Cost-benefit Analysis of Scenarios for Cost-Effective Emission Controls after 2020

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Acknowledgement is also made of the contribution to the methods that underpin this analysis by numerous contributors in the past, particularly members of the ExternE Project team and those who collaborated on the CBA under the CAFE Project and subsequent work on revision of the Gothenburg Protocol and assessment of air pollution co-benefits of climate policies.

Executive Summary

This report has been prepared as part of the process to inform the revision of the EU's thematic Strategy on Air Pollution. The methods used here follow those adopted for the development of the Strategy in 2005 under the Clean Air For Europe (CAFE). Methods have been kept under review since 2005 and occasional refinements made. Methods will also be updated in the course of the TSAP process as new information, for example on the health impacts (based on WHO projects REVIHAAP and HRAPIE) and on the valuation of health and environment damage, becomes available.

The analysis follows from two reports produced by IIASA:

- TSAP Report#6: TSAP-2012 Baseline: Health and Environmental Impacts (Amann, 2012a)
- TSAP Report#7: Scenarios of Cost-effective Emission Controls after 2020 (Amann, 2012b)

IIASA's baseline report considers the anticipated development of emissions and their effects over the period 2000 to 2030, for both the TSAP 2012 baseline (CLE) and Maximum Technically Feasible Reduction (MTFR) conditions. The second report from IIASA deals with a set of policy scenarios between CLE and MTFR varying in their ambition level for improvement of the following indicators:

- Health impacts (specifically mortality) from long term exposure to $PM_{2.5}$
- Health impacts (again mortality) from short term exposure to ozone
- Ecological risk from acidification
- Ecological risk from eutrophication

The policy scenarios are referred to as 'LOW', 'MID' and 'HIGH' reflecting a closure of 25%, 50% and 75% of the gap between CLE and MTFR for each of the impact indicators.

The cost-benefit analysis (CBA) has focused on the health benefits of improved air quality under these scenarios. Under the CLE scenario it is estimated that there would be 2.55 million years of life lost (YOLL) in the EU27[1] annually (4.28 million YOLLs annually across Europe) as a consequence of exposure to fine particles by 2030, despite measures that have already been introduced to curb air pollution. This could fall to 1.85 million YOLLs in the EU27 (3.53 million YOLLs for Europe) under the MTFR scenario. Other health impacts estimated for 2030 include 233 million days of restricted activity attributable to air pollution in the EU27 (354 million in Europe) falling to 169 million in the EU27 under MTFR. Of these 22% of restricted activity days are estimated as 'work loss days'.

The CBA suggests that the optimal position for abatement (i.e. where marginal benefits and costs are equal) would lie between the HIGH and MTFR scenarios. This finding is consistent with earlier analysis of the Gothenburg Protocol revision.

Limited time has been available for production of this report. A second version will be released including further detail, for example extending the comparison of costs and benefits down to national level.

[1] The updated report will be extended to include Croatia in the EU28.

Contents

1 Introduction

1.1 Background

This report has been prepared as part of the process to inform the review of the Thematic Strategy on Air Pollution.

The methods used here follow those adopted for the development of the Strategy in 2005 under the Clean Air For Europe (CAFE) Programme (Holland et al, 2005a, b; Hurley et al, 2005). Methods have been kept under review since 2005 and occasional refinements made (see, e.g., Holland et al, 2011). Methods will also be updated in the course of the TSAP process as new information, for example from the REVIHAAP and HRAPIE studies being led by WHO, becomes available. Also the valuation of damage to human health will be reviewed in light of recent relevant information, e.g. the OECD review of valuation of health and mortality (OECD 2012)[2].

The analysis follows from two reports produced by IIASA:

- TSAP Report#6: TSAP-2012 Baseline: Health and Environmental Impacts (Amann, 2012a)
- TSAP Report#7: Scenarios of Cost-effective Emission Controls after 2020 (Amann, 2012b)

1.2 Scenarios considered

IIASA's baseline report (Amann, 2012a) considers the anticipated development of emissions and their effects over the period 2000 to 2030, for both the TSAP 2012 baseline (CLE) and Maximum Technically Feasible Reduction (MTFR) conditions. The second report from IIASA (Amann, 2012b) deals with a set of arbitrarily chosen policy scenarios between CLE and MTFR varying in their ambition level for improvement of the following indicators:

- Health impacts (specifically mortality) from long term exposure to $PM_{2.5}$
- Health impacts (again mortality) from short term exposure to ozone
- Ecological risk from acidification
- Ecological risk from eutrophication

The policy scenarios are referred to as 'LOW', 'MID' and 'HIGH' reflecting a closure of 25%, 50% and 75% of the gap between COB and MTFR for each of the impact indicators.

1.3 Scope

The cost-benefit analysis (CBA) presented here is focused primarily on the assessment of health impacts across Europe in 2030 for the five scenarios listed above. Past work (e.g. Holland et al, 2011) has found that health impacts dominate European air pollution CBAs, though this is in part a function of the problem of quantifying ecosystem damage/benefits in monetary terms for integration to the CBA.

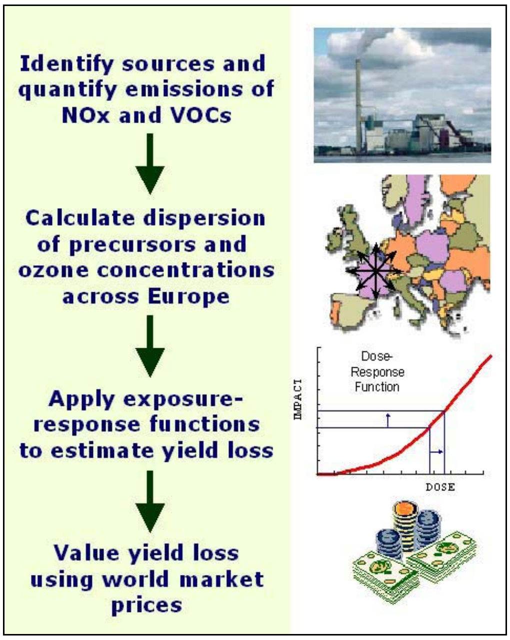
[2] http://www.oecd.org/greengrowth/environmentalpolicytoolsandevaluation/mortalityriskvaluationinenvironmenthealthandtransportpolicies.htm

2 Methods

2.1 Overview

Quantification of impacts and subsequent monetisation uses the 'impact pathway approach' developed under the ExternE Project with an example for one endpoint (effects of ozone on crops) shown in Figure 2.1. This approach follows a logical progression from emission, through dispersion and exposure to quantification of impacts and their valuation.

Figure 2.1. Impact Pathway Approach, illustrated with the example of the effects of emissions of NOx and VOCs on ozone concentrations and crop yield



The general form of the equation for the calculation of impacts is:

Impact = Pollution x Stock at risk x Response function

Pollution may be expressed in terms of:

- **Concentration**, for example in the case of impacts to human health impacts where exposure to the pollutants of interest in this study occurs through inhalation, or
- **Deposition**, for example in the case of damage to building materials where damage is related to the amount of pollutant deposited on the surface.

The term 'stock at risk' relates to the amount of sensitive material (people, ecosystems, materials, etc.) present in the modelled domain. For the health impact assessment, account is taken of the distribution of population and of effects on demographics within the population, such as children, the elderly, or those of working age. Incidence rates considered representative of the rate of occurrence of different health conditions across Europe are used to modify the stock at risk for each type of impact quantified.

2.2 Background to the methods for benefits assessment

The methods used by Holland et al (1999) and Holland and King (1999) for CBA of the original Gothenburg Protocol and EU NEC Directive were developed under the European Commission-funded ExternE (Externalities of Energy) Project during the 1990s. Whilst that work had been extensively reviewed during its development it was considered appropriate for the EU's CAFE Programme to conduct a thorough review of the methods, to consult widely with stakeholders and to subject the methodology to a formal, independent and international peer review. This is documented on the CAFE-CBA website, as follows:

- Methodology Volume 1: Overview of Methodology (Holland et al, 2005a)
- Methodology Volume 2: Health Impact Assessment (Hurley et al, 2005)
- Methodology Volume 3: Uncertainty in the CAFE-CBA (Holland, 2005b)
- Peer review: Krupnick et al (2005)

The methodology developed under CAFE remains broadly applicable now, though some changes were made for the Gothenburg Protocol analysis (Holland et al, 2011). Ongoing developments on health and ecological impact assessment are not sufficiently advanced for inclusion in the methods for the present report. They will, however, be integrated with the CBA during the TSAP revision process if opportunity arises.

One change made to the methods used for the CBA of the Gothenburg Protocol is the inclusion of fine secondary organic aerosol and a fixed portion (27%) of what was earlier described as 'coarse nitrate aerosol' in estimated concentrations of $PM_{2.5}$.[3]

2.3 Health impact assessment

The health impacts quantified in this report are listed in Figure 2.1, with details of the population considered for each effect. For the CAFE CBA two sets of response functions were identified, those for which evidence was considered most robust were grouped as the 'core' set whilst those for which quantification was considered less robust formed a 'sensitivity' set. In practice, the sensitivity functions were seldom used as their contribution to total damage was small. This first report includes only the 'core' set of functions for the CBA.

For the purposes of the present report, the effect of chronic exposure to $PM_{2.5}$ on mortality is expressed in two ways, in terms of the loss of life expectancy (expressed as the total number of life years lost annually across the affected population) and the number of deaths brought forward (expressed as number of cases (deaths) per year). The loss of life expectancy is the preferred measure of impact on theoretical and practical grounds, though deaths brought forward is included for valuation purposes. The two estimates are not additive.

Quantification of impacts only against exposure to ozone and $PM_{2.5}$ does not mean that there are no effects of exposure to NO_2 and SO_2 on health. However, it is felt at this stage that separate inclusion of functions for these pollutants would incur a serious risk of double counting the effects quantified when using the functions based on $PM_{2.5}$ exposure, so it is not done.

[3] EMEP, personal communication.

Table 2.1. List of health impacts quantified - core set.

Impact / population group	Population	Exposure metric
Mortality from acute exposure	All ages	O_3, SOMO35
Respiratory Hospital Admissions	Over 65 years	O_3, SOMO35
Minor Restricted Activity Days (MRADs)	15 to 64 years	O_3, SOMO35
Respiratory medication use	Adults over 20 years	O_3, SOMO35
Mortality from chronic exposure as life years lost or premature deaths	Over 30 years	$PM_{2.5}$, annual average
Infant Mortality	1 month to 1 year	$PM_{2.5}$, annual average
Chronic Bronchitis	Over 27 years	$PM_{2.5}$, annual average
Respiratory Hospital Admissions	All ages	$PM_{2.5}$, annual average
Cardiac Hospital Admissions	All ages	$PM_{2.5}$, annual average
Restricted Activity Days (RADs)	15 to 64 years	$PM_{2.5}$, annual average
Including lost working days	15 to 64 years	$PM_{2.5}$, annual average
Respiratory medication use	5 to 14 years	$PM_{2.5}$, annual average
Respiratory medication use	Over 20 years	$PM_{2.5}$, annual average
Lower Respiratory Symptom days	5 to 14 years	$PM_{2.5}$, annual average
Lower Respiratory Symptom days	Over 15 years	$PM_{2.5}$, annual average

2.4 Valuation of health impacts

Valuation is performed as follows:

Economic damage = Impact x Unit value of impact

Unit values seek to describe the full economic effect of the impacts that they are linked with. For health impacts, for example, which dominate the analysis, this will include elements associated with the costs of health care, lost productivity amongst workers and aversion to premature death or ill health. Valuation data have been updated since the CAFE work was completed to 2005 prices for consistency with the cost data generated by the current version of the GAINS model (an increase over 2000 values of 11% for the health impacts).

Table 2.2. Updated values for the health impact assessment (price year 2005)

Impact / population group	Unit cost	Unit
Ozone effects		
Mortality from acute exposure	57,700 / 138,700	€/life year lost (VOLY)
Respiratory Hospital Admissions	2,220	€/hospital admission
Minor Restricted Activity Days (MRADs)	42	€/day
Respiratory medication use	1	€/day of medication use
$PM_{2.5}$ effects		
Mortality from chronic exposure as: Life years lost, or Premature deaths	 57,700 / 138,700 1.09 to 2.22 million	 €/life year lost (VOLY) €/death (VSL)
Infant Mortality	1.6 to 3.3 million	€/case
Chronic Bronchitis	208,000	€/new case of chronic bronchitis
Respiratory Hospital Admissions	2,220	€/hospital admission
Cardiac Hospital Admissions	2,220	€/hospital admission
Restricted Activity Days (RADs)	92	€/day
Respiratory medication use	1	€/day of medication use
Lower Respiratory Symptom days	42	€/day

3 Health benefits

3.1 Aggregated results for EU27 and Europe

The Tables below provide the following results:

- Table 3.1. Estimated annual health impacts in 2030 due to air pollution for core scenarios, EU27
- Table 3.2. Estimated annual health impacts in 2030 due to air pollution for core scenarios, all countries
- Table 3.3. Change in estimated annual health benefits relative to the baseline in 2030 due to air pollution for core scenarios, EU27.
- Table 3.4. Change in estimated annual health benefits relative to the baseline in 2030 due to air pollution for core scenarios, all countries.
- Table 3.5. Quasi-marginal change in estimated annual health benefits relative to the preceding scenario for 2030 due to air pollution for core scenarios, EU27.
- Table 3.6. Quasi-marginal change in estimated annual health benefits relative to the preceding scenario for 2030 due to air pollution for core scenarios, all countries.
- Table 3.7. Monetised equivalent of health impacts in 2030 due to air pollution, EU27, €million/year, 2005 prices.
- Table 3.8. Monetised equivalent of health impacts in 2030 due to air pollution, all countries, €million/year, 2005 prices.
- Table 3.9. Benefits over baseline (top half of the table) and over the previous scenario ('quasi-marginal' benefits, lower half of the table) for the EU27 in 2030, €million/year, 2005 prices.
- Table 3.10. Benefits over baseline (top half of the table) and over the previous scenario ('quasi-marginal' benefits, lower half of the table) for all countries in 2030, €million/year, 2005 prices.

These tables indicate substantial health benefits from the policies under debate. There are over 2.5 million life years lost per year in the EU27under the TSAP 2012 baseline scenario and many more cases of hospital admissions, chronic bronchitis and various effects that may be minor at the level of the individual, but which could affect a very large number of people.

Figure 3.1 shows the distribution of monetary health damage across impact categories taking the case where mortality is valued using the lower estimate of the VOLY. It is clear that effects quantified against $PM_{2.5}$ exposure greatly dominate effects quantified against ozone exposure. Overall $PM_{2.5}$ effects of chronic exposure on mortality account for almost three quarters of damage. For morbidity, chronic bronchitis (12%), restricted activity days (9%) and lower respiratory symptom days (6%) all make significant contributions. In contrast, infant mortality, hospital admissions and respiratory medication use make a negligible contribution to the total monetised damage.

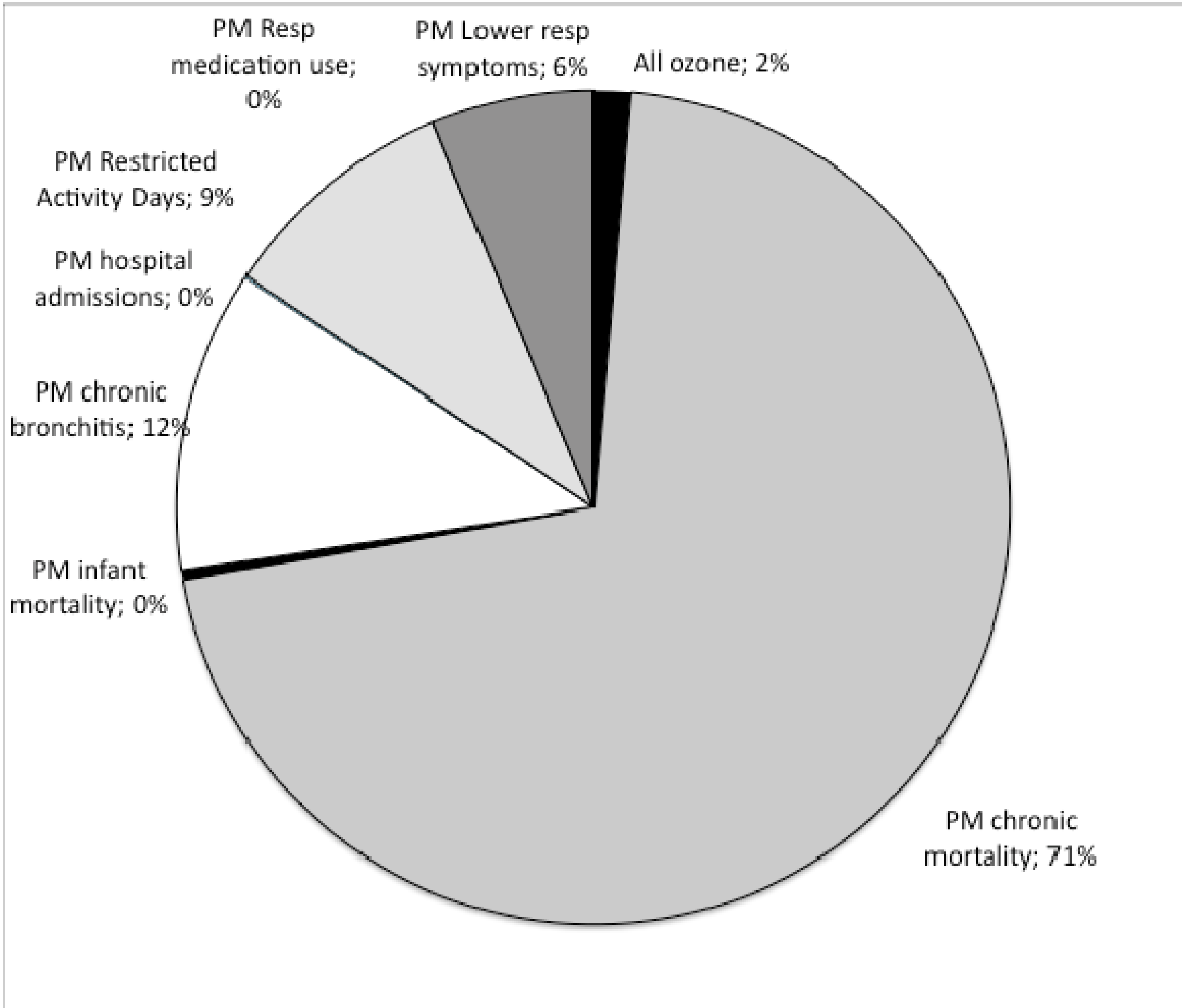


Figure 3.1. Proportion of damage attributable to each impact category for the baseline in 2030 (median VOLY applied for mortality impacts)

Table 3.1. Estimated annual health impacts in 2030 due to air pollution for core scenarios, EU27

IMPACTS: EU27			CLE	LOW	MID	HIGH	MTFR
Acute Mortality (All ages)	Premature deaths	O3	23,778	22,788	21,879	20,934	20,003
Respiratory Hospital Admissions (65yr +)	Cases	O3	25,279	24,233	23,264	22,261	21,272
Minor Restricted Activity Days (MRADs 15-64yr)	Days	O3	46,149,916	44,243,719	42,497,563	40,681,572	38,889,516
Respiratory medication use (adults 20yr +)	Days	O3	18,670,639	17,898,725	17,188,898	16,451,937	15,724,744
Chronic Mortality (All ages) Life Years Lost *	Life years lost	PM	2,545,293	2,370,534	2,195,653	2,021,090	1,845,343
Chronic Mortality (30yr +) deaths *	Premature deaths	PM	304,789	283,742	262,880	241,779	221,029
Infant Mortality (0-1yr)	Premature deaths	PM	390	362	337	309	282
Chronic Bronchitis (27yr +)	Cases	PM	134,586	125,301	116,163	106,920	97,706
Respiratory Hospital Admissions (All ages)	Cases	PM	48,435	45,103	41,820	38,505	35,176
Cardiac Hospital Admissions (All ages)	Cases	PM	29,871	27,817	25,792	23,747	21,694
Restricted Activity Days (RADs 15-64yr)	Days	PM	233,306,591	217,260,722	201,370,440	185,417,482	169,331,859
Respiratory medication use (children 5-14yr)	Days	PM	2,645,340	2,463,719	2,290,904	2,110,802	1,929,711
Respiratory medication use (adults 20yr +)	Days	PM	22,776,114	21,205,640	19,661,044	18,098,340	16,537,261
LRS symptom days (children 5-14yr)	Days	PM	121,364,668	113,107,514	104,878,172	96,661,563	88,220,035
LRS among adults (15yr +) with chronic symptoms	Days	PM	230,606,395	214,714,350	199,075,687	183,264,473	167,442,900

* life years lost and deaths from chronic exposure to $PM_{2.5}$ are alternate measures of the same effect

Table 3.2. Estimated annual health impacts in 2030 due to air pollution for core scenarios, all countries

IMPACTS: All countries			CLE	LOW	MID	HIGH	MTFR
Acute Mortality (All ages)	Premature deaths	O3	35,564	34,375	33,291	32,162	31,053
Respiratory Hospital Admissions (65yr +)	Cases	O3	33,279	32,086	30,988	29,850	28,729
Minor Restricted Activity Days (MRADs 15-64yr)	Days	O3	66,519,443	64,258,814	62,198,174	60,051,342	57,940,676
Respiratory medication use (adults 20yr +)	Days	O3	26,043,200	25,140,919	24,315,441	23,456,853	22,612,533
Chronic Mortality (All ages) Life Years Lost *	Life years lost	PM	4,278,904	4,092,960	3,903,462	3,716,167	3,531,539
Chronic Mortality (30yr +) deaths *	Premature deaths	PM	484,871	462,602	440,156	417,672	395,960
Infant Mortality (0-1yr)	Premature deaths	PM	821	791	762	732	703
Chronic Bronchitis (27yr +)	Cases	PM	196,259	186,518	176,805	167,043	157,471
Respiratory Hospital Admissions (All ages)	Cases	PM	71,394	67,895	64,402	60,896	57,437
Cardiac Hospital Admissions (All ages)	Cases	PM	44,031	41,874	39,719	37,557	35,423
Restricted Activity Days (RADs 15-64yr)	Days	PM	354,189,040	337,281,593	320,295,622	303,358,393	286,594,852
Respiratory medication use (children 5-14yr)	Days	PM	3,579,885	3,391,394	3,210,006	3,022,020	2,835,475
Respiratory medication use (adults 20yr +)	Days	PM	33,342,674	31,694,578	30,052,070	28,400,811	26,778,813
LRS symptom days (children 5-14yr)	Days	PM	184,276,348	175,585,424	166,801,040	158,088,443	149,303,297
LRS among adults (15yr +) with chronic symptoms	Days	PM	338,809,291	322,127,029	305,490,322	288,777,488	272,335,340

* life years lost and deaths from chronic exposure to $PM_{2.5}$ are alternate measures of the same effect

Table 3.3. Change in estimated annual health benefits relative to the baseline in 2030 due to air pollution for core scenarios, EU27.

BENEFITS (cases, etc.): EU27			LOW	MID	HIGH	MTFR
Acute Mortality (All ages)	Premature deaths	O3	991	1,900	2,844	3,775
Respiratory Hospital Admissions (65yr +)	Cases	O3	1,046	2,015	3,018	4,007
Minor Restricted Activity Days (MRADs 15-64yr)	Days	O3	1,906,197	3,652,353	5,468,345	7,260,400
Respiratory medication use (adults 20yr +)	Days	O3	771,913	1,481,741	2,218,702	2,945,895
Chronic Mortality (All ages) LYL *	Life years lost	PM	174,759	349,640	524,203	699,950
Chronic Mortality (30yr +) deaths *	Premature deaths	PM	21,047	41,909	63,010	83,760
Infant Mortality (0-1yr)	Premature deaths	PM	28	53	81	108
Chronic Bronchitis (27yr +)	Cases	PM	9,285	18,423	27,665	36,880
Respiratory Hospital Admissions (All ages)	Cases	PM	3,332	6,615	9,930	13,259
Cardiac Hospital Admissions (All ages)	Cases	PM	2,055	4,080	6,124	8,177
Restricted Activity Days (RADs 15-64yr)	Days	PM	16,045,869	31,936,151	47,889,109	63,974,732
Respiratory medication use (children 5-14yr)	Days	PM	181,621	354,436	534,538	715,629
Respiratory medication use (adults 20yr +)	Days	PM	1,570,474	3,115,070	4,677,774	6,238,853
LRS symptom days (children 5-14yr)	Days	PM	8,257,154	16,486,496	24,703,105	33,144,633
LRS among adults (15yr +) with chronic symptoms	Days	PM	15,892,046	31,530,708	47,341,922	63,163,495

* life years lost and deaths from chronic exposure to $PM_{2.5}$ are alternate measures of the same effect

Table 3.4. Change in estimated annual health benefits relative to the baseline in 2030 due to air pollution for core scenarios, all countries.

BENEFITS (cases, etc.): All countries			**LOW**	**MID**	**HIGH**	**MTFR**
Acute Mortality (All ages)	Premature deaths	O3	1,189	2,273	3,402	4,511
Respiratory Hospital Admissions (65yr +)	Cases	O3	1,192	2,290	3,429	4,549
Minor Restricted Activity Days (MRADs 15-64yr)	Days	O3	2,260,630	4,321,269	6,468,102	8,578,768
Respiratory medication use (adults 20yr +)	Days	O3	902,281	1,727,759	2,586,347	3,430,667
Chronic Mortality (All ages) LYL *	Life years lost	PM	185,945	375,442	562,737	747,366
Chronic Mortality (30yr +) deaths *	Premature deaths	PM	22,269	44,715	67,199	88,911
Infant Mortality (0-1yr)	Premature deaths	PM	30	59	89	118
Chronic Bronchitis (27yr +)	Cases	PM	9,741	19,454	29,216	38,788
Respiratory Hospital Admissions (All ages)	Cases	PM	3,499	6,992	10,497	13,957
Cardiac Hospital Admissions (All ages)	Cases	PM	2,158	4,312	6,474	8,608
Restricted Activity Days (RADs 15-64yr)	Days	PM	16,907,447	33,893,417	50,830,647	67,594,188
Respiratory medication use (children 5-14yr)	Days	PM	188,490	369,878	557,865	744,410
Respiratory medication use (adults 20yr +)	Days	PM	1,648,096	3,290,604	4,941,863	6,563,861
LRS symptom days (children 5-14yr)	Days	PM	8,690,923	17,475,308	26,187,905	34,973,051
LRS among adults (15yr +) with chronic symptoms	Days	PM	16,682,262	33,318,970	50,031,804	66,473,951

* life years lost and deaths from chronic exposure to $PM_{2.5}$ are alternate measures of the same effect

Table 3.5. Quasi-marginal change in estimated annual health benefits relative to the preceding scenario for 2030 due to air pollution for core scenarios, EU27.

BENEFITS (cases, etc.): EU27			LOW	MID	HIGH	MTFR
Acute Mortality (All ages)	Premature deaths	O3	991	909	944	931
Respiratory Hospital Admissions (65yr +)	Cases	O3	1,046	969	1,003	989
Minor Restricted Activity Days (MRADs 15-64yr)	Days	O3	1,906,197	1,746,156	1,815,991	1,792,056
Respiratory medication use (adults 20yr +)	Days	O3	771,913	709,828	736,961	727,193
Chronic Mortality (All ages) LYL *	Life years lost	PM	174,759	174,882	174,563	175,747
Chronic Mortality (30yr +) deaths *	Premature deaths	PM	21,047	20,862	21,101	20,750
Infant Mortality (0-1yr)	Premature deaths	PM	28	26	27	28
Chronic Bronchitis (27yr +)	Cases	PM	9,285	9,138	9,242	9,214
Respiratory Hospital Admissions (All ages)	Cases	PM	3,332	3,283	3,315	3,329
Cardiac Hospital Admissions (All ages)	Cases	PM	2,055	2,025	2,045	2,053
Restricted Activity Days (RADs 15-64yr)	Days	PM	16,045,869	15,890,282	15,952,958	16,085,623
Respiratory medication use (children 5-14yr)	Days	PM	181,621	172,815	180,102	181,091
Respiratory medication use (adults 20yr +)	Days	PM	1,570,474	1,544,597	1,562,704	1,561,079
LRS symptom days (children 5-14yr)	Days	PM	8,257,154	8,229,342	8,216,609	8,441,528
LRS among adults (15yr +) with chronic symptoms	Days	PM	15,892,046	15,638,662	15,811,214	15,821,573

* life years lost and deaths from chronic exposure to $PM_{2.5}$ are alternate measures of the same effect

Table 3.6. Quasi-marginal change in estimated annual health benefits relative to the preceding scenario for 2030 due to air pollution for core scenarios, all countries.

BENEFITS (cases, etc.): All countries			LOW	MID	HIGH	MTFR
Acute Mortality (All ages)	Premature deaths	O3	1,189	1,084	1,129	1,109
Respiratory Hospital Admissions (65yr +)	Cases	O3	1,192	1,098	1,139	1,120
Minor Restricted Activity Days (MRADs 15-64yr)	Days	O3	2,260,630	2,060,639	2,146,833	2,110,666
Respiratory medication use (adults 20yr +)	Days	O3	902,281	825,478	858,588	844,320
Chronic Mortality (All ages) LYL *	Life years lost	PM	185,945	189,497	187,295	184,628
Chronic Mortality (30yr +) deaths *	Premature deaths	PM	22,269	22,446	22,484	21,712
Infant Mortality (0-1yr)	Premature deaths	PM	30	29	30	29
Chronic Bronchitis (27yr +)	Cases	PM	9,741	9,713	9,762	9,572
Respiratory Hospital Admissions (All ages)	Cases	PM	3,499	3,494	3,505	3,460
Cardiac Hospital Admissions (All ages)	Cases	PM	2,158	2,155	2,162	2,134
Restricted Activity Days (RADs 15-64yr)	Days	PM	16,907,447	16,985,970	16,937,229	16,763,541
Respiratory medication use (children 5-14yr)	Days	PM	188,490	181,388	187,987	186,545
Respiratory medication use (adults 20yr +)	Days	PM	1,648,096	1,642,508	1,651,260	1,621,998
LRS symptom days (children 5-14yr)	Days	PM	8,690,923	8,784,385	8,712,597	8,785,146
LRS among adults (15yr +) with chronic symptoms	Days	PM	16,682,262	16,636,708	16,712,834	16,442,147

* life years lost and deaths from chronic exposure to $PM_{2.5}$ are alternate measures of the same effect

Table 3.7. Monetised equivalent of health impacts in 2030 due to air pollution, EU27, €million/year, 2005 prices.

DAMAGE, EU27		CLE	LOW	MID	HIGH	MTFR
Acute Mortality (All ages) median VOLY	O3	1,372	1,315	1,262	1,208	1,154
Acute Mortality (All ages) mean VOLY	O3	3,298	3,161	3,035	2,904	2,774
Respiratory Hospital Admissions (65yr +)	O3	56	54	52	49	47
Minor Restricted Activity Days (MRADs 15-64yr)	O3	1,938	1,858	1,785	1,709	1,633
Respiratory medication use (adults 20yr +)	O3	19	18	17	16	16
Chronic Mortality (All ages) LYL median VOLY	PM	146,863	136,780	126,689	116,617	106,476
Chronic Mortality (All ages) LYL mean VOLY	PM	353,032	328,793	304,537	280,325	255,949
Chronic Mortality (30yr +) deaths median VSL	PM	332,220	309,279	286,540	263,539	240,921
Chronic Mortality (30yr +) deaths mean VSL	PM	676,631	629,908	583,594	536,749	490,684
Infant Mortality (0-1yr) median VSL	PM	637	592	550	506	461
Infant Mortality (0-1yr) mean VSL	PM	1,298	1,206	1,121	1,030	938
Chronic Bronchitis (27yr +)	PM	27,994	26,063	24,162	22,239	20,323
Respiratory Hospital Admissions (All ages)	PM	108	100	93	85	78
Cardiac Hospital Admissions (All ages)	PM	66	62	57	53	48
Restricted Activity Days (RADs 15-64yr)	PM	21,464	19,988	18,526	17,058	15,579
Respiratory medication use (children 5-14yr)	PM	3	2	2	2	2
Respiratory medication use (adults 20yr +)	PM	23	21	20	18	17
LRS symptom days (children 5-14yr)	PM	5,097	4,751	4,405	4,060	3,705
LRS among adults (15yr +) with chronic symptoms	PM	9,685	9,018	8,361	7,697	7,033
Total, with median VOLY		215,987	201,235	186,552	171,842	157,049
Total, with mean VOLY		424,421	395,410	366,465	337,515	308,387
Total, with median VSL		400,262	372,717	345,445	317,870	290,663
Total, with mean VSL		745,755	694,363	643,457	591,974	541,257

Table 3.8. Monetised equivalent of health impacts in 2030 due to air pollution, all countries, €million/year, 2005 prices.

DAMAGE all countries		CLE	LOW	MID	HIGH	MTFR
Acute Mortality (All ages) median VOLY	O3	2,052	1,983	1,921	1,856	1,792
Acute Mortality (All ages) mean VOLY	O3	4,933	4,768	4,617	4,461	4,307
Respiratory Hospital Admissions (65yr +)	O3	74	71	69	66	64
Minor Restricted Activity Days (MRADs 15-64yr)	O3	2,794	2,699	2,612	2,522	2,434
Respiratory medication use (adults 20yr +)	O3	26	25	24	23	23
Chronic Mortality (All ages) LYL median VOLY	PM	246,893	236,164	225,230	214,423	203,770
Chronic Mortality (All ages) LYL mean VOLY	PM	593,484	567,694	541,410	515,432	489,824
Chronic Mortality (30yr +) deaths median VSL	PM	528,510	504,236	479,770	455,263	431,596
Chronic Mortality (30yr +) deaths mean VSL	PM	1,076,414	1,026,976	977,147	927,232	879,031
Infant Mortality (0-1yr) median VSL	PM	1,343	1,294	1,247	1,197	1,149
Infant Mortality (0-1yr) mean VSL	PM	2,734	2,635	2,539	2,439	2,341
Chronic Bronchitis (27yr +)	PM	40,822	38,796	36,775	34,745	32,754
Respiratory Hospital Admissions (All ages)	PM	158	151	143	135	128
Cardiac Hospital Admissions (All ages)	PM	98	93	88	83	79
Restricted Activity Days (RADs 15-64yr)	PM	32,585	31,030	29,467	27,909	26,367
Respiratory medication use (children 5-14yr)	PM	4	3	3	3	3
Respiratory medication use (adults 20yr +)	PM	33	32	30	28	27
LRS symptom days (children 5-14yr)	PM	7,740	7,375	7,006	6,640	6,271
LRS among adults (15yr +) with chronic symptoms	PM	14,230	13,529	12,831	12,129	11,438
Total, with median VOLY		350,243	334,585	318,738	303,002	287,488
Total, with mean VOLY		700,429	669,588	638,279	607,253	576,669
Total, with median VSL		629,838	600,708	571,397	542,031	513,573
Total, with mean VSL		1,179,764	1,125,397	1,070,655	1,015,811	962,749

Table 3.9 and Table 3.10 and show the benefits of each scenario relative to the baseline (top half of the table) and relative to the preceding scenario ('quasi-marginal' benefits, lower half of the table), for all affected countries and the EU27 respectively. Sensitivity to use of the median and mean estimates of the VOLY and VSL is shown. These results are compared with costs below.

Table 3.9. Benefits over baseline (top half of the table) and over the previous scenario ('quasi-marginal' benefits, lower half of the table) for the EU27 in 2030, €million/year, 2005 prices.

Benefits, EU27	LOW	MID	HIGH	MTFR
Benefits over baseline				
Total with median VOLY	14,751	29,435	44,145	58,938
Total with mean VOLY	29,011	57,956	86,906	116,034
Total with median VSL	27,544	54,817	82,392	109,599
Total with mean VSL	51,391	102,297	153,780	204,498
Quasi-marginal benefits				
Total with median VOLY	14,751	14,683	14,710	14,793
Total with mean VOLY	29,011	28,944	28,950	29,128
Total with median VSL	27,544	27,272	27,575	27,207
Total with mean VSL	51,391	50,906	51,483	50,718

Table 3.10. Benefits over baseline (top half of the table) and over the previous scenario ('quasi-marginal' benefits, lower half of the table) for all countries in 2030, €million/year, 2005 prices.

Benefits, all countries	LOW	MID	HIGH	MTFR
Benefits over baseline				
Total with median VOLY	15,658	31,504	47,241	62,755
Total with mean VOLY	30,841	62,150	93,176	123,760
Total with median VSL	29,130	58,441	87,808	116,266
Total with mean VSL	54,367	109,109	163,953	217,016
Quasi-marginal benefits				
Total with median VOLY	15,658	15,847	15,737	15,514
Total with mean VOLY	30,841	31,309	31,025	30,584
Total with median VSL	29,130	29,311	29,366	28,458
Total with mean VSL	54,367	54,742	54,844	53,062

The change in quasi-marginal benefits from scenario to scenario is almost identical. This is a consequence of the identical (25%) change in ambition level of successive scenarios. The difference in benefits between Table 3.9 and Table 3.10 is small (around 7%), indicating that most of the benefit from abatement in the EU27 is accrued by EU Member States.

3.2 National results

A summary of key health indicators is provided in Appendix 1, covering life years lost to chronic exposure to $PM_{2.5}$, deaths linked with short-term exposure to ozone, and work loss days (a subset of 'restricted activity days') associated with short-term $PM_{2.5}$ exposure. Appendix 2 provides aggregated health damage cost data by country.

4 Non-health benefits

4.1 Monetised non-health benefits

Simplified methods have been applied to quantify the change in damage to materials from acid deposition and crops from ozone exposure in 2030 under the policy scenarios, drawing on past €/tonne emission estimates of marginal damage to these receptors. This analysis is currently only possible for states in the EU27. Benefits above the TSAP 2012 baseline for the two receptors combined are shown in the following tables.

Table 4.1. Benefits to materials and crops compared to baseline, 2030, €M/year 2005 prices.

	LOW	MID	HIGH	MTFR
Austria	1.5	4.5	7.8	11.2
Belgium	5.9	10.4	17.0	18.9
Bulgaria	0.7	4.2	13.0	14.6
Cyprus				
Czech Rep.	7.0	12.5	17.5	21.6
Denmark	2.0	4.2	6.0	8.5
Estonia	0.6	0.9	1.4	1.6
Finland	0.6	1.5	2.8	3.8
France	28.1	61.2	98.3	130.1
Germany	29.9	64.0	102.7	133.9
Greece	1.7	14.3	23.2	32.3
Hungary	3.1	8.5	11.7	15.1
Ireland	2.5	4.2	6.0	7.8
Italy	16.2	38.0	67.9	84.3
Latvia	0.8	1.2	1.7	2.2
Lithuania	0.8	0.9	1.8	2.5
Luxembourg	0.1	0.3	0.8	1.6
Malta	0.1	0.1	0.2	0.3
Netherlands	2.0	8.8	12.8	13.9
Poland	9.9	36.1	51.4	62.3
Portugal	2.2	7.3	10.7	13.1
Romania	11.0	18.8	29.5	35.2
Slovakia	3.4	4.5	8.4	10.8
Slovenia	0.5	1.9	2.6	3.2
Spain	19.8	50.3	79.5	96.3
Sweden	0.8	2.7	3.7	5.3
United Kingdom	23.1	35.7	55.3	70.7
Total	**174.4**	**397.1**	**633.7**	**801.0**

Table 4.2. Quasi-marginal benefits to materials and crops (relative to previous scenario), €M/year.

	LOW	MID	HIGH	MTFR
Austria	1.5	3.0	3.3	3.5
Belgium	5.9	4.6	6.6	1.8
Bulgaria	0.7	3.5	8.9	1.5
Cyprus				
Czech Rep.	7.0	5.5	5.0	4.1
Denmark	2.0	2.2	1.8	2.5
Estonia	0.6	0.3	0.5	0.2
Finland	0.6	0.9	1.3	1.0
France	28.1	33.1	37.1	31.8
Germany	29.9	34.1	38.7	31.2
Greece	1.7	12.6	8.9	9.0
Hungary	3.1	5.4	3.2	3.4
Ireland	2.5	1.7	1.8	1.7
Italy	16.2	21.8	29.9	16.4
Latvia	0.8	0.4	0.5	0.6
Lithuania	0.8	0.1	0.9	0.6
Luxembourg	0.1	0.1	0.5	0.8
Malta	0.1	0.0	0.0	0.1
Netherlands	2.0	6.8	4.0	1.2
Poland	9.9	26.1	15.3	11.0
Portugal	2.2	5.1	3.4	2.4
Romania	11.0	7.8	10.7	5.7
Slovakia	3.4	1.2	3.9	2.4
Slovenia	0.5	1.5	0.7	0.6
Spain	19.8	30.6	29.2	16.7
Sweden	0.8	1.9	1.0	1.6
United Kingdom	23.1	12.6	19.6	15.4
Total	**174.4**	**222.8**	**236.6**	**167.2**

4.2 Other Benefits

In addition to the effects of the pollutants of interest here to crops and materials, there are also of course effects on ecosystems from eutrophication, ozone and acidification. These have not been monetised here.

5 Cost-benefit analysis

5.1 Cost data

Cost data generated by the GAINS Model and presented by Amann (2012b) have been used for the CBA. These data are also presented here, in Appendix 3, for reference.

5.2 Comparison of costs and health benefits

The CBA shown in Table 5.1, taking aggregate costs and benefits for the modelled domain and for the EU27, demonstrates net benefits for the policy scenarios in almost all cases. The few exceptions relate to the marginal assessment for the MTFR scenario. Whilst the marginal health benefits remain evenly spread across the scenarios, marginal abatement costs increase sharply approaching MTFR as the least cost-effective abatement options are introduced.

Table 5.1. Net health benefits of the policy scenarios for 2030, €M/year. Top half, EU27; lower half, all countries.

Net benefits, EU27	**LOW**	**MID**	**HIGH**	**MTFR**
Costs over baseline	**362**	**2,316**	**9,913**	**53,526**
Benefits over baseline				
Total with median VOLY	14,389	27,118	34,231	5,412
Total with mean VOLY	28,649	55,639	76,992	62,507
Total with median VSL	27,182	52,501	72,479	56,073
Total with mean VSL	51,029	99,981	143,867	150,972
Cost over preceding scenario	**362**	**1,954**	**7,597**	**43,613**
Quasi-marginal benefits				
Total with median VOLY	14,389	12,729	7,113	-28,820
Total with mean VOLY	28,649	26,990	21,353	-14,485
Total with median VSL	27,182	25,318	19,978	-16,406
Total with mean VSL	51,029	48,952	43,886	7,105

Net benefits, all countries	**LOW**	**MID**	**HIGH**	**MTFR**
Costs over baseline	**372**	**2,343**	**9,982**	**53,836**
Benefits over baseline				
Total with median VOLY	15,286	29,162	37,259	8,920
Total with mean VOLY	30,469	59,807	83,194	69,924
Total with median VSL	28,758	56,098	77,826	62,430
Total with mean VSL	53,995	106,766	153,971	163,180
Cost over preceding scenario	**372**	**1,971**	**7,639**	**43,854**
Quasi-marginal benefits				
Total with median VOLY	15,286	13,876	8,098	-28,340
Total with mean VOLY	30,469	29,338	23,386	-13,269
Total with median VSL	28,758	27,340	21,728	-15,396
Total with mean VSL	53,995	52,771	47,205	9,209

Table 5.2 provides an alternative way of comparing costs and benefits using benefit-cost ratios. A net cost is shown when this ratio falls below 1. Taking the author's preferred position (quasi-marginal benefits with mortality valued using the median VOLY) the benefit-cost ratio exceeds 40 for the LOW scenario and is equal to 8 and 2 for the MID and HIGH scenarios respectively, despite this being the most conservative case of those shown.

Table 5.2. Health benefit-cost ratios for the policy scenarios for 2030, €M/year. Top half, all countries, lower half, EU27.

Net benefits, EU27	LOW	MID	HIGH	MTFR
Benefits over baseline				
Total with median VOLY	41	13	4.5	1.1
Total with mean VOLY	80	25	8.8	2.2
Total with median VSL	76	24	8.3	2.0
Total with mean VSL	142	44	15.5	3.8
Quasi-marginal benefits				
Total with median VOLY	41	8	1.9	0.3
Total with mean VOLY	80	15	3.8	0.7
Total with median VSL	76	14	3.6	0.6
Total with mean VSL	142	26	6.8	1.2

Net benefits, all countries	LOW	MID	HIGH	MTFR
Benefits over baseline				
Total with median VOLY	42	13	4.7	1.2
Total with mean VOLY	83	27	9.3	2.3
Total with median VSL	78	25	8.8	2.2
Total with mean VSL	146	47	16.4	4.0
Quasi-marginal benefits				
Total with median VOLY	42	8	2.1	0.4
Total with mean VOLY	83	16	4.1	0.7
Total with median VSL	78	15	3.8	0.6
Total with mean VSL	146	28	7.2	1.2

6 Discussion

The analysis presented above demonstrates that consideration of health effects alone is sufficient for the benefits of the series of scenarios between the CLE and MTFR scenarios. The benefit-cost ratios of course decline from the LOW to the MID to the HIGH scenario, reflecting increasing marginal costs of abatement as targets become more ambitious, whilst marginal benefits remain roughly constant (at least across the range of scenarios considered).

Since the CAFE-CBA methodology was developed, reviewed and adopted in 2005 there have been developments in valuation of mortality, the effect that dominates health benefits. A meta-analysis performed by the OECD (2012) suggests an increase in the value of statistical life beyond the upper limit considered under CAFE, to $3.6 million (roughly €2.8 million). This would have no effect on the conclusions drawn from the analysis, given that the upper bound VSL used here is sufficient to generate a net benefit in all cases. Desaigues et al (2011) suggested a slightly lower VOLY than the lower bound adopted here (€40,000 vs €57,700). A sensitivity analysis reveals that this would have little real effect on the conclusions reached, being an insufficient change to generate net costs for any scenario where analysis using the lower bound VOLY adopted under CAFE indicates a net benefit.

As noted, the analysis presented here is focused on health effects. Inclusion of other effects (such as the impacts to materials and crops assessed in Chapter 4) is considered likely to strengthen the conclusions reached, though some trade-offs will be present (e.g. the effect of N deposition on carbon uptake by vegetation).

An extension to previous analysis addresses the cost of lost working days as a consequence of health impacts of pollutant exposure. Results are presented by country in Appendix 1. It is notable that the benefits estimated for this single effect are almost sufficient to account for the costs of the LOW policy scenario, despite a somewhat conservative position having been adopted for valuation of this impact. This suggests that whilst much of the cost associated with air quality improvement may fall on businesses, businesses generally may be expected to yield some benefits.

7 References

To be completed

Amann, M. (2012a)

Amann, M. (2012b)

Desaigues et al (2011)

Holland, M. (1999)

Holland, M. and King, K. (1999)

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OECD (2012)

Appendix 1: Key health indicators by country, 2030

Results are shown in this appendix by country for life years lost to $PM_{2.5}$ exposure, deaths linked to short term ozone exposure and lost work days linked to short term ozone exposure.

$PM_{2.5}$ Life Years Lost		CLE	LOW	MID	HIGH	MTFR
Albania	Non-EU	14,996	14,814	14,570	14,224	14,027
Austria	EU27	35,390	33,515	31,126	28,426	26,304
Belarus	Non-EU	59,410	58,588	57,141	56,076	55,254
Belgium	EU27	73,434	68,564	64,189	58,584	55,108
Bosnia & Herzegovina	Non-EU	15,283	14,895	14,432	13,973	13,727
Bulgaria	EU27	43,807	40,862	39,714	35,295	32,588
Croatia	EU28	20,267	18,895	17,479	16,139	15,252
Cyprus	EU27	8,024	7,985	7,949	7,881	7,772
Czech Republic	EU27	64,109	58,942	53,203	49,242	45,128
Denmark	EU27	21,445	20,360	18,725	17,581	15,692
Estonia	EU27	4,577	4,453	4,260	4,124	3,870
Finland	EU27	14,065	13,863	13,404	13,057	11,873
France	EU27	315,523	291,463	274,690	253,483	217,315
TFYR Macedonia	Non-EU	9,113	8,916	8,731	8,427	8,255
Germany	EU27	398,983	369,557	344,910	312,860	292,525
Greece	EU27	69,455	67,065	61,617	58,114	53,413
Hungary	EU27	64,006	59,774	53,460	49,075	45,929
Ireland	EU27	10,958	10,659	10,221	9,737	9,336
Italy	EU27	334,042	308,997	285,935	262,802	243,740
Latvia	EU27	9,535	9,219	8,743	8,238	7,354
Lithuania	EU27	15,946	15,238	14,610	13,635	12,856
Luxembourg	EU27	3,252	3,029	2,851	2,614	2,428
Malta	EU27	1,758	1,727	1,684	1,625	1,585
Netherlands	EU27	90,672	84,882	79,682	74,054	70,055
Norway	Non-EU	9,815	9,733	9,634	9,535	9,462
Poland	EU27	299,633	284,744	247,779	231,267	203,422
Portugal	EU27	48,643	42,358	39,988	33,721	29,851
Moldova	Non-EU	23,563	22,876	22,318	21,779	21,382
Romania	EU27	144,467	129,670	121,566	108,975	94,811
Russian Federation	Non-EU	1,112,785	1,111,589	1,108,957	1,107,163	1,105,608
Serbia & Montenegro	Non-EU	56,907	55,303	53,648	51,839	50,868
Slovakia	EU27	33,186	31,102	28,627	25,972	24,452
Slovenia	EU27	9,783	9,194	8,133	7,408	7,029
Spain	EU27	190,609	176,643	164,688	153,347	139,214
Sweden	EU27	23,402	22,740	22,095	21,362	20,593
Switzerland	Non-EU	32,674	31,599	30,656	29,367	28,492
Turkey	Non-EU	0	0	0	0	0
Ukraine	Non-EU	378,799	375,219	370,243	366,555	363,870
United Kingdom	EU27	216,589	203,929	191,805	178,608	171,102
EU27		2,545,293	2,370,534	2,195,653	2,021,090	1,845,343
EU28		2,565,560	2,389,430	2,213,132	2,037,229	1,860,595
Non-EU		1,713,345	1,703,530	1,690,330	1,678,938	1,670,943
Total		**4,278,904**	**4,092,960**	**3,903,462**	**3,716,167**	**3,531,539**

Ozone deaths		**CLE**	**LOW**	**MID**	**HIGH**	**MTFR**
Albania	Non-EU	177	172	167	162	158
Austria	EU27	426	407	387	368	349
Belarus	Non-EU	353	345	337	329	321
Belgium	EU27	369	352	337	320	305
Bosnia & Herzegovina	Non-EU	222	212	205	196	188
Bulgaria	EU27	537	518	498	479	461
Croatia	EU28	267	250	238	224	212
Cyprus	EU27	76	75	73	72	70
Czech Republic	EU27	502	477	453	431	409
Denmark	EU27	168	161	156	150	144
Estonia	EU27	31	30	29	28	27
Finland	EU27	102	99	97	94	91
France	EU27	2,402	2,306	2,209	2,113	2,016
TFYR Macedonia	Non-EU	137	134	130	126	123
Germany	EU27	3,696	3,530	3,382	3,225	3,076
Greece	EU27	883	857	831	804	778
Hungary	EU27	577	546	521	493	466
Ireland	EU27	125	123	120	117	115
Italy	EU27	5,318	5,083	4,848	4,613	4,378
Latvia	EU27	65	63	61	59	57
Lithuania	EU27	105	102	99	96	92
Luxembourg	EU27	17	16	16	15	14
Malta	EU27	31	30	29	28	27
Netherlands	EU27	530	506	486	463	442
Norway	Non-EU	102	100	98	96	94
Poland	EU27	1,544	1,480	1,411	1,349	1,285
Portugal	EU27	620	601	581	562	542
Moldova	Non-EU	187	182	179	174	170
Romania	EU27	1,200	1,137	1,100	1,048	1,001
Russian Federation	Non-EU	6,617	6,557	6,500	6,442	6,385
Serbia & Montenegro	Non-EU	601	578	559	539	519
Slovakia	EU27	263	249	237	225	212
Slovenia	EU27	125	118	112	105	99
Spain	EU27	2,247	2,173	2,099	2,025	1,951
Sweden	EU27	220	213	206	200	193
Switzerland	Non-EU	399	384	370	355	341
Turkey	Non-EU	0	0	0	0	0
Ukraine	Non-EU	2,722	2,672	2,630	2,584	2,539
United Kingdom	EU27	1,598	1,536	1,500	1,452	1,403
EU27		23,778	22,788	21,879	20,934	20,003
EU28		24,046	23,038	22,116	21,158	20,215
Non-EU		11,518	11,337	11,175	11,004	10,838
Total		**35,564**	**34,125**	**33,053**	**31,938**	**30,841**

Lost working days		CLE	LOW	MID	HIGH	MTFR
Albania	Non-EU	319,353	315,480	310,285	302,902	298,710
Austria	EU27	782,328	740,888	688,077	628,377	581,470
Belarus	Non-EU	971,481	958,033	934,380	916,970	903,522
Belgium	EU27	1,506,887	1,406,939	1,317,182	1,202,159	1,130,828
Bosnia & Herzegovina	Non-EU	292,963	285,531	276,651	267,863	263,143
Bulgaria	EU27	752,213	701,651	681,937	606,053	559,571
Croatia	EU28	390,135	363,736	336,479	310,670	293,607
Cyprus	EU27	186,169	185,267	184,438	182,868	180,325
Czech Republic	EU27	1,304,408	1,199,278	1,082,514	1,001,929	918,222
Denmark	EU27	428,643	406,968	374,273	351,423	313,657
Estonia	EU27	82,739	80,494	77,010	74,564	69,957
Finland	EU27	281,376	277,327	268,151	261,200	237,516
France	EU27	6,889,454	6,364,094	5,997,858	5,534,800	4,745,077
TFYR Macedonia	Non-EU	177,877	174,026	170,431	164,497	161,131
Germany	EU27	8,146,376	7,545,563	7,042,334	6,387,945	5,972,734
Greece	EU27	1,487,233	1,436,069	1,319,402	1,244,392	1,143,724
Hungary	EU27	1,181,275	1,103,165	986,644	905,708	847,640
Ireland	EU27	250,217	243,386	233,386	222,329	213,174
Italy	EU27	7,294,277	6,747,377	6,243,773	5,738,651	5,322,399
Latvia	EU27	167,974	162,403	154,019	145,122	129,544
Lithuania	EU27	267,239	255,384	244,852	228,512	215,457
Luxembourg	EU27	74,851	69,724	65,619	60,177	55,885
Malta	EU27	37,609	36,953	36,029	34,761	33,910
Netherlands	EU27	1,902,001	1,780,538	1,671,456	1,553,408	1,469,515
Norway	Non-EU	216,384	214,558	212,380	210,203	208,588
Poland	EU27	5,715,920	5,431,893	4,726,740	4,411,755	3,880,556
Portugal	EU27	1,027,099	894,384	844,331	712,018	630,296
Moldova	Non-EU	380,107	369,028	360,026	351,327	344,922
Romania	EU27	2,741,465	2,460,675	2,306,883	2,067,961	1,799,173
Russian Federation	Non-EU	17,094,562	17,076,186	17,035,761	17,008,198	16,984,310
Serbia & Montenegro	Non-EU	1,069,043	1,038,917	1,007,824	973,830	955,588
Slovakia	EU27	649,276	608,515	560,078	508,139	478,406
Slovenia	EU27	202,169	189,997	168,060	153,086	145,259
Spain	EU27	4,465,594	4,138,396	3,858,315	3,592,631	3,261,507
Sweden	EU27	508,120	493,738	479,742	463,819	447,125
Switzerland	Non-EU	744,666	720,151	698,675	669,298	649,341
Turkey	Non-EU	0	0	0	0	0
Ukraine	Non-EU	5,780,566	5,725,934	5,649,996	5,593,726	5,552,752
United Kingdom	EU27	4,621,544	4,351,397	4,092,689	3,811,102	3,650,949
EU27		52,954,457	49,312,467	45,705,791	42,084,889	38,433,876
EU28		53,344,592	49,676,203	46,042,269	42,395,559	38,727,483
Non-EU		27,047,000	26,877,843	26,656,408	26,458,813	26,322,006
Total		**80,391,591**	**76,190,310**	**72,362,199**	**68,543,702**	**64,755,882**

Cost of lost working days, €M		CLE	LOW	MID	HIGH	MTFR
Albania	Non-EU	31	31	30	30	29
Austria	EU27	76	72	67	61	57
Belarus	Non-EU	95	94	91	90	88
Belgium	EU27	147	137	129	117	110
Bosnia & Herzegovina	Non-EU	29	28	27	26	26
Bulgaria	EU27	73	69	67	59	55
Croatia	EU28	38	36	33	30	29
Cyprus	EU27	18	18	18	18	18
Czech Republic	EU27	127	117	106	98	90
Denmark	EU27	42	40	37	34	31
Estonia	EU27	8	8	8	7	7
Finland	EU27	27	27	26	26	23
France	EU27	673	622	586	541	463
TFYR Macedonia	Non-EU	17	17	17	16	16
Germany	EU27	796	737	688	624	583
Greece	EU27	145	140	129	122	112
Hungary	EU27	115	108	96	88	83
Ireland	EU27	24	24	23	22	21
Italy	EU27	713	659	610	561	520
Latvia	EU27	16	16	15	14	13
Lithuania	EU27	26	25	24	22	21
Luxembourg	EU27	7	7	6	6	5
Malta	EU27	4	4	4	3	3
Netherlands	EU27	186	174	163	152	144
Norway	Non-EU	21	21	21	21	20
Poland	EU27	558	531	462	431	379
Portugal	EU27	100	87	82	70	62
Moldova	Non-EU	37	36	35	34	34
Romania	EU27	268	240	225	202	176
Russian Federation	Non-EU	1,670	1,668	1,664	1,661	1,659
Serbia & Montenegro	Non-EU	104	101	98	95	93
Slovakia	EU27	63	59	55	50	47
Slovenia	EU27	20	19	16	15	14
Spain	EU27	436	404	377	351	319
Sweden	EU27	50	48	47	45	44
Switzerland	Non-EU	73	70	68	65	63
Turkey	Non-EU	0	0	0	0	0
Ukraine	Non-EU	565	559	552	546	542
United Kingdom	EU27	451	425	400	372	357
EU27		5,173	4,817	4,465	4,111	3,754
EU28		5,211	4,852	4,497	4,141	3,783
Non-EU		2,642	2,625	2,604	2,584	2,571
Total		**7,853**	**7,442**	**7,068**	**6,695**	**6,325**

Appendix 2: Total national damage

Mortality valued with median VOLY, €million	CLE	LOW	MID	HIGH	MTFR
Albania	1,285	1,269	1,247	1,217	1,200
Austria	3,070	2,908	2,702	2,470	2,287
Belarus	4,596	4,532	4,420	4,338	4,274
Belgium	6,165	5,757	5,391	4,922	4,631
Bosnia & Herzegovina	1,263	1,230	1,192	1,154	1,133
Bulgaria	3,514	3,280	3,187	2,837	2,622
Croatia	1,682	1,568	1,451	1,341	1,267
Cyprus	691	688	684	678	669
Czech Republic	5,329	4,901	4,427	4,100	3,759
Denmark	1,795	1,705	1,569	1,474	1,317
Estonia	369	359	343	332	312
Finland	1,185	1,168	1,129	1,100	1,001
France	27,177	25,118	23,678	21,861	18,774
Germany	34,115	31,613	29,516	26,794	25,060
Greece	5,965	5,761	5,299	5,001	4,602
Hungary	5,178	4,836	4,330	3,977	3,722
Ireland	943	917	880	839	805
Italy	29,278	27,106	25,102	23,093	21,432
Latvia	761	735	698	657	587
Lithuania	1,258	1,202	1,153	1,076	1,015
Luxembourg	278	259	244	224	208
Malta	153	150	147	142	138
Moldova	1,836	1,783	1,739	1,697	1,666
Netherlands	7,681	7,192	6,753	6,278	5,939
Norway	846	839	830	821	815
Poland	24,390	23,179	20,187	18,847	16,591
Portugal	4,161	3,632	3,430	2,903	2,576
Romania	11,790	10,591	9,934	8,913	7,767
Russian Federation	85,399	85,300	85,093	84,949	84,823
Serbia & Montenegro	4,606	4,475	4,341	4,194	4,115
Slovakia	2,722	2,551	2,349	2,133	2,008
Slovenia	832	782	692	631	599
Spain	16,781	15,566	14,524	13,535	12,306
Sweden	2,013	1,956	1,900	1,837	1,771
Switzerland	2,874	2,780	2,696	2,583	2,505
TFYR Macedonia	758	742	726	701	687
Turkey	0	0	0	0	0
Ukraine	29,112	28,833	28,450	28,164	27,955
United Kingdom	18,393	17,323	16,302	15,189	14,552
EU27 total	215,987	201,235	186,552	171,842	157,049
EU28 total	217,668	202,803	188,003	173,183	158,316
Non-EU total	132,575	131,782	130,735	129,819	129,172
Overall total	**350,243**	**334,585**	**318,738**	**303,002**	**287,488**

Mortality valued with mean VSL, €million	**CLE**	**LOW**	**MID**	**HIGH**	**MTFR**
Albania	3,116	3,078	3,027	2,955	2,913
Austria	10,413	9,862	9,160	8,367	7,744
Belarus	15,152	14,942	14,573	14,302	14,091
Belgium	20,772	19,395	18,159	16,575	15,592
Bosnia & Herzegovina	4,358	4,247	4,115	3,984	3,913
Bulgaria	13,540	12,632	12,277	10,915	10,080
Croatia	6,172	5,754	5,324	4,916	4,646
Cyprus	1,795	1,786	1,778	1,763	1,738
Czech Republic	18,102	16,645	15,028	13,911	12,750
Denmark	6,005	5,701	5,244	4,925	4,397
Estonia	1,281	1,246	1,192	1,154	1,083
Finland	4,206	4,145	4,008	3,904	3,551
France	85,835	79,303	74,745	68,986	59,174
Germany	134,688	124,768	116,458	105,657	98,797
Greece	20,594	19,886	18,277	17,241	15,852
Hungary	18,289	17,081	15,281	14,030	13,131
Ireland	3,440	3,346	3,209	3,057	2,932
Italy	109,635	101,437	93,886	86,312	80,065
Latvia	2,714	2,624	2,488	2,345	2,094
Lithuania	4,266	4,077	3,909	3,649	3,440
Luxembourg	715	666	627	575	534
Malta	515	506	493	476	464
Moldova	5,732	5,565	5,430	5,299	5,202
Netherlands	25,816	24,169	22,690	21,089	19,951
Norway	2,444	2,424	2,399	2,374	2,356
Poland	81,286	77,249	67,238	62,762	55,219
Portugal	15,150	13,201	12,464	10,521	9,319
Romania	39,098	35,102	32,913	29,513	25,689
Russian Federation	271,730	271,431	270,783	270,338	269,952
Serbia & Montenegro	14,688	14,273	13,846	13,378	13,126
Slovakia	8,450	7,920	7,291	6,616	6,229
Slovenia	2,952	2,774	2,455	2,236	2,122
Spain	52,885	49,024	45,718	42,581	38,675
Sweden	6,613	6,426	6,244	6,036	5,819
Switzerland	9,383	9,074	8,803	8,433	8,181
TFYR Macedonia	2,253	2,204	2,159	2,084	2,041
Turkey	0	0	0	0	0
Ukraine	98,980	98,042	96,741	95,775	95,070
United Kingdom	56,701	53,392	50,226	46,779	44,815
EU27 total	745,755	694,363	643,457	591,974	541,257
EU28 total	751,927	700,118	648,781	596,890	545,903
Non-EU total	427,838	425,280	421,874	418,921	416,846
Overall total	**1,179,764**	**1,125,397**	**1,070,655**	**1,015,811**	**962,749**

Appendix 3: Policy scenario cost data for 2030 from GAINS (Amann, 2012b)

Country	CLE	LOW	MID	HIGH	MTFR
Albania	145	145	145	145	145
Austria	1,779	1,785	1,819	1,952	2,812
Belarus	495	495	495	495	495
Belgium	2,695	2,703	2,754	3,025	3,843
Bosnia & Herzegovina	213	213	213	213	213
Bulgaria	1,156	1,159	1,174	1,247	1,953
Croatia	474	484	501	542	783
Cyprus	266	267	268	273	349
Czech Republic	2,245	2,256	2,319	2,456	3,404
Denmark	1,256	1,259	1,292	1,352	2,304
Estonia	366	368	376	416	608
Finland	1,165	1,168	1,190	1,291	2,311
France	12,798	12,832	13,099	14,359	21,358
TFYR Macedoonia	123	123	123	123	123
Germany	15,162	15,203	15,473	16,870	22,361
Greece	2,624	2,627	2,664	2,785	3,849
Hungary	1,266	1,271	1,318	1,406	2,036
Ireland	847	853	870	951	1,330
Italy	10,713	10,793	11,056	12,065	15,486
Latvia	422	424	435	460	1,066
Lithuania	515	520	530	597	1,103
Luxembourg	218	218	219	229	275
Malta	100	100	100	101	134
Netherlands	3,419	3,422	3,484	3,683	4,638
Norway	1,501	1,501	1,501	1,501	1,501
Poland	9,211	9,254	9,541	10,016	15,594
Portugal	1,672	1,678	1,707	1,817	2,805
Moldova	96	96	96	96	96
Romania	2,683	2,703	2,749	2,970	5,594
Russian Federation	9,098	9,098	9,098	9,098	9,098
Serbia & Montenegro	733	733	733	733	733
Slovakia	776	785	792	863	1,368
Slovenia	515	516	537	570	693
Spain	10,264	10,294	10,461	11,171	15,780
Sweden	1,511	1,513	1,537	1,598	2,169
Switzerland	1,393	1,393	1,393	1,393	1,393
Turkey	7,254	7,254	7,254	7,254	7,254
Ukraine	2,249	2,249	2,249	2,249	2,249
United Kingdom	8,343	8,378	8,539	9,380	12,290
Total EU27	93,988	94,350	96,304	103,901	147,514
Total EU28	94,462	94,834	96,805	104,444	148,297
Total non-EU	23,301	23,301	23,301	23,301	23,301
Overall total	**117,763**	**118,135**	**120,106**	**127,745**	**171,599**

Appendix 4: CBA by country (to be added)