Assessing the air pollution benefits of further climate measures in the EU up to 2020






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Executive Summary

Action to reduce CO_2 emissions has the potential to also reduce emissions of various regional air pollutants, such as SO_2, NOx and fine particles. This can arise, for example, as a result of fuel switching or through the implementation of various energy efficiency measures.

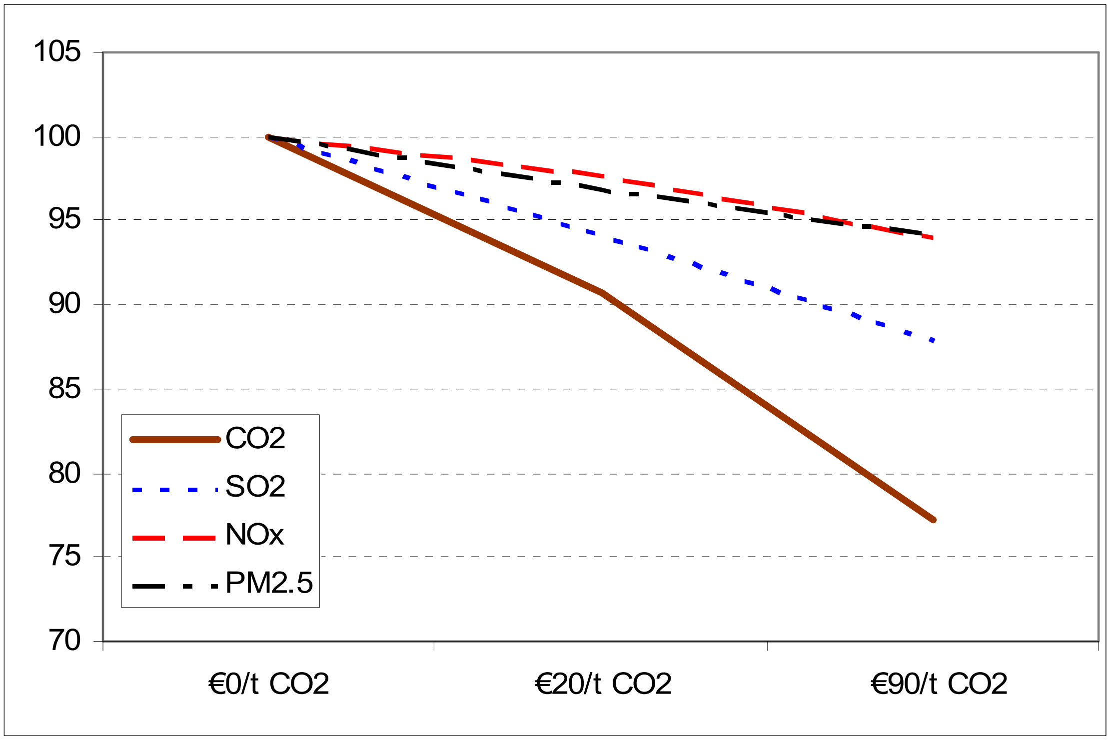
This report assesses the co-benefits of climate policy scenarios via changes in emissions of NH_3, NOx, $PM_{2.5}$, SO_2 and VOCs to get an understanding of the magnitude of these benefits. Three levels of climate policy are considered using the CAFE methodology against scenarios for the year 2020:

- Carbon price of €0;
- Carbon price of €20 and
- Carbon price of €90.

All three scenarios describe emissions assuming that current legislation (CLE, the baseline for the CAFE assessments) for air pollutants is in place. As a sensitivity these three carbon price scenarios were combined with the Maximum Feasible Reduction case (MFR) for air pollutants according to the RAINS model at price levels of €20 and €90/t CO_2.

For the Current Legislation Scenario, moving from a shadow carbon price of €0/t CO_2 to €20/t CO_2 leads to a fall in emissions of 390 million tonnes for CO_2, 277 thousand tonnes (kt) for NOx, 43 kt for $PM_{2.5}$ and 397 kt for SO_2 by 2020. Increasing the price from €20/t CO_2 to €90/t CO_2 would lead to a further increase of 563 million tonnes for CO_2, 460 thousand tonnes (kt) for NOx, 38 kt for $PM_{2.5}$ and 418 kt for SO_2 by 2020. An increase in price from €0/t CO_2 to €90/t CO_2 would thus lead to a total fall in emissions of 953 million tonnes for CO_2, 737 thousand tonnes (kt) for NOx, 81 kt for $PM_{2.5}$ and 815 kt for SO_2 by 2020.

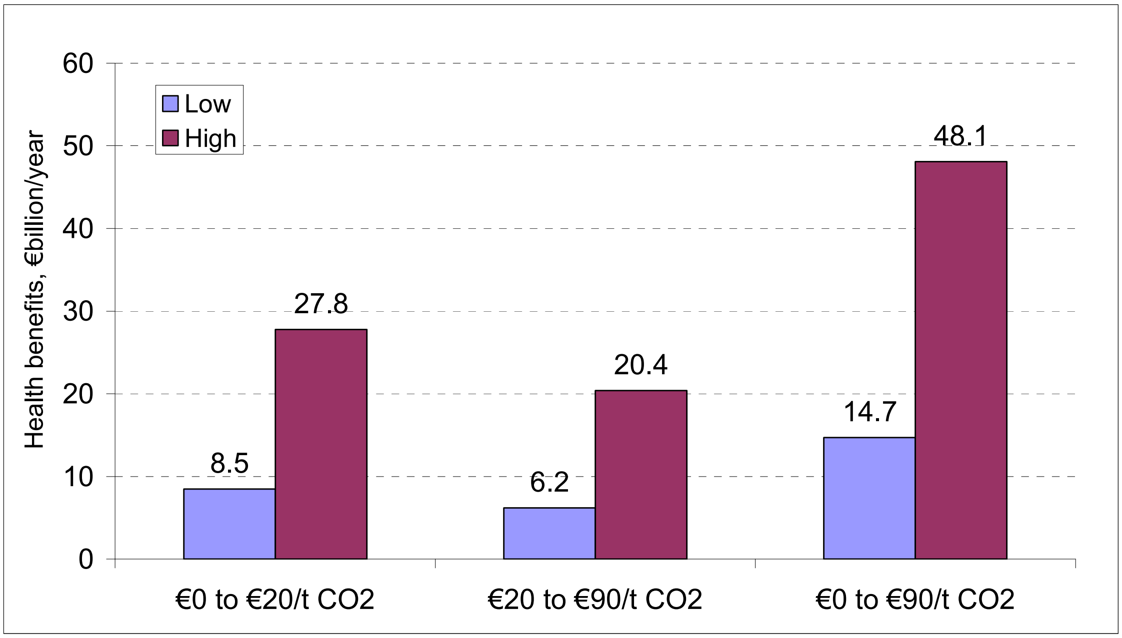
The following figure summarises these results in terms of the % change in emissions of each pollutant across the EU25 relative to a price of €0/t CO_2 t in 2020 under the Current Legislation Scenario.



Estimated % reduction (in 2020 under CLE scenario) in emissions of CO_2, NOx, $PM_{2.5}$ and SO_2 in 2020 in response to increasing levels of climate policy. Emissions of NH_3 and VOCs are little affected by climate policy.

The PRIMES model, run at the National Technical University of Athens (NTUA), was used to estimate the effect of CO_2 prices on energy consumption and fuel use in Europe. The outputs from PRIMES were used by the RAINS model to forecast emissions of NH_3, NOx, $PM_{2.5}$, SO_2 and VOCs for each country in the EU25 for baseline conditions under current legislation (CLE) for 2020 with shadow carbon prices of €0, €20 and €90/t CO_2, and also for scenarios describing the maximum feasible reduction (MFR). These emission estimates fed into the EMEP Eulerian model, which models the associated changes in air pollution concentrations.

The changes in concentration levels (relative to the baseline) were then input into the CAFE cost-benefits model; using concentration-response functions, the health impacts were estimated. The CBA analysis enables a link between changes in NOx, $PM_{2.5}$ and SO_2 and various health impacts including mortality, the incidence of bronchitis, hospital admissions for respiratory and cardiac illness and various other effects such as restrictions to daily activity and increased incidence of asthma symptoms. Quantified impacts are monetised using values agreed with stakeholders during the CAFE programme. Results are shown in the figure below. The low-high ranges reflect sensitivity to the approach used to characterise mortality impacts.



Annual co-benefits (€ billions) for climate policy under the CLE scenario in terms of the change in health impacts as a result of reduced emissions of NOx, $PM_{2.5}$ and SO_2 in 2020 for the EU-25.[1]

Results indicate that climate policy is likely to generate ancillary benefits through reductions in regional air pollutants of several €billion each year. The analysis indicate that the co-benefits can be significant and vary between nearly 10 to just under 50 billion € per year depending on how vigorous a climate policy is pursued.

The analysis does not include all impacts of NOx, PM and SO_2, perhaps most significantly the effects of SO_2 and NOx on ecosystems but also impacts on materials and crops are also missing. This clearly biases the results to underestimation of benefits.

[1] Co-benefits under the Maximum Feasible Reduction Scenario according to the RAINS model are smaller as there is significantly less emission of NOx, etc., at the starting point.

Contents

The co-benefits of climate policy

Introduction

Action to reduce CO_2 emissions has the potential to also reduce emissions of various regional air pollutants, such as SO_2, NOx and fine particles. This can arise, for example, as a result of fuel switching or through the implementation of various energy efficiency measures.

Past analysis of the benefits of abating the CAFE pollutants (NH_3, NOx, $PM_{2.5}$, SO_2 and VOCs) has started from a baseline scenario where CO_2 emissions are stabilised by 2020, with an estimated shadow price for CO_2 control of €20/t. The question then naturally arises of what additional benefits via further reductions in the CAFE pollutants could accrue from different levels of climate policy.

Scenarios investigated

As part of the CAFE work, a set of emission scenarios were developed based around three different prices for CO_2, €0/t (IIASA, 2005), €20/t and €90/t (IIASA, 2004). The PRIMES model, run at the National Technical University of Athens (NTUA), was used to estimate the effect of these prices on energy consumption and fuel use in Europe. For this analysis PRIMES implicitly assumed that the overall economy did not change (i.e. Europe produces the same amount of cement, steel, etc. in each model run) with exactly the same GDP growth between 2000 and 2020. This would of course not be the case if it was known that CO_2 would cost €90/t. The European economy would be likely to move towards different production modes, producing less energy intensive goods. One effect of this is that the model runs presented here are likely to provide an underestimate of ancillary benefits in Europe via reductions in emissions of the CAFE pollutants. A general equilibrium analysis should ideally be performed to characterise these broader impacts on the economy.

The outputs from PRIMES were used by the RAINS model to forecast emissions of NH_3, NOx, $PM_{2.5}$, SO_2 and VOCs for each country in the EU25 for baseline conditions under current legislation (CLE) for 2020 with shadow carbon prices of €0, €20 and €90/t CO_2, and also for scenarios describing the maximum feasible reduction (MFR) in each pollutant according to the measures included in RAINS for shadow carbon prices of €20 and €90/t CO_2. The results associated with the MFR scenario are shown in Appendix 1. Total emissions are shown in Table 1 and the change in emissions with increasing carbon price is shown in Table 2. National emissions of each pollutant are given in Appendix 2.

Table 1. Total emissions (kt) in 2020 under the scenarios investigated.

Pollutant	CLE, €0/t CO_2	CLE, €20/t CO_2	CLE, €90/t CO_2
NH_3	3,687	3,687	3,677
NOx	12,114	11,837	11,377
$PM_{2.5}$	1,364	1,321	1,283
SO_2	6,729	6,332	5,914
VOCs	6,135	6,139	6,107

Table 2. Change in emissions (kt) in 2020 with increased CO_2 price.

Pollutant	CLE, €0 to €20/t CO_2	CLE, €20 to €90/t CO_2	CLE, €0 to €90/t CO_2
NH_3	0	10	10
NOx	277	460	737
$PM_{2.5}$	43	38	81
SO_2	397	418	815
VOCs	-4 (increase)	32	28

Methods

The emissions data derived by RAINS for each scenario were used in the EMEP model to estimate the concentration and deposition of air pollutants across Europe on a 50 x 50 km grid. The analysis presented here then applied the CAFE methodology (Holland et al, 2005a, b; Hurley et al, 2005) to the EMEP outputs to quantify the health impacts arising from emissions of each pollutant, mediated through exposure to primary and secondary particles. Effects on both mortality and morbidity were quantified. Sensitivity analysis on mortality characterisation and valuation provides a range of estimates, as follows:

- CAFE-low: Quantifies mortality as years of life lost (YOLL) and applies the median estimate of the value of a life year (VOLY)[2].
- CAFE-low/mid: Quantifies mortality as deaths and applies the median estimate of the value of a statistical life (VSL).
- CAFE-high/mid: Quantifies mortality as YOLL and values it using the mean estimate of the VOLY.
- CAFE-high: Quantifies mortality in terms of deaths and values it using the mean estimate of the VSL.

The analysis presented here did not include quantification of various other impacts associated with emissions of NOx, PM and SO_2. The most significant omissions are likely to be:

1. Effects of acidification and eutrophication following emission of nitrogen and sulphur on ecosystems.
2. Effects of ozone on health, crops and ecosystems linked to emissions of NOx and VOCs. Following from the CAFE analysis it is very likely that these effects are small compared to the health impacts of exposure to PM. Note that effects on health and crops from ozone are usually included in the CAFE analysis.
3. Damage to materials.

Results

Estimates of health impacts from exposure to primary and secondary particles are shown in Table 3. Health impacts are subsequently shown in monetary equivalent in the following tables. Total estimates of annual damage are given in Table 4. Incremental benefits arising from the changes in CO_2 price are shown in Table 5. Results at the national level are shown in Table 6 to Table 9 for the CAFE-low and CAFE-high assumptions. Results have been

[2] More complete discussion of mortality valuation is given in Volume 2 of the CAFE-CBA methodology report (Hurley et al, 2005), and in the CAFE-CBA scenario analyses (Holland et al, 2005d, e).

checked against a simplified method, using marginal damage estimates generated using the CAFE methods, and good agreement has been found (Holland and Pye, 2006).

Table 3. Estimated annual health impacts in 2020 (EU25) via population exposure to primary and secondary particles under current legislation (CLE) scenario based on different prices applied to CO_2 (thousands).

Health endpoint	€0/t CO_2	€20/t CO_2	€90/t CO_2
Chronic Mortality – thousand years of life lost (YOLLS)[1]	2,484	2,369	2,285
Chronic Mortality – thousand deaths[1]	265	252	243
Infant Mortality (0-1yr) – thousand deaths	0.34	0.33	0.32
Chronic Bronchitis (thousand cases, adults)	125	119	115
Respiratory Hospital Admissions (thousands)	41	39	38
Cardiac Hospital Admissions (thousands)	25	24	23
Restricted Activity Days (thousands)	216,631	206,661	199,323
Respiratory medication use (thousand days, children)	1,956	1,872	1,815
Respiratory medication use (thousand days, adults)	20,359	19,409	18,708
Lower respiratory symptom days (thousands, children)	87,109	83,199	80,477
Lower respiratory symptom days (thousands, adults)	202,518	193,111	186,213

[1] For chronic mortality (PM), two alternative values are presented, based on quantification using years of life lost and numbers of premature deaths). The two measures are not additive.

Table 4. Estimated annual damage in 2020 (EU25) via population exposure to primary and secondary particles under current legislation (CLE) scenario based on different prices applied to CO_2.

Sensitivity case	€0/t (€M)	€20/t (€M)	€90/t (€M)
CAFE-low	183,084	174,606	168,410
CAFE-low/mid	312,573	297,824	286,996
CAFE-high/mid	345,197	329,219	317,556
CAFE-high	587,298	559,544	539,170

Table 5. Incremental benefits in 2020 with increasing price of CO_2 under the CLE scenario.

Sensitivity case	€0 - 20/t (€M)	€20 - 90/t (€M)	€0 - 90/t (€M)
CAFE-low	8,479	6,196	14,674
CAFE-low/mid	14,749	10,828	25,577
CAFE-high/mid	15,979	11,663	27,641
CAFE-high	27,754	20,374	48,128

Table 6. Estimated annual damage (€millions) in 2020 by country for each CO_2 price scenario using the CAFE-low assumptions (under the CLE scenario).

Country	€0/t CO_2	€20/t CO_2	€90/t CO_2
Austria	2,790	2,609	2,451
Belgium	7,408	7,154	6,914
Cyprus	267	218	220
Czech Republic	4,134	3,701	3,377
Denmark	1,850	1,793	1,785
Estonia	227	229	235
Finland	770	767	800
France	25,871	24,534	23,988
Germany	40,359	37,782	35,815
Greece	3,958	3,576	3,506
Hungary	4,406	4,128	3,845
Ireland	948	956	980
Italy	21,437	20,521	19,809
Latvia	450	440	440
Lithuania	965	938	916
Luxembourg	281	260	247
Malta	198	191	191
Netherlands	11,233	10,965	10,696
Poland	16,900	15,789	14,430
Portugal	2,222	2,185	2,205
Slovakia	2,322	2,108	1,925
Slovenia	748	707	668
Spain	8,827	8,664	8,510
Sweden	1,886	1,826	1,841
UK	22,627	22,566	22,615
Total	**183,084**	**174,606**	**168,410**

Table 7. Estimated annual damage (€millions) in 2020 by country for each CO_2 price scenario using the CAFE-high assumptions (under the CLE scenario).

Country	€0/t CO_2	€20/t CO_2	€90/t CO_2
Austria	8,649	8,086	7,598
Belgium	23,016	22,224	21,481
Cyprus	647	527	534
Czech Republic	13,544	12,124	11,062
Denmark	6,206	6,013	5,987
Estonia	825	834	856
Finland	2,444	2,437	2,540
France	75,596	71,689	70,093
Germany	137,183	128,422	121,737
Greece	14,420	13,029	12,773
Hungary	16,144	15,127	14,088
Ireland	2,398	2,418	2,478
Italy	79,012	75,635	73,012
Latvia	1,166	1,139	1,139
Lithuania	4,535	4,411	4,309
Luxembourg	664	614	584
Malta	580	560	559
Netherlands	33,306	32,511	31,714
Poland	52,065	48,643	44,455
Portugal	7,501	7,377	7,442
Slovakia	6,982	6,338	5,790
Slovenia	2,497	2,361	2,230
Spain	28,902	28,369	27,867
Sweden	5,923	5,734	5,781
UK	63,095	62,925	63,062
Total	**587,298**	**559,544**	**539,170**

Table 8. Estimated incremental benefits in 2020 by country between scenarios of increasing CO_2 price (€millions) using the CAFE-low assumptions (under the CLE scenario).

Country	€0 to 20/t CO_2	€20 to 90/t CO_2	€0 to 90/t CO_2
Austria	181	158	339
Belgium	254	240	494
Cyprus	49	-2	47
Czech Republic	433	324	757
Denmark	57	8	65
Estonia	-2	-6	-8
Finland	3	-33	-30
France	1,337	546	1,883
Germany	2,577	1,967	4,544
Greece	382	70	452
Hungary	278	283	561
Ireland	-8	-24	-32
Italy	916	712	1,628
Latvia	10	0	10
Lithuania	27	22	49
Luxembourg	21	13	34
Malta	7	0	7
Netherlands	268	269	537
Poland	1,111	1,359	2,470
Portugal	37	-20	17
Slovakia	214	183	397
Slovenia	41	39	80
Spain	163	154	317
Sweden	60	-15	45
UK	61	-49	12
Total	**8,478**	**6,196**	**14,674**

Table 9. Estimated incremental benefits in 2020 by country between scenarios of increasing CO_2 price (€millions) using the CAFE-high assumptions (under the CLE scenario).

Country	€0 to 20/t CO_2	€20 to 90/t CO_2	€0 to 90/t CO_2
Austria	563	488	1,051
Belgium	792	743	1,535
Cyprus	120	-7	113
Czech Republic	1,420	1,062	2,482
Denmark	193	26	219
Estonia	-9	-22	-31
Finland	7	-103	-96
France	3,907	1,596	5,503
Germany	8,761	6,685	15,446
Greece	1,391	256	1,647
Hungary	1,017	1,039	2,056
Ireland	-20	-60	-80
Italy	3,377	2,623	6,000
Latvia	27	0	27
Lithuania	124	102	226
Luxembourg	50	30	80
Malta	20	1	21
Netherlands	795	797	1,592
Poland	3,422	4,188	7,610
Portugal	124	-65	59
Slovakia	644	548	1,192
Slovenia	136	131	267
Spain	533	502	1,035
Sweden	189	-47	142
UK	170	-137	33
Total	**27,754**	**20,374**	**48,128**

Although overall it is found that benefits arise as carbon price increases, results for a number of countries in Table 8 and Table 9 show an increase in damage as CO_2 price increases, even though they generally have a reduction in emissions. Table 10 expresses these changes as a % of total damage for each country, whilst Table 11 and Table 12 show the changes in emissions of SO_2 and NOx between scenarios for each country, with those giving negative incremental damage (highlighted) tending to have relatively small reductions in emissions between scenarios. These results are further discussed in the conclusions, below.

Table 10. % change in health damage from $PM_{2.5}$ exposure between scenarios. Countries with a negative effect (increased damage) are highlighted (under the CLE scenario).

Country	€0 to 20/t CO_2	€20 to 90/t CO_2	€0 to 90/t CO_2
Austria	7%	6%	12%
Belgium	3%	3%	7%
Cyprus	19%	-1%	17%
Czech Republic	10%	8%	18%
Denmark	3%	0%	4%
Estonia	-1%	-3%	-4%
Finland	0%	-4%	-4%
France	5%	2%	7%
Germany	6%	5%	11%
Greece	10%	2%	11%
Hungary	6%	6%	13%
Ireland	-1%	-3%	-3%
Italy	4%	3%	8%
Latvia	2%	0%	2%
Lithuania	3%	2%	5%
Luxembourg	8%	5%	12%
Malta	3%	0%	4%
Netherlands	2%	2%	5%
Poland	7%	8%	15%
Portugal	2%	-1%	1%
Slovakia	9%	8%	17%
Slovenia	5%	5%	11%
Spain	2%	2%	4%
Sweden	3%	-1%	2%
UK	0%	0%	0%
Total	**5%**	**3%**	**8%**

Table 11. Reduction in emissions of SO_2 (kt) between CLE scenarios for 2020. Highlighted cells correspond to the cells with negative incremental damages from Table 8 and Table 9.

Country	€0 to 20/t CO_2	€20 to 90/t CO_2	€0 to 90/t CO_2
Austria	2	3	5
Belgium	8	12	20
Cyprus	0	1	1
Czech Rep	10	17	27
Denmark	1	0	1
Estonia	1	3	4
Finland	-2	6	4
France	18	23	41
Germany	94	73	167
Greece	3	10	13
Hungary	8	11	19
Ireland	0	1	1
Italy	27	38	65
Latvia	1	0	1
Lithuania	3	3	6
Luxembourg	0	0	0
Malta	1	1	2
Netherlands	-2	2	0
Poland	169	169	338
Portugal	6	7	13
Slovakia	5	8	13
Slovenia	3	2	5
Spain	15	20	35
Sweden	10	1	11
UK	16	7	23
EU25	**397**	**418**	**815**
Atlantic Ocean	0	0	0
Baltic Sea	0	0	0
Black Sea	0	0	0
Mediterranean	0	0	0
North Sea	0	0	0
Sea regions	**0**	**0**	**0**
Total	**397**	**418**	**815**

SO_2 changes in the country/scenario combinations with negative damage tend to be small (a maximum of 7 kt/year, for Portugal and the UK) compared to the other estimates (a maximum of 338 kt/year for Poland).

Table 12. Reduction in emissions of NOx (kt) between CLE scenarios for 2020. Highlighted cells correspond to the cells with negative incremental damages from Table 8 and Table 9.

Country	€0 to 20/t CO_2	€20 to 90/t CO_2	€0 to 90/t CO_2
Austria	0	10	10
Belgium	12	17	29
Cyprus	1	1	2
Czech Rep	11	23	34
Denmark	0	4	4
Estonia	1	3	4
Finland	-5	7	2
France	28	41	69
Germany	101	55	156
Greece	6	15	21
Hungary	8	7	15
Ireland	2	7	9
Italy	29	41	70
Latvia	2	0	2
Lithuania	2	2	4
Luxembourg	0	2	2
Malta	0	1	1
Netherlands	3	13	16
Poland	26	55	81
Portugal	9	15	24
Slovakia	-2	7	5
Slovenia	4	2	6
Spain	16	54	70
Sweden	11	7	18
UK	12	71	83
EU25	**277**	**460**	**737**
Atlantic Ocean	0	0	0
Baltic Sea	0	0	0
Black Sea	0	0	0
Mediterranean	0	0	0
North Sea	0	0	0
Sea regions	**0**	**0**	**0**
Total	**277**	**460**	**737**

In general, the country/scenario combinations with negative incremental damage tend to have small reductions in NOx emissions compared to those seen elsewhere, exceptions being the UK and to a lesser extent Portugal.

Discussion

Results indicate that climate policy is likely to generate ancillary benefits through reductions in regional air pollutants of several €billion each year. To illustrate, the incremental benefit through reduction in regional air pollutant emissions of moving from CLE €20/t CO_2 to CLE €90/t CO_2, is estimated at between €6 and €20 billion. Benefits of moving from CLE €0/t CO_2 to CLE €90/t CO_2 is estimated between nearly €15 and €48 billion.

Comparing the data in Table 2 with the results of Table 5 shows that the move from €0/t CO_2 to €20/t yields a rather higher benefit than the move from €20/t to €90/t, although the emission reductions for the latter are slightly higher (with the exception of $PM_{2.5}$). There are likely to be two reasons for this:

1. Non-linearities in some atmospheric processes as emission levels change.
2. Differences in the location of emission reductions. Given that these results are entirely health-driven, emissions in areas with a high regional population density (i.e. central parts of Europe, including countries such as the Czech Republic, Germany and France) will generate higher damage than emissions at the edges of Europe (e.g. in countries like Latvia, Greece or Portugal).

The benefits calculated here for moving to a higher CO_2 price are lower for the MFR scenario (see results in Appendix 1) than for the CLE scenario. In large part this is due to the MFR €20/t scenario starting at a lower level of NOx, $PM_{2.5}$ and SO_2 emission than its CLE counterpart.

Table 10 highlighted negative increments (increased damage) between scenarios of reduced emissions for some countries. Inspection of the countries concerned reveals that they are all around the edges of Europe. Six reasons are offered for this behaviour, most linked to secondary aerosol (sulphate and nitrate) formation as this underpins the health impacts quantified here.

1. In some cases there are modest increases in emission between successive scenarios, going against the trend seen in most other countries. This will reflect particular characteristics of the energy and transport sectors in the countries concerned (such as shifts from coal to gas to reduce carbon emissions that could increase NO_x emissions, or from gas to biomass that could increase PM emissions).
2. Emissions of SO_2 and NOx from shipping are not affected by the scenarios considered. The countries affected all border the sea (though some countries that border the sea, such as Italy and Greece do not behave in this way). On its own this would not lead to an increase in secondary aerosols, but provides a rich source of pollutants available for reaction with ammonia and photo-oxidants.
3. Emissions of NH_3 from agriculture are almost unaffected by the scenarios investigated. Reduced emissions of SO_2 and NOx in more central areas of Europe could lead to a larger amount of NH_3 being transported to surrounding countries and becoming available there for reactions leading to the formation of nitrate and sulphate aerosols.
4. Emissions of VOCs are similarly little affected. Reduced emissions of NOx in central parts of Europe could lead to more VOC leaking out to surrounding countries, raising ozone concentrations there and thus accelerating oxidation of SO_2 and NOx to sulphate and nitrate.

5. Non-linearities in ozone-NOx-VOC relations mean that for some countries (especially Belgium, the Netherlands and the UK, though the precise list of countries is dependent on which ozone metric is selected) a reduction in NOx emissions leads to an increase in ozone levels. Again, this would accelerate oxidation of SO_2 and NOx to sulphate and nitrate.
6. Country/scenario combinations with negative damage tend to be associated with small reductions in emissions of SO_2 and NOx (noting the apparent exceptions of the UK particularly, and Spain and Portugal, with respect to NOx).

These results emphasise the need to reduce emissions of:

- SO_2 and NOx from shipping (see point 2 above)
- NH_3 from agriculture (see point 3 above)
- VOCs from various sources (see points 4 and 5 above)

None of these are affected at all significantly by the scenarios considered. The results also emphasise the trans-boundary nature of the air pollutants considered under the CAFE Programme and the need to examine the occasional, counterintuitive small increases in damage for some countries in detail to reveal the causes (such as a change in energy supply, atmospheric chemistry). Nevertheless, the incremental benefits through reduction in regional air pollutant emissions of more demanding climate policies reflected in higher carbon prices can be significant, ranging from €6-20 billion per year (for a price increase of €20/t CO_2 to €90/t CO_2) to nearly €15 and €48 billion (for an increase of €0/t CO_2 to €90/t CO_2 with current air pollution legislation).

This scenario analysis could be improved by using the PRIMES model to perform a general equilibrium analysis to describe the overall effects of the change in the shadow price for CO_2 on the structure of the overall economy.

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Appendix 1 Co-benefits of climate policy under Maximum Feasible Reduction (MFR) scenario

The data tables in this appendix present the co-benefits of climate policy under the Maximum Feasible Reduction (MFR) scenario. Similar to the CLE analysis, they show that moving to higher CO_2 price is likely to generate benefits through air quality pollutant emission reductions, although such benefits are smaller than seen under the CLE scenario.

Table 13. Total emissions (kt) in 2020 under the MFR scenario, and change in emissions (kt) in 2020 with increased CO_2 price

Pollutant	Total emissions		Change in emissions
	MFR, €20/t CO_2	MFR, €90/t CO_2	MFR, €20 to €90/t CO_2
NH_3	2,219	2,203	16
NOx	6,582	6,329	253
$PM_{2.5}$	958	935	23
SO_2	2,257	2,111	146
VOCs	4,449	4,425	24

Table 14. Estimated annual health impacts in 2020 (EU25) via population exposure to primary and secondary particles under maximum feasible reduction (MFR) scenario based on different prices applied to CO_2 (thousands).

Health endpoint	€20/t CO_2	€90/t CO_2
Chronic Mortality – thousand years of life lost (YOLLS)[1]	1,223	1,197
Chronic Mortality – thousand deaths[1]	129	126
Infant Mortality (0-1yr) – thousand deaths	0.17	0.16
Chronic Bronchitis (thousand cases, adults)	61	60
Respiratory Hospital Admissions (thousands)	20	20
Cardiac Hospital Admissions (thousands)	13	12
Restricted Activity Days (thousands)	106,565	104,282
Respiratory medication use (thousand days, children)	986	970
Respiratory medication use (thousand days, adults)	9,993	9,770
Lower respiratory symptom days (thousands, children)	43,233	42,453
Lower respiratory symptom days (thousands, adults)	99,566	97,386

[1] For chronic mortality (PM), two alternative values are presented, based on quantification using years of life lost and numbers of premature deaths). The two measures are not additive.

Table 15. Estimated annual damage in 2020 (EU25) via population exposure to primary and secondary particles under maximum feasible reduction (MFR) scenario based on different prices applied to CO_2, and incremental benefits with increasing price of CO_2.

Sensitivity case	€20/t (€M)	€90/t (€M)	€20 - 90/t (€M)
CAFE-low	90,074	88,134	1,940
CAFE-low/mid	152,832	149,337	3,494
CAFE-high/mid	169,888	166,237	3,651
CAFE-high	287,038	280,445	6,592

Table 16. Estimated annual damage and incremental benefits (€millions) in 2020 by country for each CO_2 price scenario using the CAFE-low assumptions (under the MFR scenario).

Country	€20/t CO_2	€90/t CO_2	€20 - 90/t CO_2
Austria	1,382	1,307	75
Belgium	4,161	4,053	108
Cyprus	81	85	-4
Czech Republic	1,811	1,663	148
Denmark	962	982	-20
Estonia	99	108	-9
Finland	343	383	-40
France	12,435	12,392	43
Germany	21,634	20,579	1,055
Greece	1,274	1,263	11
Hungary	1,475	1,371	104
Ireland	553	594	-41
Italy	8,980	8,745	235
Latvia	172	180	-8
Lithuania	360	361	-1
Luxembourg	143	137	6
Malta	105	107	-2
Netherlands	6,698	6,581	117
Poland	6,937	6,428	509
Portugal	1,177	1,227	-50
Slovakia	863	794	69
Slovenia	296	280	16
Spain	4,371	4,445	-74
Sweden	993	1,029	-36
UK	12,769	13,040	-271
Total	**90,074**	**88,134**	**1,940**

Table 17. Estimated annual damage and incremental benefits (€millions) in 2020 by country for each CO_2 price scenario using the CAFE-high assumptions (under the MFR scenario).

Country	€20/t CO_2	€90/t CO_2	€20 - 90/t CO_2
Austria	4,283	4,051	232
Belgium	12,927	12,590	337
Cyprus	196	205	-9
Czech Republic	5,933	5,450	483
Denmark	3,228	3,294	-66
Estonia	362	394	-32
Finland	1,091	1,218	-127
France	36,334	36,210	124
Germany	73,535	69,947	3,588
Greece	4,642	4,603	39
Hungary	5,403	5,022	381
Ireland	1,398	1,504	-106
Italy	33,099	32,233	866
Latvia	445	467	-22
Lithuania	1,693	1,697	-4
Luxembourg	339	323	16
Malta	306	312	-6
Netherlands	19,860	19,514	346
Poland	21,371	19,802	1,569
Portugal	3,973	4,140	-167
Slovakia	2,596	2,386	210
Slovenia	989	934	55
Spain	14,311	14,555	-244
Sweden	3,118	3,231	-113
UK	35,605	36,363	-758
Total	**287,038**	**280,445**	**6,593**

Appendix 2 Emissions for the climate policy analysis.

This appendix provides emissions data for the following pollutants:

- SO_2 (Table 18)
- NOx (Table 19)
- VOCs (Table 20)
- NH_3 (Table 21)
- $PM_{2.5}$ (Table 22)
- CO_2 (Table 23)

Table 18. SO_2 emissions in 2020 under the 5 scenarios considered (kt).

SO2 Emissions	€0/t 2020 CLE	€20/t 2020 CLE	€20/t 2020 MFR	€90/t 2020 CLE	€90/t 2020 MFR
Austria	28	26	22	23	20
Belgium	91	83	51	71	47
Cyprus	8	8	3	7	2
Czech Rep	63	53	26	36	17
Denmark	14	13	10	13	9
Estonia	11	10	3	7	2
Finland	60	62	46	56	43
France	363	345	148	322	149
Germany	426	332	220	259	177
Greece	113	110	40	100	34
Hungary	96	88	32	77	29
Ireland	19	19	10	18	10
Italy	308	281	117	243	102
Latvia	9	8	2	8	2
Lithuania	25	22	11	19	11
Luxembourg	2	2	1	2	1
Malta	3	2	1	1	1
Netherlands	62	64	41	62	40
Poland	723	554	223	385	178
Portugal	87	81	33	74	30
Slovakia	38	33	13	25	9
Slovenia	19	16	8	14	7
Spain	350	335	155	315	153
Sweden	60	50	39	49	38
UK	225	209	102	202	100
EU25	**3203**	**2806**	**1357**	**2388**	**1211**
Atlantic Ocean	657	657	146	657	146
Baltic Sea	225	225	90	225	90
Black Sea	138	138	31	138	31
Mediterranean	2082	2082	464	2082	464
North Sea	424	424	169	424	169
Sea regions	**3526**	**3526**	**900**	**3526**	**900**
Total	**6729**	**6332**	**2257**	**5914**	**2111**

Table 19. NOx emissions in 2020 under the 5 scenarios considered (kt).

NOx Emissions	**€0/t 2020 CLE**	**€20/t 2020 CLE**	**€20/t 2020 MFR**	**€90/t 2020 CLE**	**€90/t 2020 MFR**
Austria	127	127	91	117	88
Belgium	202	190	112	173	104
Cyprus	19	18	10	17	10
Czech Rep	124	113	60	90	51
Denmark	105	105	65	101	63
Estonia	16	15	8	12	7
Finland	112	117	63	110	58
France	847	819	461	778	450
Germany	909	808	600	753	550
Greece	215	209	120	194	109
Hungary	91	83	42	76	38
Ireland	65	63	39	56	34
Italy	692	663	363	622	338
Latvia	17	15	9	15	9
Lithuania	29	27	15	25	15
Luxembourg	18	18	11	16	10
Malta	4	4	2	3	2
Netherlands	243	240	166	227	158
Poland	390	364	209	309	177
Portugal	165	156	97	141	86
Slovakia	58	60	34	53	31
Slovenia	28	24	16	22	15
Spain	697	681	398	627	375
Sweden	161	150	75	143	70
UK	829	817	474	746	439
EU25	**6163**	**5886**	**3540**	**5426**	**3287**
Atlantic Ocean	954	954	488	954	488
Baltic Sea	592	592	302	592	302
Black Sea	199	199	102	199	102
Mediterranean	3095	3095	1582	3095	1582
North Sea	1111	1111	568	1111	568
Sea regions	**5951**	**5951**	**3042**	**5951**	**3042**
Total	**12114**	**11837**	**6582**	**11377**	**6329**

Table 20. VOC emissions in 2020 under the 5 scenarios considered (kt).

VOC Emissions	€0/t 2020 CLE	€20/t 2020 CLE	€20/t 2020 MFR	€90/t 2020 CLE	€90/t 2020 MFR
Austria	138	139	94	139	94
Belgium	148	147	109	146	108
Cyprus	6	6	4	6	4
Czech Rep	120	120	74	119	75
Denmark	58	58	39	59	38
Estonia	17	17	11	17	11
Finland	95	97	63	96	62
France	921	924	660	935	667
Germany	783	777	618	767	612
Greece	146	144	79	139	76
Hungary	92	91	53	90	52
Ireland	46	47	29	46	29
Italy	739	735	552	740	552
Latvia	28	28	16	26	15
Lithuania	43	44	22	44	22
Luxembourg	8	8	6	7	6
Malta	2	2	1	2	1
Netherlands	203	204	145	202	144
Poland	324	321	215	314	210
Portugal	165	164	116	162	115
Slovakia	64	65	32	67	33
Slovenia	21	21	12	20	12
Spain	697	702	492	697	489
Sweden	182	179	136	177	134
UK	870	880	652	871	645
EU25	**5916**	**5920**	**4230**	**5888**	**4206**
Atlantic Ocean	35	35	35	35	35
Baltic Sea	22	22	22	22	22
Black Sea	7	7	7	7	7
Mediterranean	114	114	114	114	114
North Sea	41	41	41	41	41
Sea regions	**219**	**219**	**219**	**219**	**219**
Total	**6135**	**6139**	**4449**	**6107**	**4425**

Table 21. NH_3 emissions in 2020 under the 5 scenarios considered (kt).

NH3 Emissions	**€0/t 2020 CLE**	**€20/t 2020 CLE**	**€20/t 2020 MFR**	**€90/t 2020 CLE**	**€90/t 2020 MFR**
Austria	54	54	27	54	27
Belgium	76	76	47	76	47
Cyprus	6	6	3	6	3
Czech Rep	65	65	36	65	36
Denmark	78	78	40	78	40
Estonia	12	12	5	12	5
Finland	32	32	22	32	22
France	702	702	387	702	386
Germany	603	603	441	599	437
Greece	52	52	34	51	34
Hungary	85	85	39	85	39
Ireland	121	121	84	121	83
Italy	399	399	248	398	246
Latvia	16	16	7	16	7
Lithuania	57	57	39	57	39
Luxembourg	6	6	4	6	4
Malta	1	1	1	1	1
Netherlands	140	140	103	139	103
Poland	333	333	150	332	147
Portugal	67	67	40	67	39
Slovakia	33	33	17	32	16
Slovenia	20	20	9	20	9
Spain	370	370	197	370	197
Sweden	49	49	33	48	33
UK	310	310	206	310	203
EU25	**3687**	**3687**	**2219**	**3677**	**2203**

Table 22. $PM_{2.5}$ emissions in 2020 under the 5 scenarios considered (kt).

Primary PM2.5 Emissions	**€0/t 2020 CLE**	**€20/t 2020 CLE**	**€20/t 2020 MFR**	**€90/t 2020 CLE**	**€90/t 2020 MFR**
Austria	27	27	20	27	20
Belgium	26	24	16	22	16
Cyprus	2	2	1	2	1
Czech Rep	21	18	12	13	8
Denmark	13	13	10	13	9
Estonia	7	6	2	6	2
Finland	27	27	16	27	16
France	174	167	101	167	102
Germany	123	111	83	107	79
Greece	44	41	23	37	21
Hungary	25	22	8	22	8
Ireland	9	9	6	9	6
Italy	100	100	69	95	66
Latvia	5	4	2	4	2
Lithuania	12	12	5	12	5
Luxembourg	2	2	2	2	2
Malta	0	0	0	0	0
Netherlands	26	26	20	26	20
Poland	107	102	53	92	48
Portugal	38	37	21	38	21
Slovakia	14	14	6	12	5
Slovenia	7	6	3	5	3
Spain	92	91	56	87	54
Sweden	42	40	23	40	22
UK	69	68	48	66	47
EU25	**1012**	**969**	**606**	**931**	**583**
Atlantic Ocean	57	57	57	57	57
Baltic Sea	35	35	35	35	35
Black Sea	12	12	12	12	12
Mediterranean	182	182	182	182	182
North Sea	66	66	66	66	66
Sea regions	**352**	**352**	**352**	**352**	**352**
Total	**1364**	**1321**	**958**	**1283**	**935**

Table 23. CO_2 emissions in 2020 under the 5 scenarios considered (Mt). Note that the MFR and CLE values are the same for the €20 and €90/t CO_2 scenarios respectively. Note also that CO2 emissions in particular are subject to periodic recalculation, and that those shown here for any country may not be the latest estimates.

CO_2 Emissions	€0/t 2020 CLE	€20/t 2020 CLE	€20/t 2020 MFR	€90/t 2020 CLE	€90/t 2020 MFR
Austria	69	69	69	57	57
Belgium	131	121	121	106	106
Cyprus	9	9	9	8	8
Czech Rep	102	90	90	63	63
Denmark	44	46	46	40	40
Estonia	13	12	12	9	9
Finland	61	61	61	52	52
France	464	431	431	380	380
Germany	896	734	734	604	604
Greece	116	106	106	93	93
Hungary	66	59	59	52	52
Ireland	49	47	47	40	40
Italy	469	439	439	386	386
Latvia	11	9	9	8	8
Lithuania	22	19	19	14	14
Luxembourg	13	12	12	11	11
Malta	3	3	3	2	2
Netherlands	185	180	180	162	162
Poland	341	305	305	240	240
Portugal	87	80	80	64	64
Slovakia	48	49	49	39	39
Slovenia	18	15	15	13	13
Spain	344	324	324	286	286
Sweden	81	63	63	52	52
UK	549	515	515	455	455
EU25	**4189**	**3799**	**3799**	**3236**	**3236**