2020 and 2030 is:

- Cement production process (22 kt PM2.5, 0.13 kt BC)

Potential emission reductions (MTFR-CLE)

Key sectors and measures with large Absolute co-benefit potential of BC and PM2.5 emission control:

- (1) Wood fuels in household heating stoves; Emission reduction potential is 48 kt PM2.5 and 14 kt BC. Control measures:
    - *Pellets stoves* (95% reduction efficiency for PM2.5, 96% for BC) – increased implementation rates from 0% assumed in current legislation scenario to 65% as implied in MTFR;
    - *New installations* (80% reduction efficiency for PM2.5, 72% for BC) – increased implementation rates from 20% assumed in current legislation scenario to 35% as implied in MTFR;
- (2) Agricultural waste burning; Emission reduction potential is 37 kt PM2.5 and 4.8 kt BC. Control measures:
    - *Effective ban on open burning* (100% reduction efficiency for both PM2.5 and BC).

- (3) Brown coal in household heating stoves; Emission reduction potential is 21 kt PM2.5 and 4.3 kt BC. Control measures:
  - *Briquette stoves* (89% reduction efficiency for PM2.5, 98% for BC) – increased implementation rates from 0% assumed in current legislation scenario to 90% as implied in MTFR;
  - *New installations* (50% reduction efficiency for PM2.5, 20% for BC) – increased implementation rates from 0% assumed in current legislation scenario to 10% as implied in MTFR;
- (4) Hard coal in household heating stoves; Emission reduction potential is 10 kt PM2.5 and 3.2 kt BC. Control measures:
  - *Briquette stoves* (88% reduction efficiency for PM2.5, 98% for BC) – increased implementation rates from 0% assumed in current legislation scenario to 90% as implied in MTFR;
  - *New installations* (50% reduction efficiency for PM2.5, 20% for BC) – increased implementation rates from 0% assumed in current legislation scenario to 10% as implied in MTFR
- (5) Diesel-fuelled vehicles in agriculture; Emission reduction potential is 5 kt PM2.5 and 2 kt BC. Control measures:
  - *Control Stage 5* (97.8% reduction efficiency for PM2.5, 98.4% for BC) – increased implementation rates from 0% assumed in current legislation to 25-44% as implied in MTFR

Control measures in 5 key sectors with largest absolute potential account for 28% of the total potential reduction of PM2.5 and 84% of the total potential reduction of BC in EU in 2030. Additional input from control measures in sectors with large Relative co-benefits is 0.1% for PM2.5 and 1% for BC. These sectors include flaring in refineries (0.78 BC in PM2.5) and diesel-fuelled heavy-duty vehicles (0.76 BC in PM2.5).

The most important sectors with Neutral and Trade-off measures with high emission reduction potentials for PM2.5:

- Cement production (reduction potentials – 77 kt PM2.5, 0.5 kt BC)
- Steel production in electric arc furnaces (reduction potentials – 69 kt PM2.5, no BC)
- Brown coal combustion at large new power plants (63 kt PM2.5, no BC)

APPENDIX C: MOST IMPORTANT MEASURES IMPLEMENTED IN EU + NORWAY, SWITZERLAND AND UNITED KINGDOM-SCENARIOS

Historical development (2010 -2020)

Key sectors and measures with large Absolute co-benefit potential of BC and PM2.5 emission control:

- (1) Wood fuels in household heating stoves; Historical emission abatement due to introduced control measures is 100 kt PM2.5 and 11 kt BC. Control measures:
  - *Pellets stoves* (95% reduction efficiency for PM2.5, 96% for BC) – increased implementation rates from ~2% in 2010 to ~7% in 2020;
  - *New installations* (80% reduction efficiency for PM2.5, 72% for BC) – increased implementation rates from ~8% in 2010 to ~17% in 2020;
  - *Improved installations* (63% reduction efficiency for PM2.5, 5% for BC) – increased implementation rates from ~37% in 2010 to ~44% in 2020;

  Actual emission reduction of PM2.5 is lower due to increased activity data – 41 kt. Actual BC emissions increased by 3.3 kt.
- (2) Diesel-fuelled cars; Historical emission abatement due to introduced control measures is 63 kt PM2.5 and 51 kt BC – there is large relative co-benefit in this sector as well (0.82 BC in PM2.5). Control measures:
  - *EURO 6a/b* (~98.7% reduction efficiency for PM2.5, ~99.5% for BC) – increased implementation rates from 0% in 2010 to ~18% in 2020.
  - *EURO 6* (~98.8% reduction efficiency for PM2.5, ~99.6% for BC) – increased implementation rates from 0% in 2010 to ~30% in 2020.
  - *EURO 5* (~98.8% reduction efficiency for PM2.5, ~99.6% for BC) – increased implementation rates from 10% in 2010 to ~27% in 2020.

  Actual emission reduction is lower due to increased activity data – 52 kt for PM2.5 and 43 kt – for BC.
- (3) Diesel-fuelled heavy-duty vehicles; Historical emission reduction due to introduced control measures is 24 kt PM2.5 and 15 kt BC – there is large relative co-benefit in this sector as well (0.62 BC in PM2.5). Control measures:
  - *EURO VI* (~99.6% reduction efficiency for PM2.5, ~99.8% for BC) – increased implementation rates from 0% in 2010 to ~45% in 2020.
  - *EURO V* (~93% reduction efficiency for PM2.5, ~90% for BC) – increased implementation rates from ~15% in 2010 to ~24% in 2020.

  Actual emission reduction is slightly higher due to decreased activity data – 28 kt for PM2.5 and 17 kt – for BC.
- (4) Diesel-fuelled vehicles used in agriculture; Historical emission reduction due to introduced control measures is 21 kt PM2.5 and 9.1 kt BC. Control measures:
  - *Control Stage 4* (94% reduction efficiency for both PM2.5, 98.3% for BC) – increased implementation rates from ~0% in 2010 to ~32% in 2020.
  - *Control Stage 3B* (94% reduction efficiency for both PM2.5, 98.2% for BC) – increased implementation rates from ~0% in 2010 to ~25% in 2020.

  Actual emission reduction is higher due to decreased activity data – 25 kt for PM2.5 and 11 kt – for BC.
- (5) Diesel-fuelled light duty vehicles; Historical emission reduction due to introduced control measures is 19 kt PM2.5 and 14 kt BC – there is large relative co-benefit in this sector as well (0.77 BC in PM2.5). Control measures:
  - *EURO 6a/b* (~98.8% reduction efficiency for PM2.5, ~99.5% for BC) – increased implementation rates from 0% in 2010 to ~12% in 2020.
  - *EURO 6* (~99.1% reduction efficiency for PM2.5, ~99.7% for BC) – increased implementation rates from 0% in 2010 to ~29% in 2020.
  - *EURO 5* (~99.1% reduction efficiency for PM2.5, ~99.6% for BC) – increased implementation rates from 0-1% in 2010 to ~27% in 2020.

  Actual emission reduction is higher due to decreased activity data – 22 kt for PM2.5 and 17 kt – for BC.

Control measures in 5 key sectors with largest absolute co-benefits account for 67% of the reduction of PM2.5 and 85% of the reduction of BC in EU in 2010-2020 – these reductions due to technical control measures are further affected by activity data development so that the actual emissions can be either higher or lower, depending on the sector.

Additional input in emission reductions from control measures in sectors with large Relative co-benefits is 5% for PM2.5 and 3% for BC. These sectors include diesel-fuelled construction machinery (0.52 BC in PM2.5), diesel-fuelled heavy duty buses (0.60 BC in PM2.5), generator sets on heavy fuel oil (0.51 BC in PM2.5), and carbon black production process (0.99 BC in PM2.5).

The most important sectors with Neutral and Trade-off measures where PM2.5 reductions happened between 2010 and 2020:

- Wood fuels in single house boilers (14 kt PM2.5, 3 kt BC)
- Cement production (11 kt PM2.5, 0.07 kt BC)
- Fireplaces (10 kt PM2.5, 0.4 kt BC)

Planned emission reductions (2020 -2030, current legislation)

Key sectors and measures with large Absolute co-benefit potential of BC and PM2.5 emission control:

- (1) Wood fuels in household heating stoves; Planned emission reduction due to control measures is 181 kt PM2.5 and 36 kt BC. Control measures:
    - *Pellets stoves* (95% reduction efficiency for PM2.5, 96% for BC) – increased implementation rates from ~4% in 2020 to ~10% assumed in 2030;
    - *New installations* (80% reduction efficiency for PM2.5, 72% for BC) – increased implementation rates from ~16% in 2020 to ~59% in 2030.

  Actual emission reduction is expected to be higher due to decreased activity data – 293 kt for PM2.5 and 63 kt for BC.
- (2) Wood fuels in single house boilers; Planned emission reduction due to control measures is 23 kt PM2.5 and 6.5 kt BC. Control measures:
    - *New installations* (80% reduction efficiency for PM2.5, 83% for BC) – increased implementation rates from ~12% in 2020 to ~62% assumed in 2030.

  Actual emission reduction of is expected to be higher due to decreased activity data – 40 kt for PM2.5 and 10 kt – for BC.
- (3) Diesel-fuelled cars; Planned emission reduction due to control measures is 14 kt PM2.5 and 12 kt BC – there is large relative co-benefit in this sector as well (0.88 BC in PM2.5). Control measures:
    - *EURO 6* (~98.8% reduction efficiency for PM2.5, ~99.6% for BC) – increased implementation rates from ~30% in 2020 to ~79% assumed in 2030.

  Actual emission reduction of is expected to be slightly higher due to decreased activity data – 18 kt for PM2.5 and 15 kt – for BC.
- (4) Diesel-fuelled vehicles used in agriculture; Planned emission reduction due to control measures is 11 kt PM2.5 and 4.6 kt BC. Control measures:
    - *Control Stage 5* (97.8% reduction efficiency for both PM2.5, 98.4% for BC) – increased implementation rates from ~0% in 2020 to ~54% assumed in 2030.

  Actual emission reduction of is expected to be slightly higher due to decreased activity data – 13 kt for PM2.5 and 5.1 kt – for BC.
- (5) Diesel-fuelled heavy-duty vehicles; Planned emission reduction due to control measures is 6.0 kt PM2.5 and 4.3 kt BC. Control measures:
    - *EURO VI* (~99.6% reduction efficiency for PM2.5, ~99.8% for BC) – increased implementation rates from ~45% in 2020 to ~86% assumed in 2030.

  Actual emission reduction of is expected to be higher due to decreased activity data – 6.6 kt for PM2.5 and 4.7 kt – for BC.

Control measures in 5 key sectors with largest absolute co-benefits account for 73% of expected reduction of PM2.5 and 79% of expected reductions of BC in EU in 2020-2030 – these reductions due to technical control measures are further affected by activity data development so that the actual emissions can be either higher or lower, depending on the sector.

Additional input in emission reductions from control measures in sectors with large Relative co-benefits is 2% for PM2.5 and 2% for BC. These sectors include diesel-fuelled heavy duty buses (0.66 BC in PM2.5), diesel-fuelled light duty vehicles (0.80 BC in PM2.5), hard coal grade 2 in household heating stoves (0.71 BC in PM2.5), and generator sets on heavy fuel oil (0.53 BC in PM2.5).

The most important sectors with Neutral and Trade-off measures where PM2.5 reductions are assumed to happen between 2020 and 2030:

- Fireplaces (34 kt PM2.5, 1.6 kt BC)
- Hard coal in household heating stoves (11 kt PM2.5, 3 kt BC)
- Diesel-fuelled inland waterways transport (4 kt PM2.5, 1.8 kt BC)

Potential emission reductions (MTFR-CLE)

Key sectors and measures with large Absolute co-benefit potential of BC and PM2.5 emission control:

- (1) Wood fuels in household heating stoves; Emission reduction potential is 101 kt PM2.5 and 26 kt BC. Control measures:
    - *Pellets stoves* (95% reduction efficiency for PM2.5, 96% for BC) – increased implementation rates from ~10% assumed in current legislation scenario to ~61% as implied in MTFR;
- (2) Agricultural waste burning; Emission reduction potential is 47 kt PM2.5 and 6 kt BC. Control measures:
    - *Effective ban on open burning* (100% reduction efficiency for both PM2.5 and BC).
- (3) Wood fuels in single house boilers; Emission reduction potential is 13 kt PM2.5 and 4 kt BC. Control measures:
    - *Pellet boilers* (90% reduction efficiency for PM2.5, 95% for BC) – increased implementation rates from ~6% assumed in current legislation scenario to -59% as implied in MTFR;
- (4) Hard coal in household heating stoves; Emission reduction potential is 7 kt PM2.5 and 1 kt BC. Control measures:
    - *Briquette stoves* (88% reduction efficiency for PM2.5, 98% for BC) – in majority of countries – increased implementation rates from 40% assumed in current legislation scenario to 50% as implied in MTFR;
    - *New installations* (50% reduction efficiency for PM2.5, 20% for BC) in majority of countries – increased implementation rates from 0% assumed in current legislation scenario to 50% as implied in MTFR.
- (5) Meat frying, food preparation, BBQ; Emission reduction potential is 3.9 kt PM2.5 and 0.5 kt BC. Control measures:
    - *Filters in households* (10% reduction efficiency for both PM2.5 and BC) – increased implementation rates from 0% assumed in current legislation scenario to 100% implementation rate as in MTFR.

Control measures in 5 key sectors with largest absolute potential account for 59% of the total potential reduction of PM2.5 and 87% of the total potential reduction of BC in EU in 2030. Additional input from control measures in sectors with large Relative co-benefits is 0.4% for PM2.5 and 2% for BC. These sectors include flaring in refineries (0.78 BC in PM2.5), venting and flaring of APG during oil and gas production (0.76 BC in PM2.5), and carbon black production (0.86 BC in PM2.5).

The most important sectors with Neutral and Trade-off measures with high emission reduction potentials for PM2.5:

- Industrial processes (reduction potentials – 20 kt PM2.5, no BC)
- Fireplaces (reduction potentials – 16 kt PM2.5, 0.3 kt BC)
- Biomass fuels in industrial furnaces (8 kt PM2.5, 0.7 kt BC)