COSTS, BENEFITS AND ECONOMIC IMPACTS OF THE EU CLEAN AIR STRATEGY AND THEIR IMPLICATIONS ON INNOVATION AND COMPETITIVENESS

December 20, 2017

Editor: Markus Amann
International Institute for Applied Systems Analysis (IIASA)

International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

Abstract

Reducing air pollution has a number of benefits to society, improving health of the population and reducing damage to crops, forests, ecology and building and other materials. Quantification of the benefits of the revised emission ceilings indicates that they will exceed costs by a large margin. Taking a conservative position on the valuation of mortality leads to benefits:cost ratios in excess of 14, taking a less conservative position pushes the ratio above 50. Even this position is based on valuations that are low when compared to those recommended elsewhere.

The authors

This report has been produced by

Markus Amann[1)]
Mike Holland [2)]
Rob Maas [3)]
Bert Saveyn[4)]
Toon Vandyck[4)]

Affiliations:

[1)] International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

[2)] EMRC, UK

[3)] National Institute for Public Health and the Environment (RIVM), The Netherlands

[4)]Joint Research Centre (JRC) of the European Commission, Seville, Spain

How to cite this report: Amann, M., Holland, M., Maas, R., Vandyck, T. and B. Saveyn (2017). Costs, benefits and economic impacts of the EU Clean Air Strategy and their implications on innovation and competitiveness. IIASA report. (http://gains.iiasa.ac.at)

Acknowledgements

This report was produced under Specific Agreement 11 under Framework Contract ENV.C.3/FRA/2013/00131 of DG-Environment of the European Commission.

Disclaimer

Executive Summary

Reducing air pollution has a number of benefits to society, improving health of the population and reducing damage to crops, forests, ecology and building and other materials.

The policy discussions on the revised Directive on National Emission Ceilings (NECD, 2016/2284/EU) were informed by systematic cost-effectiveness and cost-benefit analyses conducted around 2013 with the GAINS integrated assessment and ALPHA-Riskpoll benefits models. Since the time these analyses have been conducted, a number of important factors have changed. Complementing the 2017 outlook into future air quality in Europe (Amann M. et al. 2017), this report presents a re-assessment of the costs, benefits and economic impacts of the latest clean air strategies and their implications on innovation and competitiveness.

In addition to updates of the standard quantification of premature mortality and morbidity and their economic valuation, this report addresses work days lost due to the exposure to air pollution in more detail as it constitutes a potentially important element of a cost-benefits analysis. For the recent emission scenarios, it is estimated that working days lost due to air pollution decline from 0.63 per worker on average to 0.3 under the policy scenarios. For the EU28, costs associated with lost working days fall from €18.5 billion/year in 2005 to €8.5 billion/year by 2030 under the policy scenarios.

Quantification of the benefits of the revised emission ceilings indicates that they will exceed costs by a large margin. Taking a conservative position on the valuation of mortality leads to benefits:cost ratios in excess of 14, taking a less conservative position pushes the ratio above 50. Even this position is based on valuations that are low when compared to those recommended elsewhere.

Case studies demonstrate that there are clear winners from stricter environmental policy regulation. A strong domestic market – due to domestic environmental and energy policies – emerged as an important success factor in all cases. In this context it is surprising that enterprises that produce clean technology seem less involved in stakeholder consultations than the enterprises that have a vested interest and are required to take additional abatement measures (or are at least less vocal in the public debate).

List of acronyms

ALPHA-Riskpoll	Model to estimate monetized benefits of air pollution control strategies
CAPRI	Agricultural model developed by the University of Bonn
CBA	Cost-Benefits Analysis
EC4MACS	European Consortium for Modelling Air Pollution and Climate Strategies
EEA	European Environment Agency
ERR	Emission Reduction Requirements of the NEC Directive
EU	European Union
GAINS	Greenhouse gas - Air pollution Interactions and Synergies model
GDP	Gross domestic product
GEM-E3	General Equilibrium Model for Economy – Energy - Environment
IIASA	International Institute for Applied Systems Analysis
JRC	Joint Research Centre for the EU
kt	kilotons = 10^3 tons
NEC	National Emission Ceilings (Directive)
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O_3	Ozone
PJ	Petajoule = 10^{15} joule
PM10	Fine particles with an aerodynamic diameter of less than 10 µm
PM2.5	Fine particles with an aerodynamic diameter of less than 2.5 µm
PRIMES	Energy Systems Model of the National Technical University of Athens
SO_2	Sulphur dioxide
SOMOxx	An ozone metric relevant for human health: Sum of means over xx ppb (daily maximum 8-hour concentrations)
TSAP	Thematic Strategy on Air Pollution
VOLY	Value of life year
VSL	Value of statistical life

Contents

Costs, benefits and economic impacts of the EU clean air strategies and their implications on innovation and competitiveness

1 Context

In its Clean Air Programme for Europe (COM(2013)918 final), the European Commission has laid out a comprehensive approach to improve air quality in Europe. It contains provisions for a regular tracking of the progress towards the programme objectives by 2020 and every five years thereafter.

The main legislative instrument to achieve the 2030 objectives of the Clean Air Programme is Directive 2016/2284/EU on the reduction of national emissions of certain atmospheric pollutants, which entered into force on 31 December 2016 (the NEC Directive or NECD). This directive sets national reduction commitments for the five pollutants (sulphur dioxide, nitrogen oxides, volatile organic compounds, ammonia and fine particulate matter) responsible for particulate matter and NO_2 concentrations and for acidification, eutrophication and ground-level ozone pollution, which leads to significant negative impacts on human health and the environment. The Commission proposal for the revised NECD, which was adopted by the European Commission on December 18, 2013, was informed by extensive cost-effectiveness and cost-benefits analyses with IIASA's GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model (Amann et al. 2011) and cost-benefit analysis undertaking the ALPHA-Riskpoll model (Holland, 2013b). After that, additional technical analyses were conducted with the GAINS model to support negotiations in the Council and the European Parliament (Amann et al. 2014a); (Amann et al. 2014b) (Amann, M. et al. 2015).

In this context, this report presents a re-assessment of the costs, benefits and economic impacts of the latest clean air strategies and their implications on innovation and competitiveness. This report complements the Commission's Clean Air Outlook into the future of air quality in Europe as expected from the implementation of the revised NEC directive and other recent source-oriented emission legislation, and the more detailed underlying report 'Progress towards achievement of the EU's air quality and emissions objectives' (Amann M. et al. 2017). In particular, the Outlook takes into account retrospective changes of emission inventories for 2005 and their knock-on effects for later years, new projections of economic activities, and new source-oriented emission regulations that have been agreed after 2013.

This report examines the economic impacts for the following emission control scenarios for 2030:

- For the PRIMES 2016 REFERENCE scenario, emissions resulting from
    - the legislation in place in 2017,
    - the additional measures that would meet the Emission Reduction Requirements of the NEC directive at least costs (the ERR 2030 scenario); and
- For the PRIMES CLIMATE AND ENERGY POLICY scenario, emissions resulting from
    - the legislation in place in 2017,

- the additional measures that would meet the Emission Reduction Requirements of the NEC directive at least costs (the ERR 2030 scenario).

The analysis presented here is focused primarily on the assessment of health impacts across Europe in 2005 and 2030 for the scenarios listed above. Past work (e.g. Holland et al, 2011, 2014) 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. The analysis is extended here to include effects on building materials in some applications (though excluding cultural heritage), forests, crops and ecosystems. It also provides additional detail on issues such as productivity losses and healthcare costs. Analysis of forests and ecosystems was not included in earlier CBA reports on air quality proposals for the Commission, with the methods used here having been developed under the ECLAIRE study funded by European Commission DG Research[1]. It is noted that the ecosystem analysis should be considered preliminary at the present time, as quantification is based on a very limited set of valuation data. This and other emerging methodological details are also discussed in the report.

Macro-economic impacts of the emission control scenarios are also presented in Section 4.2 , based on results of the JRC-GEM-E3 model operated by the Joint Research Centre (JRC) of the EU.

The remainder of the report is organized as follows: Section 2 summarizes emission control costs for the scenarios for 2030 as estimated in the report 'Progress towards achievement of the EU's air quality and emissions objectives' (Amann et al., 2017). Section 3 discusses the benefits that can be computed for these emission control scenarios, for human health, productivity and non-health related damages. Section 4 compares costs and benefits. Section 5 discusses implications on competitiveness, and conclusions are drawn in Section 6.

Methodological details and results for individual Member States are documented in a supporting report, and are available in an Excel workbook that accompanies this report.

[1] http://www.eclaire-fp7.eu/

2 Emission control costs

The European Union has established a comprehensive framework to manage air quality, including ambient air quality limit values, source-oriented emission legislation, and national emission ceilings. Assuming the PRIMES 2016 REFERENCE scenario in 2030, it is estimated that costs for implementation of all source-oriented legislation in force (as of 2017) will amount to € 79.2 bn/year in the EU-28, which constitutes about 0.53% of GDP or 153.8 €/person/year (Table 1). Compliance with the Emission Reduction Requirements (ERR) of the NECD Directive (REF) will increase these costs by € 0.95 bn/year, i.e., by 0,006% of GDP or € 1.86/person/year. The lower consumption of fossil fuels in the CLIMATE AND ENERGY POLICY scenario would reduce air pollution control costs for implementation of the current legislation to € 71 bn/year. Additional measures required to meet the ERRs would increase costs by € 0.54 bn/yr, i.e., 0.004% of GDP or by € 1.05/person/year (for details see (Amann et al. 2017)).

TABLE 1: AIR POLLUTION CONTROL COSTS IN 2030

	PRIMES 2016 REFERENCE			CLIMATE AND ENERGY POLICY		
	2017 legislation	ERR 2030	Additional costs	2017 legislation	ERR 2030	Additional costs
million €/year	79220	80180	960	71001	71540	539
% of GDP	0.527%	0.533%	0.006%	0.472%	0.476%	0.004%
€/capita	153.75	155.61	1.86	137.80	138.84	1.05

Air pollution control costs are unevenly distributed across the economic sectors (Table 2). More than 50% of total costs emerge for emission controls for road vehicles, while the power sector, industry and non-road mobile machinery carry about 13% of total costs each. In contrast, the share of agriculture in total costs is about 3%. However, 40% of the costs of all additional measures that are required to achieve the ERRs occur in agriculture, indicating the cost-effectiveness of additional emission reductions in this sector compared to the much higher costs of the remaining measures in other sectors. Note that the higher percentage of additional costs for agriculture in this analysis as compared with the original Commission proposal is largely due to the fact that additional costs for regulating domestic combustion under the NECD are lower than then assumed, because much of the costs are subsumed under the Ecodesign implementing acts for solid fuel stoves and boilers. The distribution of costs across Member States is presented in Table 3.

TABLE 2: AIR POLLUTION CONTROL COSTS IN 2030, BY SECTOR (MILLION €/YR)

	PRIMES 2016 REFERENCE			CLIMATE AND ENERGY POLICY		
	2017 legislation	ERR 2030	Additional costs	2017 legislation	ERR 2030	Additional costs
Power sector	10257	10488	231	8752	8778	26
Domestic	4171	4228	57	3122	3154	32
Industry	10187	10468	281	10034	10141	107
Road transport	43180	43180	0	38602	38602	0
Non-road mobile machinery	9370	9377	6	8434	8439	5
Agriculture	2120	2505	385	2120	2488	369
Total	**79285**	**80246**	**960**	**71063**	**71602**	**539**
Power sector	13%	13%	24%	12%	12%	5%
Domestic	5%	5%	6%	4%	4%	6%
Industry	13%	13%	29%	14%	14%	20%
Road transport	54%	54%	0%	54%	54%	0%
Non-road mobile machinery	12%	12%	1%	12%	12%	1%
Agriculture	3%	3%	40%	3%	3%	68%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 3: Emission control costs for the 2017 legislation scenario and the cost-effective achievement of the emission reduction requirements in 2030 (ERR 2030), for the PRIMES 2016 REFERENCE and the CLIMATE AND ENERGY POLICY projections (million €/year)

	PRIMES 2016 REFERENCE			CLIMATE AND ENERGY POLICY		
	2017 legislation	ERR 2030	Additional costs	2017 legislation	ERR 2030	Additional costs
Austria	1725	1730	5	1584	1589	5
Belgium	2365	2379	14	2133	2143	10
Bulgaria	1000	1004	3	905	908	3
Croatia	461	472	11	438	448	10
Cyprus	120	120	0	111	111	0
Czech Rep.	2114	2137	23	2008	2020	12
Denmark	1235	1236	1	1112	1113	0
Estonia	288	293	5	217	220	3
Finland	1214	1218	3	1105	1107	2
France	9924	9997	72	9055	9070	14
Germany	14218	14747	529	12402	12646	244
Greece	1463	1466	3	1338	1338	0
Hungary	939	948	10	868	874	6
Ireland	960	1000	40	877	915	38
Italy	8226	8267	41	7356	7382	26
Latvia	223	224	0	196	197	0
Lithuania	428	429	1	400	401	1
Luxembourg	296	298	2	258	259	1
Malta	41	41	0	39	39	0
Netherlands	3253	3329	76	3121	3185	64
Poland	9131	9181	50	7977	8016	39
Portugal	1155	1161	7	1061	1066	4
Romania	1833	1842	9	1737	1745	7
Slovakia	731	735	3	697	699	3
Slovenia	428	430	1	383	384	0
Spain	6794	6805	12	5935	5946	10
Sweden	1395	1396	1	1203	1204	1
UK	7257	7294	37	6482	6519	37
EU-28	79220	80180	960	71001	71540	539

3 Benefits

While environmental measures entail certain pollution control costs, they are motivated by the interests of improved well-being, reduced damage to human health, and a cleaner environment to safeguard the sustainability of ecosystems and their services. Although monetary valuations of these aspects are challenging, a host of valuation studies show that the economic benefits of many air pollution control measures substantially exceed their costs (e.g., Holland, 2014). In such cost-benefit studies a broad definition of 'welfare' is applied, including elements that are not included in the formal definition of gross domestic production (GDP), such as changes in public health (premature death, pain and suffering) and the loss of natural capital. Past work (e.g., Holland et al, 2011, 2013a, 2014) 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.

This report presents a re-analysis of earlier valuation studies on the benefits of clean air strategies in Europe, for the most recent projections of economic development, emissions and air quality that are presented in the progress report (Amann et al. 2017). The analysis is extended here to include effects on building materials in some applications (though excluding cultural heritage), forests, crops and ecosystems. It also provides additional detail on issues such as productivity losses and healthcare costs. Analysis of forests and ecosystems was not included in earlier CBA reports on air quality proposals for the Commission, with the methods used here having been developed under the ECLAIRE study funded by European Commission DG Research. It is noted that the ecosystem analysis should be considered preliminary at the present time, as quantification is based on a very limited set of valuation data. This and other emerging methodological details are also discussed in the report.

Some damage categories are included in traditional GDP figures, although they would not account for more than five percent of the total damage estimate including mortality and morbidity impacts (Amann et al. 2013):

- Damage to materials (iron, plastic) and cultural heritage: additional maintenance efforts are both an economic cost and expenditure in the construction sector.
- Damage to crops and forests: production losses generally lead to higher prices and additional management efforts (e.g., liming, pest control). The latter are both a cost and an expenditure that will add to the GDP.
- Healthcare costs associated with pollution: costs of medicines and of hospitalisation. These costs also entail incomes and employment in the health care sector.
- Sick leave and loss of working days due to air pollution: although the pain and suffering is not included in the GDP definition, sick leave reduces labour productivity, could lead to production losses, lower wages or higher production costs. The total direct cost of lost working days due to acute PM2.5 exposure in 2015 was valued at around €15bn (Holland, 2014). This damage category is of special interest as the loss of working days could have a longer-term impact on the economic performance of a country.

3.1 Health benefits

3.1.1 Method

The method used here follows the impact pathway approach developed under the ExternE project (ExternE, 1995, 1999, 2005) and the CBA for the Clean Air For Europe (CAFE) Programme, and applied in the 2013 analysis of the revision of the Thematic Strategy on Air Pollution (Holland, 2014). This approach follows a logical progression from emission, through dispersion and exposure to quantification of impacts and their valuation (Figure 1).

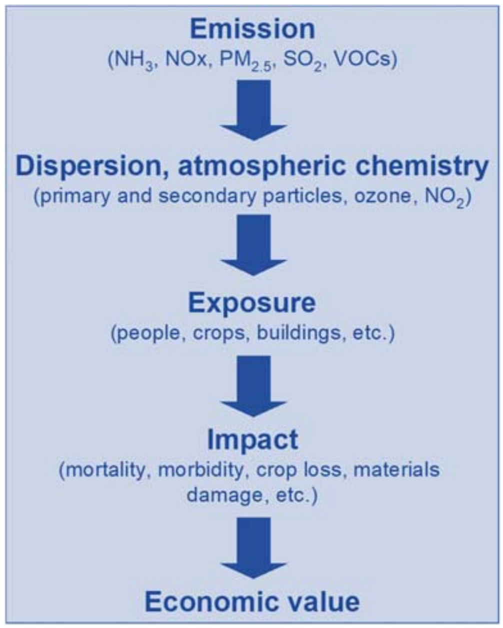

FIGURE 1: IMPACT PATHWAY APPROACH, TRACING THE CONSEQUENCES OF POLLUTANT RELEASE FROM EMISSION TO IMPACT AND ECONOMIC VALUE

The methods used by Holland et al (1999) and Holland and King (1998) 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 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)

Methods were reviewed and updated under the EC4MACS study (Holland et al, 2013b), inter alia to incorporate the conclusions from the REVIHAAP project of the World Health Organization (WHO) regarding updated mortality assessment for ozone and PM (WHO, 2013a). Subsequent work on the HRAPIE project (WHO, 2013b) provides further information on morbidity impacts (hospital admissions, incidence of bronchitis, lost work days, etc.), and was used for the CBA for the revision of the TSAP in 2013. For the purpose of comparison with the earlier work it was agreed that the analysis presented here would follow the same method as used previously, unless significant new developments were identified. The health functions and unit values applied to health impacts have therefore been kept the same as for the 2013 analysis.

The final recommendations of the HRAPIE study are shown in Table 4. HRAPIE recommends that the functions for which confidence is highest be given an 'A' rating and those for which confidence is less (though still sufficiently high to be quantified) be given a 'B' rating. This is supplemented by '*' for effects that are additive for the purpose of the CBA. Effects that are not additive can be quantified to provide additional information, though this has not been performed here.

TABLE 4: LIST OF HEALTH IMPACTS – HRAPIE RECOMMENDATIONS

Impact / population group	Rating	Population	Exposure metric
Ozone			
All cause mortality from chronic exposure	B	Over 30 years	O_3, SOMO35, summer months
All cause mortality from acute exposure	A*/A	All ages	O_3, SOMO35 (A*), SOMO10 (A)
Cardiac and respiratory mortality from acute exposure	A	All ages	O_3, SOMO35 (A*), SOMO10 (A)
Respiratory hospital admissions	A*/A	Over 65 years	O_3, SOMO35 (A*), SOMO10 (A)
Cardiovascular hospital admissions	A*/A	Over 65 years	O_3, SOMO35 (A*), SOMO10 (A)
Minor Restricted Activity Days (MRADs)	B*/B	All ages	O_3, SOMO35 (B*), SOMO10 (B)
PM2.5			
All cause mortality from chronic exposure as life years lost or premature deaths	A*	Over 30 years	$PM_{2.5}$, annual average
Cause-specific mortality from chronic exposure	A	Over 30 years	$PM_{2.5}$, annual average
Infant Mortality	B*	1 month to 1 year	$PM_{2.5}$, annual average
Chronic bronchitis in adults	B*	Over 27 years	$PM_{2.5}$, annual average
Bronchitis in children	B*	6 – 12 years	$PM_{2.5}$, annual average
All cause mortality from acute exposure	A	All ages	$PM_{2.5}$, annual average
Respiratory Hospital Admissions	A*	All ages	$PM_{2.5}$, annual average
Cardiovascular Hospital Admissions	A*	All ages	$PM_{2.5}$, annual average
Restricted Activity Days (RADs)	B*	All	$PM_{2.5}$, annual average
Including lost working days	B*	15 to 64 years	$PM_{2.5}$, annual average
Asthma symptoms in asthmatic children	B*	5 to 19 years	$PM_{2.5}$, annual average
NO_2			
All cause mortality from chronic exposure	B*	Over 30 years	NO_2 annual mean >20ug.m^{-3}
All cause mortality from acute exposure	A*	All ages	NO_2 annual mean
Bronchitis in children	B*	5 – 14 years	NO_2 annual mean
Respiratory hospital admissions	A*	All ages	NO_2 annual mean

It is not yet possible to apply the HRAPIE recommendations in full. The main reasons for this are as follows:

- For ozone, SOMO10 exposure data are currently unavailable.
- For NO_2, there is a lack of agreement regarding the extent to which exposure data quantified using EMEP outputs properly reflect exposure of the population. Quantification of NO_2 effects has therefore not been attempted.
- For effects of chronic exposure to ozone and NO_2 (leaving aside the issues of exposure modelling) on mortality, protocols for dealing with the potential for double counting against the function applied for PM2.5 have not been agreed. Neither is therefore added into total benefits. The HRAPIE report states that: 'Some of the long-term NO_2 effects may overlap with effects from long-term PM2.5 (up to 33%).' This statement could of course be turned around to say that at least 67% of the NO_2 impact is not accounted for within the PM2.5 function, providing a bias to underestimation.

Valuation of health effects is performed by multiplying impacts (e.g., respiratory hospital admissions) by an appropriate estimate of the unit value of each impact (e.g., the cost of a respiratory hospital admission), as shown in Table 5. 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 welfare losses/ lost utility, reflecting aversion to premature death or ill health. The price year of 2005 has been retained for consistency with the cost-effectiveness analysis carried out by IIASA using the GAINS model. There is some evidence that the valuations adopted here are conservative, biasing to underestimation of impacts. This is discussed in more depth below.

Valuation of mortality generates the largest damage costs in the analysis. Sensitivity analysis is applied to demonstrate the effect of different assumptions on the balance of costs and benefits. Mortality is either valued against loss of life expectancy (life years lost) using the value of a life year (VOLY) or against deaths using the value of statistical life (VSL). In both cases median and mean estimates are available, leading to a range for the VOLY of €57,700 to €138,700 and for the VSL of €1.09 to €2.22 million. The results presented in this report mainly focus on the most conservative position, based on the median VOLY. This is not intended to reflect a preference for the median VOLY, but simply to provide a baseline for the assessment.

TABLE 5: VALUES USED FOR THE HEALTH IMPACT ASSESSMENT (PRICE YEAR 2005)

Impact / population group	Unit cost	Unit
Ozone effects		
Mortality from chronic exposure as:		
Life years lost, or	57,700 / 138,700	€/life year lost (VOLY)
Premature deaths	1.09 / 2.22 million	€/death (VSL)
Mortality from acute exposure	57,700 / 138,700	€/life year lost (VOLY)
Respiratory Hospital Admissions	2,220	€/hospital admission
Cardiovascular Hospital Admissions	2,220	€/hospital admission
Minor Restricted Activity Days (MRADs)	42	€/day
$PM_{2.5}$ effects		
Mortality from chronic exposure as:		
Life years lost, or	57,700 / 138,700	€/life year lost (VOLY)
Premature deaths	1.09 / 2.22 million	€/death (VSL)
(all-cause and cause-specific mortality)		
Mortality from acute exposure	57,700 / 138,700	€/life year lost (VOLY)
Infant Mortality	1.6 to 3.3 million	€/case
Chronic Bronchitis in adults	53,600	€/new case of chronic bronchitis
Bronchitis in children	588	€/case
Respiratory Hospital Admissions	2,220	€/hospital admission
Cardiac Hospital Admissions	2,220	€/hospital admission
Restricted Activity Days (RADs)	92	€/day
Work loss days	130	€/day
Asthma symptoms, asthmatic children	42	€/day
NO_2 effects (though not quantified in this report)		
Mortality from chronic exposure as:		
Life years lost, or	57,700 / 138,700	€/life year lost (VOLY)
Premature deaths	1.09 / 2.22 million	€/death (VSL)
Mortality from acute exposure	57,700 / 138,700	€/life year lost (VOLY)
Bronchitis in children	588	€/case
Respiratory Hospital Admissions	2,220	€/hospital admission

Health care costs are presented separately, calculated using the information presented in Table 6. Overall, the positions adopted are conservative. There is also emerging information on a number of possible additional health impacts that could have major added costs - dementia, diabetes and obesity (see RCP, 2016). However, evidence on these effects is as yet not conclusive.

TABLE 6: AVAILABILITY OF HEALTHCARE COST DATA FOR HEALTH IMPACTS OF AIR POLLUTION

Effect	Commentary
Mortality	
Acute Mortality	For adults it is assumed that there is no additional healthcare cost for 'acute mortality' beyond what would have been incurred had death occurred slightly later. In essence, the primary cause of death seems likely to be unchanged at least in the vast majority of cases.
Chronic Mortality	The position with respect to chronic mortality is more complicated than for acute given that air pollution would have a greater role in causing the ill-health that leads to early death. There is, however, a question of the aggregate effect on health services per individual, given that we all die at some time and so will likely need health care at some point. It is possible that prolongation of life may have no significant effect on overall demand for health services.
Infant Mortality	The small number of cases of infant mortality estimated here indicates that the aggregate of healthcare cost associated with these infant deaths will be low, even if the average treatment cost per child is high. However, like the situation with chronic mortality for adults, this is a 'tip of the iceberg' situation, given that we quantify no morbidity effects for this age group. It is quite illogical to consider that the only effect of air pollution on infant health is mortality, if we accept the link to mortality as robust.
Morbidity	
Minor Restricted Activity Days (acute)	Given that these are defined as 'minor' restricted activity days it is anticipated that whilst overall number are high, those experiencing the effect would be unlikely to seek medical intervention.
Chronic Bronchitis in adults	Healthcare costs for chronic bronchitis have been assessed systematically in a number of European countries in a major study reporting in 2003. Results varied significantly between countries: • France: €530/patient/year (Piperno et al, 2003) • Italy: €1,261/patient per year (Dal Negro et al, 2003) • Netherlands: €614/patient/year (Wouters, 2003) • Spain: €3,238/patient/year (Izquiero, 2003) • UK €1,147/patient/year (Britton, 2003) The average figure across these countries is €1,358. Based on information provided by Holland (2014) an estimate of 10 years average duration is adopted.
Chronic bronchitis in children	Children with persistent symptoms would be taken to the doctor. Drawing on Netten and Curtis (2000, as reported by Hurley et al, 2005) the cost of a consultation would be in the order of €45.
Respiratory Hospital Admissions (acute)	Hospital admissions are valued at €2,220 per case. Of this, €1,000 is attributed to healthcare costs. However, this seems likely to be an underestimate given the average stay lengths linked to respiratory hospital admissions in WHO's Hospital Morbidity Database and costs indicated by WHO's CHOICE database.
Cardiac Hospital Admissions (acute)	Hospital admissions are valued at €2,220 per case. Of this, €1,000 is attributed to healthcare costs. However, this seems likely to be an underestimate given the average stay lengths linked to cardiovascular hospital admissions in WHO's Hospital Morbidity Database and costs indicated by WHO's CHOICE database.

Effect	Commentary
Asthma symptom days (children 5-19yr)	As a minimum it would be anticipated that children experiencing an asthma symptom day would receive some medication, valued previously at €1 per day (Hurley et al, 2005).
Restricted Activity Days (acute)	The broad definition of a 'restricted activity day' prevents attribution of an average cost for healthcare. In many cases it is envisaged that there would be no healthcare cost. However, given the large numbers involved a significant aggregate cost could arise if just a minority of cases involved some level of intervention.

3.1.2 Results

Analysis has been performed for two sets of population data. The first uses a constant population, fixed at 2005 levels for consistency with the GAINS model. The use of a constant population permits change in the risk of adverse impacts to be assessed, and is appropriate to the objectives of the GAINS cost-effectiveness analysis, in line with the metrics used during the negotiations on the NECD. However, for a cost-benefits analysis, it is appropriate to consider changes in population over time, for consistency with the underlying demand and emissions modelling. Summary data for both sets of results are presented here, though the CBA is only applied to results that account for population change. Overall differences between the two sets of results (constant 2005 population, vs population adjusted by year) are small. The range for the constant 2005 population for 2030 baseline is €214-610 billion/year, which falls within the range for the 2030 baseline with 2030 population assumed (€201-724 billion/year).

Annual health impacts and their monetized equivalents are presented for the EU-28 as well for all of Europe, reflecting the impacts of EU emissions on non-EU countries (Table 7 to Table 12). Emissions from the EU28 will clearly impact other countries in the European region (Switzerland, Serbia, Russia, Ukraine, etc.). Inclusion of these countries would add roughly 60% to the total damage costs.

The economic analyses conducted for the Clean Air Policy package identified work days lost due to the exposure to air pollution as a potentially important element of a cost-benefits analysis (Holland, 2014). Across the scenarios considered, the direct economic value of the expected reduction of lost working days was estimated between € 0,7 bn/yr and almost € 3 bn/yr, substantially offsetting the emission control costs of the proposed reduction scenario. It was, however, acknowledged that this analysis was based on a limited literature, and so further consideration is given in Annex 1 to the validity of the estimates made earlier. The conclusion from the comparison is that the methods used in the core CBA analysis for the Commission are conservative and likely to underestimate impacts on productivity.

Table 7: Annual health impacts for the EU28 in 2030, thousand events (deaths, cases, days, etc.), constant 2005 population (ERR 2030: Emission reduction requirements of the NECD)

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
Ozone					
Acute mortality	30	19	18	18	18
Respiratory hospital admissions	20	13	12	13	12
Cardiac hospital admissions	92	56	55	55	54
Minor restricted activity days	123,819	76,988	75,088	75,312	73,988
PM2.5					
Chronic mortality (years of life lost) *	5,002	2,533	2,312	2,442	2,269
Chronic mortality (deaths) *	449	228	208	220	204
Infant mortality	1	1	0	1	0
Chronic bronchitis (adults)	365	186	169	179	166
Chronic bronchitis (children)	1,341	680	621	655	609
Respiratory hospital admissions	168	85	78	82	76
Cardiac hospital admissions	124	65	59	62	58
Restricted activity days	515,845	260,198	237,822	250,954	233,495
Lost working days	142,489	73,982	67,181	71,182	65,953
Asthma symptom days	14,138	7,162	6,541	6,907	6,424

Table 8: Monetised equivalent of annual health impacts for the EU28, €billion2005, constant 2005 population (ERR 2030: Emission reduction requirements of the NECD)

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
Ozone					
Acute mortality (median VOLY) *	1.7	1.1	1.1	1.1	1.0
Acute mortality (mean VOLY) *	4.2	2.6	2.5	2.5	2.5
Respiratory hospital admissions	0.05	0.03	0.03	0.03	0.03
Cardiac hospital admissions	0.2	0.1	0.1	0.1	0.1
Minor restricted activity days	5.2	3.2	3.2	3.2	3.1
PM2.5					
Chronic mortality (median VOLY) *	289	146	133	141	131
Chronic mortality (medium VSL) *	998	506	462	488	453
Infant mortality (median VSL)	1.8	0.9	0.8	0.8	0.8
Infant mortality (mean VSL)	3.7	1.8	1.6	1.7	1.6
Chronic bronchitis (adults)	19.6	9.9	9.1	9.6	8.9
Chronic bronchitis (children)	0.8	0.4	0.4	0.4	0.4
Respiratory hospital admissions	0.4	0.2	0.2	0.2	0.2
Cardiac hospital admissions	0.3	0.1	0.1	0.1	0.1
Restricted activity days	47.5	23.9	21.9	23.1	21.5
Lost working days	18.5	9.6	8.7	9.3	8.6
Asthma symptom days	0.6	0.3	0.3	0.3	0.3
Total (low)	**385**	**196**	**179**	**189**	**176**
Total (high)	**1,099**	**559**	**510**	**539**	**501**

Table 9: Health care costs linked to air pollution for the EU28, €million2005/year, constant 2005 population (ERR 2030: Emission reduction requirements of the NECD)

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
Ozone					
Respiratory hospital admissions (>64)	20	13	12	13	12
Cardiovascular hospital admissions (>64)	92	56	55	55	54
PM2.5					
Chronic Bronchitis (adults)	4,182	2,125	1,939	2,049	1,904
Bronchitis in children aged 6 to 12	60	31	28	29	27
Respiratory Hospital Admissions (All ages)	168	85	78	82	76
Cardiac Hospital Admissions (>18 years)	124	65	59	62	58
Asthma symptom days (children 5-19yr)	14	7	7	7	6
Not quantified					
Effects assumed to have negligible healthcare costs	Acute mortality (NO_2, O_3) Minor restricted activity days (O_3)				
Unquantified effects that **may** have significant healthcare costs	Chronic morbidity (in addition to chronic bronchitis) (NO_2, O_3 and $PM_{2.5}$) Infant morbidity ($PM_{2.5}$) Restricted activity days ($PM_{2.5}$) Child bronchitis (NO_2) Respiratory hospital admissions (NO_2)				
Total where quantified	**4,661**	**2,382**	**2,270**	**2,178**	**2,297**

Table 10: Annual health impacts for the EU28 in 2030, thousand events (deaths, cases, days, etc.), forecast population for 2030 (ERR 2030: Emission reduction requirements of the NECD)

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
Ozone					
Acute mortality	30	23	22	22	22
Respiratory hospital admissions	20	20	19	19	19
Cardiac hospital admissions	92	87	84	85	83
Minor restricted activity days	123,819	82,439	80,424	80,653	79,252
PM2.5					
Chronic mortality (years of life lost) *	5,002	2,279	2,082	2,197	2,043
Chronic mortality (deaths) *	449	274	250	264	245
Infant mortality	1	0	0	0	0
Chronic bronchitis (adults)	365	211	192	203	189
Chronic bronchitis (children)	1,341	659	602	635	591
Respiratory hospital admissions	168	90	82	87	81
Cardiac hospital admissions	124	70	63	67	62
Restricted activity days	515,845	288,525	263,879	278,290	259,085
Lost working days	142,489	68,614	62,419	66,033	61,266
Asthma symptom days	14,138	6,989	6,389	6,742	6,275

Table 11: Monetised equivalent of annual health impacts for the EU28, €billion2005, forecast population for 2030 (ERR 2030: Emission reduction requirements of the NECD)

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
Ozone					
Acute mortality (median VOLY) *	1.7	1.3	1.3	1.3	1.3
Acute mortality (mean VOLY) *	4.2	3.1	3.1	3.1	3.0
Respiratory hospital admissions	0.05	0.04	0.04	0.04	0.04
Cardiac hospital admissions	0.2	0.2	0.2	0.2	0.2
Minor restricted activity days	5.2	3.5	3.4	3.4	3.3
PM2.5					
Chronic mortality (median VOLY) *	289	132	120	127	118
Chronic mortality (medium VSL) *	998	608	555	586	545
Infant mortality (median VSL)	1.8	0.6	0.5	0.6	0.5
Infant mortality (mean VSL)	3.7	1.2	1.1	1.1	1.1
Chronic bronchitis (adults)	19.6	11.3	10.3	10.9	10.1
Chronic bronchitis (children)	0.8	0.4	0.4	0.4	0.3
Respiratory hospital admissions	0.4	0.2	0.2	0.2	0.2
Cardiac hospital admissions	0.3	0.2	0.1	0.1	0.1
Restricted activity days	47.5	26.5	24.3	25.6	23.8
Lost working days	18.5	8.9	8.1	8.6	8.0
Asthma symptom days	0.6	0.3	0.3	0.3	0.3
Total (low)	**385**	**185**	**169**	**178**	**166**
Total (high)	**1,099**	**664**	**606**	**640**	**595**

TABLE 12: HEALTH CARE COSTS LINKED TO AIR POLLUTION FOR THE EU28, €MILLION2005/YEAR, FORECAST POPULATION FOR 2030 (ERR 2030: EMISSION REDUCTION REQUIREMENTS OF THE NECD)

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
Ozone					
Respiratory hospital admissions (>64)	20	20	19	19	19
Cardiovascular hospital admissions (>64)	92	87	84	85	83
PM2.5					
Chronic Bronchitis (adults)	4,182	2,413	2,204	2,327	2,164
Bronchitis in children aged 6 to 12	60	30	27	29	27
Respiratory Hospital Admissions (All ages)	168	90	82	87	81
Cardiac Hospital Admissions (>18 years)	124	70	63	67	62
Asthma symptom days (children 5-19yr)	14	7	6	7	6
Not quantified					
Effects assumed to have negligible healthcare costs	Acute mortality (NO_2, O_3) Minor restricted activity days (O_3) Chronic morbidity (in addition to chronic bronchitis) (NO_2, O_3 and $PM_{2.5}$)				
Unquantified effects that **may** have significant healthcare costs	Infant morbidity ($PM_{2.5}$) Restricted activity days ($PM_{2.5}$) Child bronchitis (NO_2) Respiratory hospital admissions (NO_2)				
Total where quantified	4,661	2,716	2,487	2,620	2,442

3.2 Work days lost

The economic analyses conducted for the Clean Air Policy package identified work days lost due to the exposure to air pollution as a potentially important element of a cost-benefits analysis (Holland, 2014). Across the scenarios considered, the direct economic value of the expected reduction of lost working days was estimated between € 0,7 bn/yr and almost € 3 bn/yr, substantially offsetting the emission control costs of the proposed reduction scenario. It was, however, acknowledged that this analysis was based on a limited literature, and so further consideration is given in Annex 1 regarding the validity of the estimates. The conclusion is that the methods used in the core CBA analysis for the Commission and presented here are conservative, and likely to underestimate impacts on productivity.

3.2.1 Approach taken for this study

The HRAPIE (Health Response to Air Pollutants in Europe) study carried out by the World Health Organization for the revision of the Thematic Strategy on Air Pollution of the European Commission did not provide specific response functions for absenteeim, but referred to the logic of the impact being present and to the quality of the core study referenced (Ostro, 1987) – see Table 13 It was noted that the confidence interval for this effect is very tight around the best estimate (relative risk of 1.046 in a range of 1.039 to 1.053 per 10μg.m^{-3}). Given the limited literature considered for this effect, the range was expanded in the uncertainty analysis subsequently performed as part of the CBA, though the best estimate was retained. The applied range for Monte Carlo analysis was +/-80% of the best estimate with a uniform distribution.

TABLE 13. SUMMARY OF RECOMMENDATIONS FOR EFFECTS OF SHORT TERM $PM_{2.5}$ EXPOSURE ON THE INCIDENCE OF ABSENTEEISM (WORK DAYS LOST)

Work days lost	
Group	B* (lower confidence than category A effects, but still to be included in CBA)
Pollutant metric	Annual average $PM_{2.5}$ with no threshold
Population	Working age (20-64).
Effect	Work days lost.
Relative risk	1.046, 95%CI 1.039 to 1.053 per 10 μg.m^{-3}. Range based on results for a population of 12,000 adults aged 20-64 from 49 metropolitan areas of the USA. Result to be subtracted from estimate of RADs where both are applied together.
Population and incidence data	UN mid estimates for population. For baseline rates, country-specific data on absenteeism from work due to illness is provided by WHO's European Health for All database (HFA-DB) (http://data.euro.who.int/hfadb/). Though the baseline rates are available for most countries, the definitions and criteria used for registering sick leave differ between countries increasing uncertainty of burden estimates.
References	Ostro (1987)

3.2.2 Results

The impacts on workdays lost of the air pollution control scenarios presented in the Outlook and report have been estimated here by applying the same broad method (with updates on employment and absence statistics) as used for the evaluation of the Thematic Strategy on Air Pollution (TSAP) in 2013 (Holland, 2014). Impacts on lost working days, not accounting for mortality, are shown in Table 14. Across the EU in 2005, it is estimated that 142 million work days were lost as a result of exposure to air pollution. Results are calculated for a uniform population, identical to 2005, to factor out the impacts of demographic change (this is accounted for elsewhere in the study outputs). By 2030 it is forecast that the number of lost working days will have declined to 74 million under current legislation. The policy scenarios considered here then further reduce impacts to around 66 million lost working days per year.

To put these figures into context, they correspond to a decline from 0.63 working days lost to air pollution per worker on average to 0.3 under the policy scenarios.

Costs associated with lost working days are shown in Table 15, with costs for the EU28 in 2005 of €18.5 billion/year, falling to €8.5 billion/year by 2030 under the policy scenarios.

As noted in Annex 1, analysis elsewhere (e.g., USEPA, 2011; Ricardo/IOM, 2014; World Bank, 2016), suggests additional impacts on productivity beyond those described by the response function for acute exposure to $PM_{2.5}$ and work days lost. These arise from impacts on mortality amongst those in the workforce and other morbidity impacts. A broad indication of the costs arising from the wider assessment of lost productivity can be gained by applying the ratio of total impact from the Ricardo/IOM study to their estimate of costs associated specifically with the loss of working days quantified for $PM_{2.5}$ using the function from Ostro, as recommended by HRAPIE. Results are shown in Table 16, with costs for the EU28 in 2005 of €66 billion/year, falling to €30 billion/year by 2030 under the policy scenarios.

TABLE 14: WORK DAYS LOST (THOUSANDS) UNDER THE SCENARIOS CONSIDERED. CONSTANT 2005 POPULATION ASSUMED

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
EU countries					
Austria	2,003	1,091	1,007	1,045	976
Belgium	3,317	1,927	1,632	1,852	1,607
Bulgaria	2,631	1,004	949	966	915
Cyprus	201	130	129	130	129
Czech Republic	4,412	2,427	2,195	2,346	2,159
Germany	30,749	18,329	16,127	17,718	15,985
Denmark	878	475	447	457	434
Estonia	157	107	103	103	100
Spain	11,088	4,360	4,215	4,194	4,071
Finland	612	433	426	404	399
France	14,303	7,107	6,583	6,756	6,394
United Kingdom	7,692	3,531	3,270	3,506	3,265
Greece	4,323	1,707	1,673	1,651	1,636
Croatia	1,655	735	677	717	667
Hungary	3,258	1,705	1,492	1,666	1,475
Ireland	480	244	234	239	229
Italy	18,846	10,025	9,067	9,681	9,001
Lithuania	533	321	309	310	301
Luxembourg	107	58	52	56	52
Latvia	367	226	219	219	213
Malta	48	26	25	26	25
Netherlands	4,991	2,674	2,419	2,586	2,387
Poland	18,561	10,120	9,072	9,426	8,769
Portugal	2,455	1,038	981	1,018	968
Romania	5,775	2,459	2,277	2,389	2,215
Sweden	863	574	555	558	542
Slovenia	692	341	301	322	294
Slovakia	1,489	808	746	842	747
Non-EU countries					
Albania	640	338	334	336	333
Bosnia and H.	807	409	396	405	394
Belarus	1,760	1,348	1,321	1,331	1,311
Switzerland	1,508	1,031	986	1,009	980
Serbia and M.	3,008	1,378	1,337	1,365	1,330
Moldova	842	563	550	558	546
TFYR Macedonia	97	45	44	44	44
Norway	517	411	405	409	404
Russian Federation	21,047	18,721	18,683	18,694	18,665
Ukraine	4,217	3,223	3,185	3,208	3,176
EU total	142,489	73,982	67,181	71,182	65,953
Non-EU total	34,443	27,466	27,241	27,358	27,182
Total	176,932	101,447	94,422	98,540	93,135

TABLE 15: VALUE OF LOST WORKING DAYS (€MILLION/YEAR)

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
EU countries					
Austria	260	142	131	136	127
Belgium	431	250	212	241	209
Bulgaria	342	130	123	126	119
Cyprus	26	17	17	17	17
Czech Republic	574	316	285	305	281
Germany	3,997	2,383	2,097	2,303	2,078
Denmark	114	62	58	59	56
Estonia	20	14	13	13	13
Spain	1,441	567	548	545	529
Finland	80	56	55	53	52
France	1,859	924	856	878	831
United Kingdom	1,000	459	425	456	424
Greece	562	222	218	215	213
Croatia	215	96	88	93	87
Hungary	424	222	194	217	192
Ireland	62	32	30	31	30
Italy	2,450	1,303	1,179	1,259	1,170
Lithuania	69	42	40	40	39
Luxembourg	14	8	7	7	7
Latvia	48	29	28	28	28
Malta	6	3	3	3	3
Netherlands	649	348	314	336	310
Poland	2,413	1,316	1,179	1,225	1,140
Portugal	319	135	128	132	126
Romania	751	320	296	311	288
Sweden	112	75	72	73	70
Slovenia	90	44	39	42	38
Slovakia	194	105	97	109	97
Non-EU countries					
Albania	83	44	43	44	43
Bosnia and H.	105	53	51	53	51
Belarus	229	175	172	173	170
Switzerland	196	134	128	131	127
Serbia and M.	391	179	174	177	173
Moldova	109	73	71	73	71
TFYR Macedonia	13	6	6	6	6
Norway	67	53	53	53	52
Russian Federation	2,736	2,434	2,429	2,430	2,426
Ukraine	548	419	414	417	413
EU total	18,524	9,618	8,734	9,254	8,574
Non-EU total	4,478	3,571	3,541	3,557	3,534
Total	23,001	13,188	12,275	12,810	12,108

TABLE 16: UPPER BOUND ESTIMATE OF PRODUCTIVITY IMPACTS (€MILLION/YEAR)

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
EU countries					
Austria	923	503	464	482	450
Belgium	1,529	888	752	854	741
Bulgaria	1,213	463	438	445	422
Cyprus	93	60	59	60	59
Czech Republic	2,034	1,119	1,012	1,081	995
Germany	14,175	8,449	7,435	8,168	7,369
Denmark	405	219	206	211	200
Estonia	72	49	47	48	46
Spain	5,112	2,010	1,943	1,933	1,877
Finland	282	199	196	186	184
France	6,594	3,276	3,035	3,114	2,948
United Kingdom	3,546	1,628	1,507	1,616	1,505
Greece	1,993	787	771	761	754
Croatia	763	339	312	330	307
Hungary	1,502	786	688	768	680
Ireland	221	113	108	110	106
Italy	8,688	4,621	4,180	4,463	4,149
Lithuania	246	148	142	143	139
Luxembourg	49	27	24	26	24
Latvia	169	104	101	101	98
Malta	22	12	12	12	12
Netherlands	2,301	1,233	1,115	1,192	1,101
Poland	8,556	4,665	4,182	4,345	4,042
Portugal	1,132	479	452	469	446
Romania	2,662	1,133	1,050	1,101	1,021
Sweden	398	265	256	257	250
Slovenia	319	157	139	149	136
Slovakia	686	372	344	388	344
Non-EU countries					
Albania	295	156	154	155	153
Bosnia and H.	372	188	182	187	181
Belarus	811	622	609	614	604
Switzerland	695	475	455	465	452
Serbia and M.	1,387	635	616	629	613
Moldova	388	260	253	257	252
TFYR Macedonia	45	21	20	20	20
Norway	238	189	187	188	186
Russian Federation	9,703	8,630	8,613	8,618	8,605
Ukraine	1,944	1,486	1,468	1,479	1,464
EU total	65,687	34,105	30,970	32,814	30,404
Non-EU total	15,878	12,661	12,558	12,612	12,531
Total	**81,564**	**46,766**	**43,528**	**45,426**	**42,935**

3.2.3 Main findings

There is broad consensus that air pollution affects productivity in the economy, with studies carried out in Europe, the USA, and by international organisations including WHO, OECD and World Bank.

There are a variety of mechanisms by which productivity can be affected:

- Effects of short term (acute) exposure on morbidity, leading to an inability to attend work
- Effects leading to reduced performance at work (presenteeism)
- Reduction in the size of the labour force through impacts on mortality
- Inability to work through longer term health issues (e.g. associated with cardiovascular or respiratory illness)

Existing analysis for the European Commission for the CBA is limited to the first of these mechanisms. Results appear to be of a reasonable order of magnitude, averaging around 0.5 work days lost per year per employee from air pollutant exposure. There is broad consistency between the response function adopted for this analysis and the response functions adopted for other health conditions.

Overall, it is considered that the restricted analysis performed for the European Commission to date is likely to be conservative, providing a lower bound for impacts on productivity.

Taking a range based largely around the question of whether or not mortality is included in the analysis of productivity losses gives the following estimates for the EU28:

- 2005: €19 - €66 billion/year
- 2030, current legislation: €10 - €35 billion/year
- 2030, policy scenarios: €8.5 - €30 billion/year

Associated damage is therefore significant. This paper provides a rationale for considering the estimates made so far for the European Commission to be conservative.

3.3 Non-health benefits

The impact assessment of the EU air policy package only describes the physical damage of air pollution to nature, i.e., the percentage of Natura2000 areas in a grid cell with an exceedance of the critical load of nitrogen is used as a proxy for potential biodiversity loss. In the FP7 project ECLAIRE, efforts were made to monetise the loss of biodiversity (ECLAIRE, 2015). Several methods were explored, such as

- monetisation of damage to the local economy (e.g., reduced wood production); lost opportunities of carbon sequestration;
- reduced value of nature due to species loss (derived from stated preference surveys);
- increased costs of nature management to remove excess nitrogen; or
- the implied costs of sufficiently reducing nitrogen emissions in and around the assigned Natura2000 areas to guarantee a 'favourable' conservation status for these areas (the so-called regulatory revealed preference method).

Whatever method was used, the estimated damage to nature was modest compared to the monetised mortality figures. While the low-end (willingness to pay based) estimates of the damage to nature would be more than twice the sum of damage to crops and materials, the monetised damage to nature would be 'only' 3-12% of the damage to health.

A sensitivity analysis with the GAINS-model showed that the incremental benefits of adding an additional 75% gap-closure target for nature conservation (on top of a 70% gap-closure for health protection) would exceed the 1% increase in abatement costs. Such a strategy would imply additional ammonia measures for large farms at a cost of €23 million for the EU28, while additional nature benefits would be worth €35-2500 million (ECLAIRE, 2015b).

For the purpose of this assessment, and in line with earlier benefit analyses for the Clean Air Policy package, monetized benefits have been estimates for crops, forest production, carbon sequestration, ecosystems and materials, both for the EU-Member States and the non-EU countries (Table 17).

TABLE 17: NON HEALTH IMPACTS, BY SCENARIO. €MILLION2005/YEAR

	2005	PRIMES 2016 REFERENCE		CLIMATE AND ENERGY POLICY	
		2017 legislation	ERR 2030	2017 legislation	ERR 2030
Crops: EU	8,649	6,515	6,448	6,430	6,390
Crops: Non-EU	2,613	2,159	2,151	2,149	2,143
Crops: total	11,262	8,674	8,599	8,579	8,533
Forest production: EU	2,911	2,398	2,381	2,377	2,367
Forest production: non-EU	nq	nq	nq	nq	nq
Forest production: total	2,911	2,398	2,381	2,377	2,367
Forest C sequestration: EU	1,536	5,054	5,019	5,009	4,989
Forest C sequestration: non-EU	nq	nq	nq	nq	nq
Forest C sequestration: total	1,536	5,054	5,019	5,009	4,989
Ecosystems: EU	3,435	2,826	2,570	2,791	2,542
Ecosystems: non-EU	nq	nq	nq	nq	nq
Ecosystems: total	3,435	2,826	2,570	2,791	2,542
Materials: EU	1,501	356	314	322	302
Materials: non-EU	nq	nq	nq	nq	nq
Materials: total	1,501	356	314	322	302
Total non-health: EU	18,032	17,149	16,733	16,929	16,590
Total non-health: non-EU	2,613	2,159	2,151	2,149	2,143
Total non-health, all countries	20,645	19,308	18,883	19,077	18,733

4 Comparison of costs and benefits

4.1 Comparison of costs and health benefits

The comparison of costs and benefit focuses on the results based on 2030 population, to be consistent with the demand, and hence cost data, for 2030 (hence based on the health impacts quantified in Table 10 onwards, above).

A number of comparisons are possible using the results generated here. In this report we focus on the benefits of moving to the revised ceilings from different starting points.

The tables that follow include totals for the EU28. Benefits of actions by EU Member States on countries outside of the EU28 are not accounted for here, though they are included in the overall analysis to the extent covered by the EMEP dispersion modelling on which the benefits assessment is based. The comparison of costs and benefits accounts for quantified benefits to health, crops, forests, ecosystems and materials. Results demonstrate that the emission ceilings generate a substantial net benefit, with benefit:cost ratios for the EU28 as a whole exceeding 14 in all cases for the lower valuation of mortality (based on use of the median VOLY) and in excess of 50 for the higher valuation of mortality (based on use of the mean VSL).

TABLE 18: COMPARISON OF COSTS AND BENEFITS TO EU MEMBER STATES OF ACHIEVING THE REVISED EMISSION CEILINGS, RELATIVE TO DIFFERENT BASELINES

Activity projection Emission controls	PRIMES 2016 REFERENCE 2017 legislation	CLIMATE AND ENERGY POLICY 2017 legislation
Median VOLY		
EU benefit	16,258	12,682
EU cost	960	539
EU net benefit	15,298	12,143
EU benefit cost ratio	16.93	23.53
Mean VSL		
EU benefit	58,355	45,397
EU cost	960	539
EU net benefit	57,395	44,858
EU benefit cost ratio	60.77	84.24

A number of factors indicate a bias against overestimation of the benefits through the methods applied here:

- Mortality valuation elsewhere (OECD, USEPA) follows use of the VSL only.
- The VSL adopted here is roughly 50% lower than that recommended by OECD (2012) following a major meta-analysis of available estimates based on stated preference methods. USEPA prefers use of VSL estimates based on revealed preference (wage-risk) studies that generate higher values still.
- A number of possible health impacts of air pollution are omitted from the analysis, several of which (effects of NO_2, impacts identified by RCP (2016) on dementia, obesity, diabetes) could be substantial.
- The methods used for quantification of productivity impacts in this analysis omit a number of pathways by which air pollution may affect productivity.

- The valuation of damage to ecosystems adopts the most conservative position of those elaborated under the ECLAIRE study.
- Exclusion of impacts of EU emissions on non-Member States: a strict interpretation of the polluter pays principle would require that these are included in the analysis.

In conclusion, the magnitude of the benefit:cost ratios and the potential for underestimation in the benefits analysis, indicate that the conclusion that benefits of the actions identified using the GAINS model will exceed costs is robust. Estimates of cost would need to be underestimated by more than an order of magnitude (and depending on the assumptions adopted in the benefits analysis, possibly by substantially more than an order of magnitude) to reach a different conclusion.

4.1.1 Equity issues

While comparing total costs with total benefits is informative, it will be not sufficient to understand all political trade-offs and conflicting interests of stakeholders. It is also important to know who pays and who benefits. What are the differences in marginal costs and benefits among countries? Who profits most? For which countries are the marginal benefits lower than the marginal costs?

As shown in Section 2, air pollution control costs are unevenly distributed across the economic sectors (Table 2). The current legislation implies that more than 50% of total costs emerge for emission controls at road vehicles, while the power sector, industry and non-road mobile machinery carry about 13% of total costs each. In contrast, the share of agriculture in total costs is about 3%. However, 40% of the costs of all additional measures that are required to achieve the ERRs occur in agriculture, indicating the cost-effectiveness of additional emission reductions in this sector compared to the much higher costs of the remaining measures in other sectors. Thus, the EU air policy package involves increases in direct emission control costs for agriculture and some other sectors, which however carry currently only a small portion of costs (Figure 2).

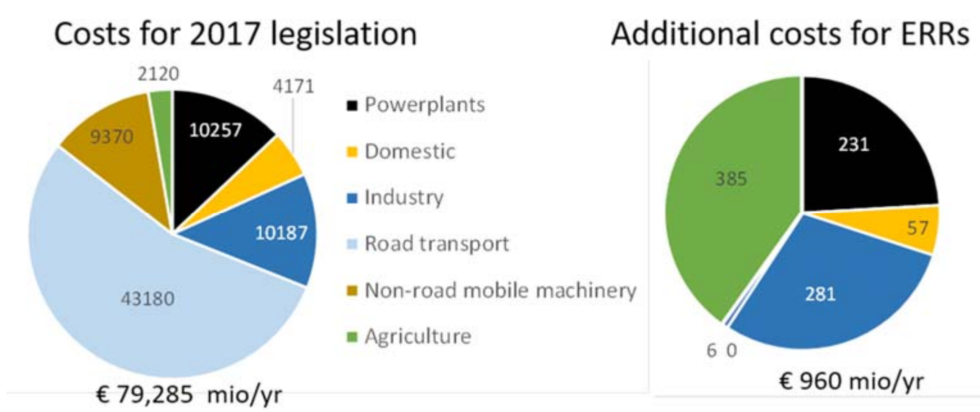

FIGURE 2: DISTRIBUTION OF EMISSION CONTROL COSTS IN 2030 ACROSS SECTORS (MILLION €/YR), LEFT PANEL: FOR THE IMPLEMENTATION OF ALL MEASURES REQUIRED BY THE 2017 LEGISLATION, RIGHT PANEL: THE ADDITIONAL COSTS IMPLIED BY THE ERRS OF THE NECD

As shown in Amann et al. (2017), additional control costs of the EU air policy package amount to € 960 million/year (or € 539 million/year for the 2030 Climate and Energy Policy scenario). This is 0.006% of total GDP in the EU28. However there are large differences between Member States: (Figure 3). At the same time, the analysis of benefits presented above clearly demonstrates that even in these countries the additional benefits will exceed the additional costs, based on the assumption of a uniform willingness-to-pay for reducing mortality risks across Europe.

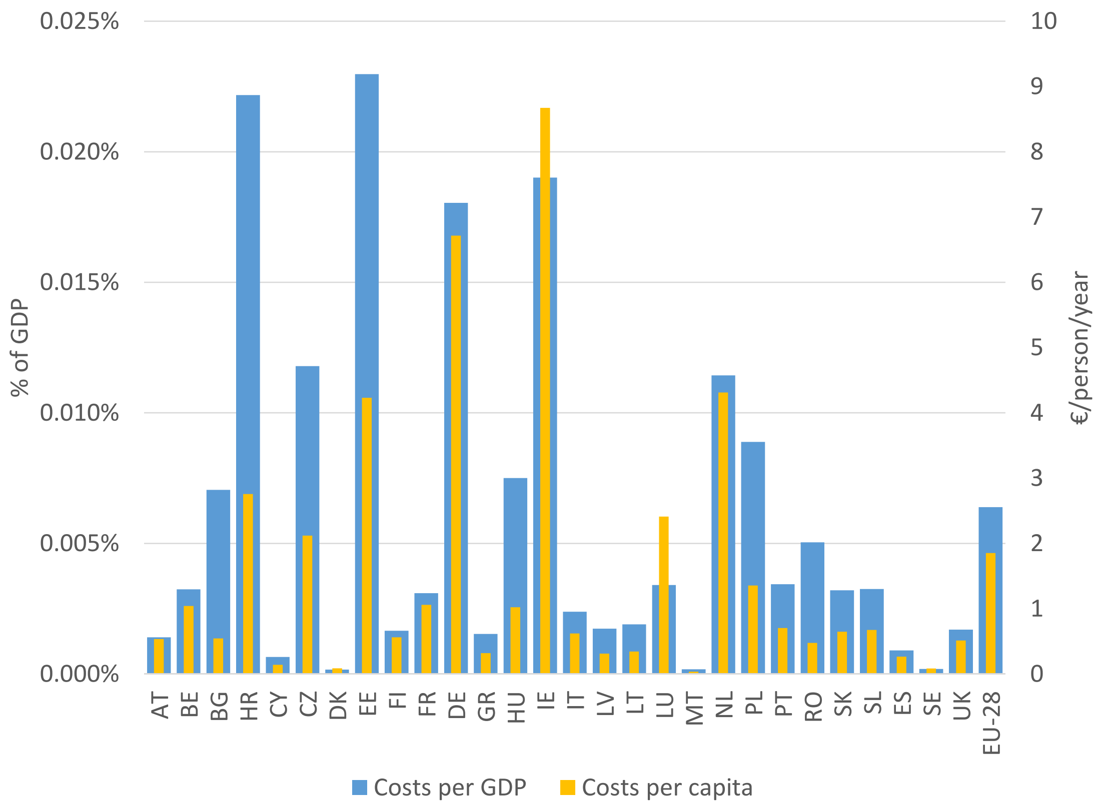

FIGURE 3: ADDITIONAL EMISSION CONTROL COSTS TO ACHIEVE THE ERRS IN 2030 BY MEMBER STATE, PER GDP AND PER-CAPITA

4.2 Market-based costs and benefits: macro-economic and sector-specific assessment

The JRC-GEM-E3 model has been employed by the JRC to assess market costs and benefits of the clean air policy measures in a macro-economic context. To this end, the analysis was restricted to lost work days and improved agricultural crop yields. This section thus studies the costs and benefits of meeting the air pollution reduction targets set out in the new NECD in a general equilibrium context, which means that not only *direct* emission control costs and benefits in terms of reduced number of sick leave days and agricultural crop yields are taken into account, but also *indirect* effects, capturing several relevant mechanisms. First, affected sectors use intermediate inputs. Therefore the changes in one industry can propagate to other sectors via linkages throughout the supply chain. In addition, pollution abatement generates demand for output of those sectors that deliver goods and services related to the abatement activity. Second, firms provide employment opportunities. Air pollution policy may affect the number of jobs and the wages, influencing households' disposable incomes and welfare. If reducing sick leave leads to increases in income and employment, a positive feedback loop arises where households spend more money on consumption, further boosting economic activity. Third, air pollution control costs may affect the competitiveness of sectors that are active in an international market, leading to changes in international trade flows. The JRC-GEM-E3 model (described in full in Capros et al., 2013) is designed to capture abovementioned mechanisms. The methodology adopted here follows EC (2013b) and Vrontisi et al. (2016)

The results are summarised in Figure 4 and indicate that the implementation of the emission reduction requirements of the NECD lead to net societal gains (both in GDP and household consumption), even when only accounting for market benefits. The positive effect of avoided lost work days due to air pollution-related illness is the key mechanism to achieve these gains. Two sets of results are shown, reflecting different starting points to reach the agreed emission ceilings. Both include the air pollution legislation in place in 2017, but they differ in terms of climate policy (Reference versus 2030 climate and energy package).

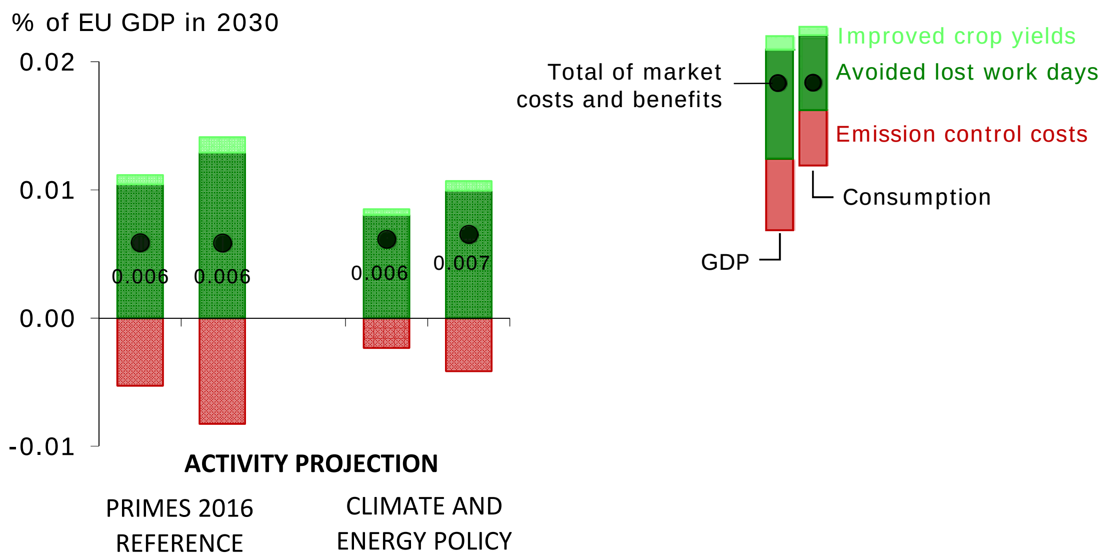

FIGURE 4: MACRO-ECONOMIC ASSESSMENT OF MARKET COSTS AND BENEFITS: GDP AND HOUSEHOLD CONSUMPTION. RESULTS SHOW THE IMPACT OF REACHING THE AGREED EMISSION CEILINGS FROM TWO DIFFERENT STARTING POINTS: THE PRIMES 2016 REFERENCE AND THE 2030 CLIMATE AND ENERGY POLICY PACKAGE. SOURCE: JRC-GEM-E3 MODEL

Detailed sector-level impact on output, employment and trade flows are shown in Table 19 to Table 21.

As shown in Section 2, roughly 40% of the additional pollution control costs to reach the emission ceilings (assuming Reference climate policy) are borne by the agricultural sector. The results on sector-specific output levels presented in Table 19 indicate that this translates into 0.08% output reduction. Taking into account the benefits on avoided lost work days and especially crop yields mitigates the output loss in agriculture by improving the competitiveness position, which leads to increased next exports (Table 21) compared to the cost-only assessment. For all other sectors, policy action to meet the emission reduction targets leads to increased output levels when the benefits on lost work days are accounted for. The overall cost estimate is in the same order of magnitude (but slightly larger) as the numbers presented by Brink and Smeets (2017).

TABLE 19: IMPACT (% IN 2030 COMPARED TO BENCHMARK) ON GDP AND SECTOR OUTPUT. SOURCE: JRC-GEM-E3

Activity projection	PRIMES 2016 REFERENCE			CLIMATE AND ENERGY POLICY		
Emission controls	2017 legislation			2017 legislation		
Health benefits included?*	No	Yes	Yes	No	Yes	Yes
Crop benefits included?	No	No	Yes	No	No	Yes
GDP	-0.005	0.005	0.006	-0.002	0.006	0.006
Sector output						
Agriculture	-0.08	-0.07	-0.05	-0.07	-0.06	-0.05
Coal, oil & gas	-0.01	0.00	0.00	0.00	0.00	0.00
Electricity supply	0.03	0.04	0.04	0.03	0.04	0.04
Ferrous and non-ferrous metals	-0.01	0.01	0.01	0.00	0.02	0.02
Chemical Products	0.01	0.02	0.02	0.01	0.02	0.02
Other energy intensive	0.00	0.01	0.01	0.00	0.01	0.01
Electric Goods	0.02	0.04	0.04	0.02	0.03	0.03
Transport equipment	0.00	0.02	0.02	0.00	0.02	0.02
Other Equipment Goods	0.01	0.04	0.04	0.01	0.03	0.03
Consumer Goods Industries	-0.01	0.00	0.00	-0.01	0.00	0.00
Construction	0.02	0.03	0.03	0.01	0.02	0.02
Transport	0.00	0.01	0.01	0.00	0.01	0.01
Market Services	0.00	0.01	0.01	0.00	0.01	0.01
Non Market Services	0.00	0.01	0.01	0.00	0.01	0.01

* Only the reduction in lost work days due to avoided air pollution-related illness is considered here.

Importantly, taking into account the positive effects on sickness leave implies a boost for EU-wide employment (Table 20). When only looking at the cost side, the results indicate a shift of employment opportunities from agriculture towards other sectors, which a small reduction in jobs overall. Clearly, in a real-world setting, such a shift may require re-training and corresponding human capital investments, which indicates the importance of complementary labour market and human resource policies to smoothen the transition. When the positive feedback of clean air on reduced sickness leave are included in the analysis, the numbers in Table 20 highlight that the improved productivity of workers can boost EU-wide employment, in turn driving up disposable incomes and consumption levels.

The impact on competitiveness and international trade is illustrated in Table 21. Expenditures on pollution control mechanisms lead to higher imports, particularly of agricultural goods. Net exports of energy intensive goods are slightly reduced because abatement expenditures affect relative prices compared to non-EU producers. Nearly a quarter of all expenditures (assuming Reference climate and energy policy, see Section 4.2) are done in electricity generation. As electricity volumes that are traded beyond EU's borders are very small, these expenditures have a limited direct impact on EU aggregate exports, but also affect the energy costs in the rest of the economy.

A number of sectors (Other energy intensive, Electric Goods, Transport equipment) hardly face costs of abatement expenditure. Moreover, these sectors deliver a substantial share of the 'abatement good' (75% for households, 15% for firms). In addition, these sectors benefit from reduced labour and capital costs brought about by lower labour and capital demand from other sectors. As a result, these sectors see an increase in output and exports. The shift of labour to export-oriented sectors leads to a positive impact on aggregate EU exports, albeit very small. As there may be some constraints to labour and capital mobility across sectors in a real-world setting in the short run, this result should not be overly stressed. When the 2030 climate and energy policies are considered as a starting point (without benefits), costs borne by energy-intensive export-oriented (e.g. Ferrous and non-ferrous metals, Other energy intensive, Chemicals) are substantially lower than in the other scenario, further contributing to a positive impact on exports.

When the benefits of avoided work days lost are taken into account, exports are higher than in a situation without air quality regulation on the aggregate level, but there is substantial variation across sectors.

TABLE 20: IMPACT (IN 2030 COMPARED TO BENCHMARK) ON HOUSEHOLD CONSUMPTION (%) AND SECTOR EMPLOYMENT ('000 JOBS). SOURCE: JRC-GEM-E3

Activity projection	PRIMES 2016 REFERENCE			CLIMATE AND ENERGY POLICY		
Emission controls	2017 legislation			2017 legislation		
Health benefits included?*	No	Yes	Yes	No	Yes	Yes
Crop benefits included?	No	No	Yes	No	No	Yes
Household consumption (%)	-0.008	0.005	0.006	-0.004	0.006	0.007
Sector employment ('000)						
Agriculture	-9	-7	-7	-9	-7	-7
Coal, oil & gas	0	0	0	0	0	0
Electricity supply	1	1	1	1	1	1
Ferrous and non-ferrous metals	0	1	1	0	1	1
Chemical Products	1	2	2	0	1	1
Other energy intensive	0	1	1	0	1	1
Electric Goods	0	1	1	0	1	1
Transport equipment	0	1	1	0	1	1
Other Equipment Goods	1	4	4	1	3	3
Consumer Goods Industries	-1	1	2	-1	1	1
Construction	5	8	8	3	6	6
Transport	0	3	3	0	3	3
Market Services	0	13	13	1	10	11
Non Market Services	1	9	9	1	7	7
Aggregate employment ('000)	-1	39	39	-1	30	30

* Only the reduction in lost work days due to avoided air pollution-related illness is considered here.

TABLE 21: IMPACT (% IN 2030 COMPARED TO BENCHMARK) ON AGGREGATE AND SECTOR-SPECIFIC TRADE

Activity projection	PRIMES 2016 REFERENCE			CLIMATE AND ENERGY POLICY		
Emission controls	2017 legislation			2017 legislation		
Health benefits included?*	No	Yes	Yes	No	Yes	Yes
Crop benefits included?	No	No	Yes	No	No	Yes
Aggregate imports	**0.007**	**0.007**	**0.007**	**0.005**	**0.006**	**0.005**
Sector imports						
Agriculture	0.23	0.24	0.18	0.23	0.24	0.20
Coal, oil & gas	0.00	0.01	0.01	0.00	0.01	0.01
Electricity supply	0.15	0.17	0.17	0.03	0.04	0.04
Ferrous and non-ferrous metals	0.04	0.03	0.03	0.00	-0.01	0.00
Chemical Products	0.02	0.02	0.03	0.00	0.00	0.00
Other energy intensive	0.02	0.02	0.02	0.00	0.01	0.01
Electric Goods	0.00	0.00	0.00	0.00	0.00	0.01
Transport equipment	-0.02	-0.03	-0.02	-0.01	-0.02	-0.02
Other Equipment Goods	-0.02	-0.02	-0.02	-0.01	-0.02	-0.02
Consumer Goods Industries	0.03	0.03	0.02	0.03	0.03	0.02
Construction	0.02	0.03	0.03	0.01	0.01	0.01
Transport	0.00	0.01	0.01	0.00	0.01	0.01
Market Services	-0.02	0.00	0.00	-0.01	0.00	0.00
Non Market Services	0.00	-0.01	-0.01	0.00	-0.01	-0.01
Aggregate exports	**0.003**	**0.016**	**0.016**	**0.005**	**0.016**	**0.015**
Sector exports						
Agriculture	-0.38	-0.37	-0.29	-0.37	-0.36	-0.31
Coal, oil & gas	-0.05	-0.06	-0.06	-0.02	-0.03	-0.03
Electricity supply	-0.05	-0.06	-0.06	0.00	0.00	0.00
Ferrous and non-ferrous metals	-0.03	-0.01	-0.01	0.00	0.02	0.02
Chemical Products	0.00	0.01	0.00	0.01	0.01	0.01
Other energy intensive	-0.01	0.00	-0.01	0.00	0.01	0.01
Electric Goods	0.03	0.04	0.04	0.02	0.03	0.03
Transport equipment	0.01	0.04	0.03	0.01	0.03	0.03
Other Equipment Goods	0.03	0.06	0.06	0.02	0.05	0.05
Consumer Goods Industries	-0.03	-0.02	-0.01	-0.03	-0.02	-0.01
Construction	0.01	0.01	0.01	0.01	0.01	0.01
Transport	0.00	0.00	0.00	0.00	0.00	0.00
Market Services	0.01	0.01	0.01	0.01	0.01	0.01
Non Market Services	0.01	0.02	0.02	0.01	0.02	0.02

* Only the reduction in lost work days due to avoided air pollution-related illness is considered here.

5 Innovation and competitiveness implications of clean air strategies

Even with a least-cost allocation of emission control measures, environmental regulation could entail higher production costs and negative employment effects in some sectors. But there are also positive economic impacts, as environmental measures will lead to additional expenditures and employment in e.g. equipment and construction. Rayment et al (2009) concluded that the net effects of environmental policies on employment are positive or neutral.

According to the JRC-GEM-E3 model, the net employment impact of the EU air policy package is positive for many sectors, with the exception of agriculture and refineries (Section 4.2). In this estimate environmental regulation outside the EU is assumed to be unchanged. In such case it is harder for these 'exposed' sectors to pass through additional costs to their customers (Vrontisi et al, 2016).

Positive economic impacts can become larger when comparable additional environmental measures are assumed abroad. This would improve the relative competitiveness of the EU and could stimulate the export of environmental technologies. There are multiple examples of this so-called 'first mover advantage', e.g. the export of Dutch sewage water treatment technology throughout the world in the 1970s, the export of German FGD-technology in the 1990s (and more recently of CCS) and the export of Danish wind power technology in the 2000s.

Crippa et al (2016) show that European vehicle standards triggered regulations in China, India and the Middle East. However data on future trade of environmental technologies between countries is highly uncertain and data about price differences are lacking. According to future global abatement scenarios (e.g., IEA, 2016) an important potential export market for clean technology could be Asia, but actual export of technology depends on the speed in which technological know-how is copied and improved by local producers. For several clean technologies (e.g. manure injection techniques) intellectual property rights are not protected.

According to the Porter-hypothesis, strict environmental standards induce efficiency and encourage innovations that help to improve competitiveness. First movers would be able to exploit innovations via patenting and fast learning, make a more efficient use of resources, and attain a strong competitive position compared to countries that introduce environmental regulations later.

Recent literature presents evidence that environmental policy does not harm and can even stimulate economic development (Albrizio et al, 2017). Morales-Lage et al (2016) showed that stringent environmental regulations stimulate R&D-expenditures, patent applications and resource productivity. Earlier, Dekker et al (2012) demonstrated how international air policy agreements triggered new patents and knowledge transfers.

A joint report of the Nordic competition authorities demonstrates that a positive relationship between economic and environmental policy requires prices to reflect environmental externalities, e.g., via environmental taxes. Also green public procurement would be a powerful tool to stimulate the development of markets for green goods.

As urban areas contain an accumulation of industrial activities, traffic, waste production, population, and exposure to noise and air pollution, environmental expenditures are higher in cities. Muller and Jha (2017) recently found that reducing air pollution in urban areas does not decrease the economic benefits of urbanization and that environmental goals and economic goals are not at odds with each other.

The OECD report on Green Growth prepared for the G7 Environment ministers (2017) gives several examples of positive links between jobs, growth and green policies. The OECD emphasizes that potential skill mismatches between sectors that lose jobs and sectors that will grow should not be overestimated as green policies tend to create and destroy similar job types, although training policy remains important to ensure a smooth transition of workers across sectors.

5.1 Case studies

5.1.1 Flue gas desulphurization

The high dependency on coal and increasingly stringent emission regulations around the globe drove investments in flue-gas desulfurization (FGD) system installations. Wet scrubbers have a removal efficiency of more than 90% and are mainly applied at larger plants (>400MW). Dry scrubbers have a removal efficiency of less than 80% and are applied at smaller plants.

Around 30% of the market for FGD is currently in Asia, 20% in the Middle East and 20% in Latin America (Marketsandmarkets.com, 2016). Total global sales are around $15-20 billion. This is less than 5% of the size of the global coal market. The average growth rate was 5-6%. Future expectations are mixed and will depend whether countries will try to reduce their dependency on coal in view of the Paris Climate Agreement, although some market analysts expect a further demand in China and India (Future market insights, 2017).

The 2017 World Energy Outlook of the International Energy Agency (IEA, 2017) suggests a substantial global growth in FGD and SCR installations for the coming decades, to a large extent in China and India (Figure 5). In addition to new installation, the market will also demand for replacement of already installed equipment after the end of its lifetime.

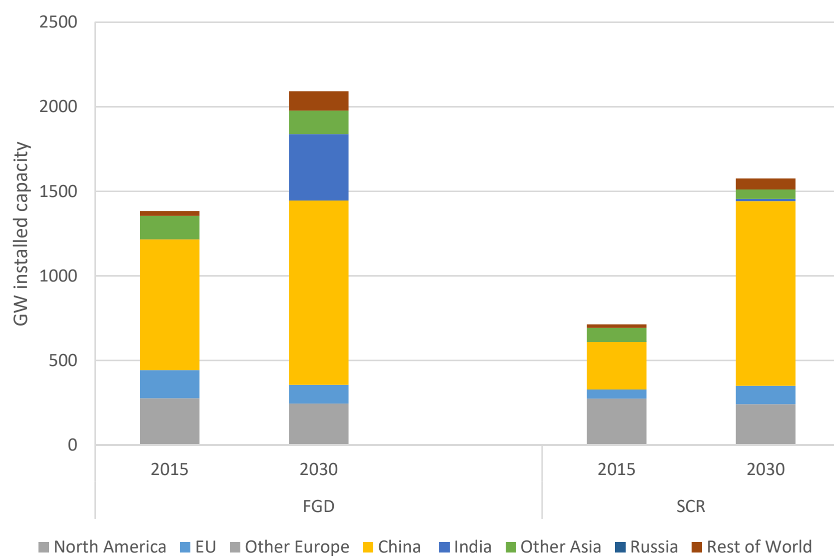

FIGURE 5: PLANT CAPACITY (MW EL) INSTALLED WITH FGD AND SCR IN 2015 AND THE BASELINE PROJECTION FOR 2030 OF THE 2017 WORLD ENERGY OUTLOOK OF THE INTERNATIONAL ENERGY AGENCY (IEA, 2017)

Flue gas desulphurization installations in the power sector are mainly produced by large (internationally operating) manufacturers. Smaller enterprises such as construction companies and enterprises that deliver components or specialized support have profited from additional investments in abatement technology, but whether this off spin employment is significantly more compared to other investments remains doubtful.

The larger manufacturers have gained a strong competitive position in international trade and will be able to profit from stricter environmental regulation outside Europe. Five of the ten largest vendors of flue gas desulphurization installations are based in the US. European companies operating in the global flue gas desulfurization system market include Alstom SA (France), FLSmidth & Co. A/S (Denmark), Hamon Corporation (London) and Siemens AG (Germany). Outside the EU and the US, Mitsubishi Electric Corporation, Ltd. (Japan) and Thermax Limited (India) are large players. The latter shows that the technology is also available within Asia, which could potentially reduce the opportunities for European producers on the Asian market.

References

Future market insights, 2017, Flue Gas Desulphurization Market: Global Industry Analysis and Opportunity Assessment 2015-2025, REP-GB-440

Global data, 2013, Flue-gas desulfurization systems market analysis to 2020, 2013 update - global market size, equipment market share, competitive landscape, regulations and pricing analysis

Marketsandmarkets.com, 2016, Flue Gas Desulfurization Systems Market by Type (Wet FGD, Dry & Semi-Dry FGD), Application (Power Generation, Chemical, Iron & Steel, Cement Manufacturing, Others), Region (North America, Europe, APAC, Middle East & Africa, Latin America) - Global Forecast to 2021)

5.1.2 Selective catalytic reduction

According to Global Market Insights Inc (2016), the global market for stationary catalytic systems was over $3 billion in 2015 and will grow at more than 6% from 2016 to 2024. The SCR market is around one fifth of the current flue gas desulphurization market.

The market in China contributed over 30% and is expected to grow over 4%, subject to increasing implementation of coal fired power plants. As of 2016, China has over 900 GW of coal fired power plant installed and 200 GW capacity of coal fired plant under construction. Growing demand for construction and renovation of port, railway and road infrastructure will favour the growth of the market from stationary catalytic systems in India. In Europe, stationary catalytic systems market size is expected to grow with stringent government regulations for industry particulate emission. Germany contributed over 25% of regional revenue share in 2015, and is predicted to exceed $320 million by 2024. Most vendors of stationary catalytic systems are based in North America. Major European producers include Amec Foster Wheeler (UK), Johnson Matthey (UK) and BASF (Germany).

The catalytic converter market for vehicles is considerably larger, and is projected to grow by 8% per year, to reach a market size of $55 billion by 2021 (or around $500 per light vehicle sold). The market for catalytic converters is primarily driven by the stringent emission regulations, increasing vehicle production, and composition of the vehicle park. The global selective catalytic reduction market for diesel commercial vehicles is expected to grow more than 9% per year during the period 2016-2020 (Research and Markets, 2016)

Large producers dominate the global market. North American producers cover almost 45% of the global market, European producers 30% and Asian producers 25%. Large European catalytic converter manufacturers include Faurecia SA (France), Eberspacher Group (Germany), Benteler International AG (Germany), and Magneti Marelli S.p.A. (Italy). Faurecia's customers include Citroen, Volkswagen, Renault , BMW, Fiat, Ford, General Motors, Toyota and Hyini-Kia.

References

Global Market Insights Inc, 2016, Global Stationary Catalytic Systems Industry - Price Trends, Growth Potential, Competitive Market Share & Forecast, 2016 – 2024

Marketsandmarkets.com , 2017,Catalytic Converter Market by Type (Three-way Catalytic Converter, Selective Catalytic Reduction, Diesel Oxidation Catalyst, and Lean NOx Trap), Material (Platinum, Palladium, Rhodium), Region, and Aftermarket by Region - Global Forecast to 2021

Research and Markets, 2016, Global Selective Catalytic Reduction Market for Diesel Commercial Vehicles 2016-2020"

5.1.3 Manure application

Strict regulations for manure application in the Netherlands and Flanders created a new market both for manure injection technology and treatment of manure to make it into an export product.

In the Netherlands, manure injection has contributed to a shift in employment from family run farms to larger contractor firms. This coincided with a lack of family successors that was experienced by many farmers. Together with the relative high environmental costs for small scale farmers, this caused a further increase in the scale of the remaining farms.

In the early 1990s, manure injectors were developed and produced by some 50 agro-technical enterprises with on average almost 100 employees. Thanks to the so-called early mover advantage, several of these enterprises have developed into exporters of the technology. The technology is actively transferred outside the Netherlands and Europe. As the manure injection technology is not protected under intellectual property rights, ultimately production of such machines will take place in the countries with the lowest production costs.

Export of dried manure to countries with a negative soil nutrient balance is potentially a growing market that could compete with artificial fertilizers. Much will depend on the buying power of receiving farms and the costs of alternative ways to get rid of surplus manure of livestock farms.

5.1.4 Chemical air scrubbers for stables

The market for chemical air scrubbers is a relatively new market. Currently, the Dutch market is among the largest in the EU. There are around 15 specialized producers of air scrubbers. Some of the larger enterprises (with more than 100 employees) also started to export air scrubbers.

5.1.5 Wood pellet burners in the residential sector

The heating pellet sector has grown steadily in the past decade. The heating pellet markets are primarily driven by the comparative costs of heating fuels. Pellets have historically been the lowest cost fuel for heating in most regions. Low oil prices have recently challenged pellets' position as the lowest cost heating fuel. If recent trends in oil prices continue, pellets will soon again be the lowest cost heating fuel (Strauss, 2017).

Currently Italy, followed by Germany, Sweden, France and Austria, are the largest users of pellets and account for almost 80% of the EU-market. In the EU, around 300.000 pellet burners are sold every year, of which 50% in Italy. Emerging markets are Germany, France and Spain. Palazetti is the largest pellet burner producer in the EU. Italian producers had a first mover advantage. The early and widespread availability of pellet burners and pellet wood caused that Italy became the country with the largest penetration of pellet burners (Palazetti, 2011).

The pellet burner market is growing fastest in Germany. Almost 25% of the households in Germany use a wood pellet central heating system. Of the new installed installations, only 15% are traditional individual fireplaces, 85% are pellet central heating systems. In Germany, the average price for pellet burners has decreased over time to about 3000 Euro. Despite the low oil and gas prices, the market of wood pellets is steadily increasing. The use of wood pellet burners is expected to further increase as they are a popular part of the energy transition (Biomass.de, 2016).

Austria and the Scandinavian countries still have a relatively low penetration of pellet burners, but a high availability of pellet wood. These countries have a long and strong wood burning tradition, which can explain the slower growth rate of pellet burners. As the number of houses that use wood for heating is not much increasing, the growth of the use of pellet burners depends on the replacement of traditional stoves. Such investments are mainly done by higher income groups.

References

Strauss W, 2017, Global pellet market outlook in 2017, in: Canadian Biomass

Biomass.de, 2016, Pellet heating in Germany: pellet burner market trends, 15-03-2016

Palazzetti, 2011, Pelletburning-stoves-development-of-the-market

6 Conclusions

The quantification of the benefits of reducing air pollution in the EU28 has considered effects on a range of receptors, including human health, crops, forests (via effects on both productivity and carbon sequestration), natural ecosystems, and materials.

The analysis of health impacts follows the methods as reported by Holland (2014) for quantification of the benefits of revisions to the Thematic Strategy on Air Pollution of December 2013. Analysis of some other receptors, notably crops, forests and natural ecosystems, has been revised, drawing on the conclusions of the ECLAIRE study funded by DG Research. The addition of a number of additional non-health endpoints does not have a major effect on the outcome of the CBA, with associated impacts contributing roughly 6% to overall damage estimates.

The review of the health impact assessment and valuation methods against recent literature indicates that the assumptions and values adopted in the analysis are in many cases conservative. This concerns the valuation of both morbidity and mortality. With respect to mortality, even the highest values adopted here are below those now recommended by OECD and adopted by USEPA. A number of impacts are omitted from the analysis at the present time, either because methods for assessment of exposure do not currently align with the modelling framework (NO_2) or because available evidence in the peer reviewed literature is limited and hence has not been subject to review by health experts similar to the WHO-led HRAPIE and REVIHAAP studies. Some of these effects, on obesity, diabetes and dementia particularly, could add significantly to both welfare losses and health care costs.

However, the analysis concludes that benefits at the level of the EU28 will substantially exceed the costs of attaining the revised ceilings, with a low estimate of the benefit:cost ratio calculated at 14, and extending beyond 50 for alternative assumptions on quantification. Whilst the extent to which benefits exceeds costs varies depending on the starting position (current legislation with or without additional measures introduced since the revision of the TSAP was agreed, or the EUCO30 scenario that integrates effects of the Climate and Energy Package), the conclusion that quantified benefits exceed costs holds firm.

The social gains from reaching the agreed air pollution reduction outweigh the private costs. This conclusion holds even when excluding the non-market benefits for ecosystems and avoided premature mortality. A reduction in the number of lost work days due to air pollution-related illness is the key mechanism providing net economic gains.

The estimates of damage to ecosystems are modest compared to health effects. However, they are sufficient to justify additional targeted action on reducing air pollutant exposure of ecosystems. Alternative approaches to valuation of ecosystem damage identified in the ECLAIRE study would lead to increased estimates of ecosystem damage, though the general method followed here, being based on expression of personal preference rather than repair costs or the (implicit) views of regulators, is most robust from an economic perspective. It is possible that the scenarios described in the valuation studies do not adequately reflect the risk faced by European ecosystems from nitrogen deposition, given the widespread extent of critical loads exceedance in Europe.

Case studies demonstrate that there are clear winners from stricter environmental policy regulation. A strong domestic market – due to domestic environmental and energy policies – emerged an important success factor in all cases. It is surprising that enterprises that produce clean technology seem less involved in stakeholder consultations than the enterprises that have a vested interest and are required to take additional abatement measures. At least, they are less vocal in the public debate.

Annex 1: Work days lost

The economic analyses conducted for the Clean Air Policy package identified work days lost due to the exposure to air pollution as a potentially important element of a cost-benefits analysis (Holland, 2014). It was, however, acknowledged that this analysis was based on a limited literature, and so further consideration is given here to the validity of the estimates made earlier.

A1.1 Results from other studies

A1.1.1 USEPA (2011)

Analysis of Amendments to the US Clean Air Act estimates benefits of 13 million avoided lost work days in 2010, rising to 17 million in 2020, as well as 3.2 million avoided lost school days in 2010, rising to 5.4 million in 2020. The analysis covers several endpoints in addition to the explicit quantification of work days lost associated with acute exposures. Analysis also factors in impacts on the labour force associated with mortality, which provide the largest contribution to productivity impacts (50% of the total). Overall, the study estimates that the U.S. labour force would be 0.34% smaller in 2010 and 0.57% smaller in 2020 if the Clean Air Act Amendments had not been enacted.

TABLE 22: WORK DAYS LOST PER CASE FOR DIFFERENT MORBIDITY ENDPOINTS, AS ASSUMED BY USEPA (2011, TABLE 8.3).

PM[2]		
Acute Myocardial Infarction[3]	Age <25: N/A Age 25-34: 17.7 days Age 35-44: 14.5 days	Age 45-54: 23.7 days Age 55-65: 137.0 days Age>65: 0 days
Chronic Bronchitis[3]	Age <25: N/A Age 25-34: 50.3 days Age 35-44: 42.2 days	Age 45-54: 55.5 days Age 55-65: 73.5 days Age >65: 0 days
Hospital Admissions, Cardiovascular[4]	Age 0-14: N/A Age 15-44: 18.3 days	Age 45-64: 17.9 days Age >64: 7.0 days
Hospital Admissions, Respiratory[4]	Age 0-14: N/A Age 15-44: 30.7 days	Age 45-64: 30.1 days Age >64: 7.5 days
Emergency Room Visits, Respiratory[5]	Average across all age groups: 0.2 days	
Work Loss Days	Average among working age population: 1 day	
Ozone[6]		
School Loss Days[7]	Average across all age groups: 0.7 days	
Worker Productivity	Not applicable[8]	
Hospital Admissions, Respiratory[9,10]	Age <2: 0 days Age >64: 7.5 days	
Emergency Room Visits, Respiratory[5]	Average across all age groups: 0.2 days	

A1.1.2 World Bank (2016)

The World Bank / Institute of Health Metrics (2016) study quantifies impacts on productivity through assessment of mortality and the reduction in working lives. No account is taken of morbidity effects on productivity, though the USEPA (2011) study suggests that impacts will be dominated by effects linked to mortality in those of working age. The focus on mortality is partly a result of the study following the methods of the Global Burden of Disease for health impact assessment. Lost income is estimated at $225 billion globally for 2013, with $30 billion in the region 'Europe and Central Asia'. Demographic and economic factors influence the lost labour output, with increasing life expectancy in regions such as Europe and North America reducing the likelihood of death during one's working life, offsetting increases in income over time.

A1.1.3 OECD (2016)

The market impacts of outdoor air pollution, which include impacts on labour productivity, health expenditures and agricultural crop yields, are projected to lead to global economic costs that gradually increase to 1% of global GDP by 2060. The projected increase in concentrations of PM2.5 and ozone will in turn lead to substantial effects on the economy. According to the calculations in this report, global air pollution-related healthcare costs are projected to increase from USD 21 billion (using constant 2010 USD and PPP exchange rates) in 2015 to USD 176 billion 2005 in 2060. By 2060, the annual number of lost working days, which affect labour productivity, are projected to reach 3.7 billion (currently around 1.2 billion) at the global level. Assessment of impacts on labour productivity are undertaken using two methods, the first focused on estimates of work days lost (in line with the HRAPIE recommendation) and the second concerning impacts on the work force associated with mortality. Both give a similar estimate for OECD-Europe of a reduction in GDP of about 0.2%, with the second approach giving a higher estimate, around 1% of GDP, for 'Rest of Europe and Asia'. Overall, it is concluded that impacts on productivity are small compared to welfare losses.

A1.1.4 UK

The UK has adopted a more extensive analysis of impacts on productivity than has so far been carried out for the European Commission based on a report by Ricardo and IOM (2014). The approach is broadly similar to USEPA (2011). Whilst analysis for the EC is limited to quantification of the impacts of fine particles on lost working days from those in paid employment, Ricardo/IOM considers:

- Lost working days by volunteers and carers, in addition to those in paid employment
- Lost working days through illness
- Lost working days through the premature death of those in employment
- Presenteeism (attendance at work when unwell and unable to operate at normal levels of effectiveness) from those in paid employment
- Direct impacts on productivity of lost work days
- Indirect impacts on productivity through lost work days leading to reduced customer satisfaction

Results are shown in Table 23. The most important effect is associated with chronic exposure to PM2.5 and mortality, accounting for 45% of the total (and a further 13% when volunteers and carers are accounted for), with absenteeism linked to acute PM2.5 exposures accounting for 28%. Presenteeism linked to acute exposure to PM2.5 accounts for a further 10%. NO_2 and ozone are also included in the analysis, though to a lesser degree. For both, mortality is accounted for using functions for acute exposures, with the emerging COMEAP position on NO_2 and chronic mortality unavailable at the time that the report was produced.

The analysis includes some significant innovation, especially linked to the impacts of chronic exposure to PM2.5 on mortality. To describe these effects on the workforce it is necessary to take a view on lost life expectancy within those participating in the labour market. A critical part of this analysis concerns assumptions on the number of individuals affected, how much life expectancy they lose, and when they lose it (i.e., whether they are still active in the labour market). Following COMEAP (2010), the authors consider that typical estimates of the number of 'air pollution deaths' represent not an actual number of individuals, but an aggregate across the population representing the mortality burden in terms of 'equivalent attributable deaths'. This concept recognises that air pollution will interact with other stresses on the body, for example from poor diet, lack of exercise and smoking, together leading to death at an earlier age than would otherwise have been the case in the absence of stress. The study thus quantifies the number of deaths that may be linked in part to air pollution, based on the number of deaths associated with cardiovascular disease, and assuming an average loss of life expectancy linked to air pollution for these deaths of two years (explaining the high number of deaths brought forward in the top row of the table). Response functions used for both mortality and morbidity are similar to those adopted for use by the Commission under the HRAPIE study.

Questions remain about several positions adopted in the analysis:

- The number of premature deaths amongst those actually in work, recognising that those most likely to die early may well be unable to work to the same age as others.
- The link between chronic morbidity, expressed against a function for chronic bronchitis, and premature retirement, which requires a position to be taken on the severity of impacts linked specifically to pollution exposure.
- The behaviour of different groups (paid workers, volunteers, carers) with respect to illness and working time.
- The valuation of indirect as well as direct impacts on productivity.
- The valuation of non-market impacts incurred by volunteers and carers.
- The inclusion of impacts on consumption (it is unclear how these are factored into the analysis, given apparent inconsistencies in the text of the report).

Beyond impacts on productivity per se, there is a further issue of the quantification and valuation of impacts of days of restricted activity more generally. It is also noted that there is no valuation provided of the loss of school days through sickness.

Application outside of the UK requires further consideration of certain aspects of the analysis. A prominent issue concerns the effect of death of workers. The Ricardo/IOM analysis assumes full employment, which is reasonable for the UK given prevailing rates of unemployment.

These questions are not intended to detract from the Ricardo/IOM report. It remains an interesting study that pushes the boundaries of quantification. The omission of estimates of impacts on productivity from CBA on air pollution policies, either wholly or in part, clearly biases results, leading to underestimation of the benefits of reducing emissions. Further debate on the study is important to refine the methods adopted. However, it can be noted here that the analysis provides a firm logic for concluding that the methods used in the core CBA analysis for the Commission are conservative and likely to underestimate impacts on productivity.

Table 23. Disaggregated estimates of annual productivity losses from air pollution for the UK from Ricardo/IOM (2014)

			Life yeas lost	Deaths brought forward	Working years lost	Work days lost ('000s)	Care hours ('000s)	Volunteering hours ('000s)	Productivity loss (£M, PV, 2012 prices)	% of total productivity loss
Chronic mortality	PM2.5	All employed (productivity), all persons (consumption)	420,426	210,213	47,033				1,210	44.6%
Acute mortality	NO2	All employed (productivity), all persons (consumption)	5,123	5,123	599				16	0.6%
Acute mortality	O3 >35ppb	All employed (productivity), all persons (consumption)	993	993	116				3	0.1%
Absenteeism	PM2.5	All employed (productivity)				6,522			765	28.2%
Presenteeism	PM2.5	All employed (productivity)				2,250			264	9.7%
Presenteeism	O3 >35ppb	All employed (productivity)				431			51	1.9%
		All above	*426,542*	*216,329*	*47,748*	*9,203*	-	-	*2,308*	*85.2%*
Chronic mortality	PM2.5	Carers					13,431		238	8.8%
Acute mortality	NO2	Carers					167		3	0.1%
Acute mortality	O3 >35ppb	Carers					32		1	0.0%
Absenteeism	PM2.5	Carers					1,760		32	1.2%
		All carers	-	-	-	-	*15,390*	-	*273*	*10.1%*
Chronic mortality	PM2.5	Volunteers						10,698	119	4.4%
Acute mortality	NO2	Volunteers						133	2	0.1%
Acute mortality	O3 >35ppb	Volunteers						26	0.3	0.0%
Absenteeism	PM2.5	Volunteers						735	8	0.3%
		All volunteers	-	-	-	-	-	*11,592*	*129*	*4.8%*
Total			426,542	216,329	47,748	9,203	15,390	11,592	2,711	

A1.2 Review of the epidemiological literature on lost work days

Over 60 papers relevant to the endpoint of lost productivity were identified (Table 24). Around half of these papers concerned epidemiological studies investigating the loss of school days. The popularity of assessing lost school days is likely a consequence of the interest in investigating impacts on the young, and the comparatively ready availability of data on many individuals (school children) from a small number of organisations in any area. The literature review collated information from all of the papers, with key issues for each of the endpoint areas discussed below.

TABLE 24: OVERVIEW OF PAPERS ON RESTRICTED ACTIVITY DAYS REVIEWED FOR THIS STUDY

Endpoint	Total number	Epidemiology	HIA	Other
Work days lost	12	10	1	1
School days lost	34	31	2	1
Restricted activity days	12	2	11	0
Presenteeism	3	3	0	0
Economic	6	0	6	6

Work days lost

Given that the literature review covered a period back to the 1970s the small number of studies identified for work days lost from air pollution is disappointing. However, studies have been conducted in several countries (USA, Finland, Canada, New Zealand, Netherlands, etc.) and for a range of pollutants (SO_2, NO_2, PM, O_3, sulphates, "air pollution"). There is some greater focus on those working outside, which is to be expected as these are the group likely to be most exposed to air pollution, particularly if they are undertaking strenuous activities. A mix of significant and insignificant results is reported, depending on the pollutant considered. Ponka (1990) for example found a significant relationship with SO_2 but not NO_2. Charante and Mulder (1996) found ozone was related to absence but not significantly, whilst Brauer and Brook (1997) report a significant adverse reaction to ozone amongst farm workers.

From this limited set of studies, the work of Ostro and his colleagues seems to provide the most reasonable basis for quantification, despite the age of the study, on the following grounds:

- From a mechanistic perspective, assessment of other impacts demonstrates the potential for air pollutants, especially fine particles, to affect health.
- Given the breadth of health impacts associated with air pollution, especially fine particles, it would be illogical to conclude that there is no potential for an effect on work attendance.
- Data presented in the Ostro paper permit development of a response function.
- The response function (4.6% change per 10 $\mu g.m^{-3}$ $PM_{2.5}$) is of the same broad magnitude as the functions for other impacts, suggesting broad consistency in outcomes.

School days lost

As noted above, the literature on school absence and air pollution is more extensive than that for work days lost. Again, studies are available from countries in Asia, Europe, North and South America. Again, studies are available for a range of pollutants or activities (NO_2, SO_2, road traffic, PM_{10}, urban air pollution, ozone, coal dust, sulphate, sugar cane burning, CO, NOx, 'poor animal health', presence of smokers in houses). Several studies found no relation with NOx/NO_2 (Ponka, 1990; Gilliland et al, 2001; Park et al, 2002), though others did (Makino, 2000; Hwang et al, 2000; Duki et al, 2003, Lu et al, 2013).

Given the variability in the situations and pollutants considered, and variability in the way that results are reported, no attempt is made here to provide a meta-analysis of the studies, though this may be possible. It is concluded here that there is a sufficient weight of evidence for including school absence in policy analysis in some way. Given the uncertainties, the position taken by the Ricardo/IOM study of using functions from Ransom and Pope (1992) for PM, and Chen et al (2000) for ozone in sensitivity analysis seems reasonable. However, valuation should be focused on the value of lost education, rather than an indirect valuation of associated lost working time of those responsible for affected children (which may be considered in the estimate of work days lost in any case). No data on the value of a day of schooling have been identified.

Results of these studies substantiate the findings of the more limited number of studies on work days lost, in demonstrating that air pollutants influence both major health conditions (life expectancy, hospital admissions, etc.) but also what are, at the level of the individual, less serious impacts.

Restricted activity days

Most of the studies identified that provide some quantification of restricted activity days generally, as opposed to work loss days specifically, were health impact assessments rather than original epidemiological work, and do not add significantly to work previously reviewed under HRAPIE, beyond showing a general acceptance of quantification of restricted activity days.

Presenteeism

There is only a limited literature on presenteeism (Gill et al, 1977; Crocker and Horst, 1981; Zivin and Neidell, 2012; Chang et al, 2016). However, these papers all report effects, and for different parts of the workforce (mail workers, fruit pickers, agricultural workers and call centre workers respectively). Zivin and Neidell report a 5.5% reduction in average productivity from agricultural workers for a 10ppb increase in ozone levels, indicating that the effect on presenteeism can be significant. Crocker and Horst found a 1.4% change in earnings per 10% change in ozone. A study by Chang et al is notable as it describes impacts of air pollution on those working indoors, whilst other studies, both of presenteeism and absenteeism, have focused on those in more strenuous activities outdoors.

Economic assessments

Most of the economic studies identified took the form of impact assessments, with the most notable being described elsewhere in this paper (e.g. USEPA, 2011; Ricardo/IOM, 2014). A recent exception is the work by Isen et al (2017), which claims to provide the first empirical quasi-experimental examination of the relationship between individuals' in-utero and early childhood exposure to environmental toxins and their labour market outcomes measured 30 years later, drawing on a reduction in air pollution levels linked to the introduction of the US Clean Air Act in 1970. Analysis compared cohorts in nonattainment counties born just before and after the legislation-mandated reductions in air pollution relative to the same difference among cohorts in attainment counties. It was found that an individual's exposure to lower ambient air pollution levels in the year of birth positively impacts earnings 30 years later, with a 10% reduction in total suspended particle levels generating a one percent increase in age-30 earnings among affected cohorts in our sample states, equivalent to \$4,300 average cumulative lifetime income gain in present value terms, implying that early-life air quality contributes a total of \$6.5 billion in lifetime earnings for each affected cohort. It is suggested that benefits are linked to both improvements in educational attainment and improvements in health later in life.

References

Abbey DE et al. (1995b). Chronic respiratory symptoms associated with estimated long-term ambient concentrations of fine particulates less than 2.5 microns in aerodynamic diameter (PM2.5) and other air pollutants. Journal of Exposure Analysis and Environmental Epidemiology, 5(2):137–159.

Abbey et al (1995a) Estimated long-term ambient concentrations of PM10 and development of respiratory symptoms in a nonsmoking population. International Archives for Occupational and Environmental Health, 50(2):139–152.

Abt Associates (2012) BenMap: Environmental Benefits Mapping and Analysis Programme. User's Manual, Appendices. [www.epa.gov/airquality/benmap/models/BenMAPAppendicesOct2012.pdf.](www.epa.gov/airquality/benmap/models/BenMAPAppendicesOct2012.pdf)

Akan, A., et al. (2014) Factors affecting quality of life of children with asthma. Allergy: European Journal of Allergy and Clinical Immunology 69: 195-196.

Al Qufaidi, R., et al. (2014) Effect of asthma on the quality of life of Saudi adolescents. Allergy: European Journal of Allergy and Clinical Immunology 69: 211.

Albrizio S, T Kozluk, V Zipperer (2017) Environmental policies and productivity growth: evidence across industries and firms, Journal of Environmental Economics and Management, vol 81, pp 209-226

Ali R et al. (2010). General Lifestyle Survey 2008: overview report. Newport, Office of National Statistics (http://www.ons.gov.uk/ons/rel/ghs/general-lifestyle-survey/2008-report/index.html, accessed 20 November 2013).

Amann et al, 2016, Recent model developments and scenario runs with the GAINS model, 45th Session of the Task Force on Integrated Assessment Modelling, Lisbon, May 23-25, 2016, slide 11-12, http://www.iiasa.ac.at/web/home/research/researchPrograms/air/policy/3_Amann-TFIAM2016-distribution.pdf

Amann et al. M (2013) Baseline Projections of Greenhouse Gases and Air Pollutants in the European Union up to 2030 - EC4MACS Final Assessment. IIASA, Laxenburg, Austria

Amann M, Anderl M, Borken-Kleefeld J, et al (2017) Progress towards the achievement of the EU's air quality and emission objectives. International Institute for Applied Systems Analysis, Laxenburg, Austria

Amann M, Bertok I, Borken-Kleefeld J, et al (2011) Cost-effective Emission Reductions to Improve Air Quality in Europe in 2020. Analysis of Policy Options for the EU for the Revision of the Gothenburg Protocol. International Institute for Applied Systems Analysis

Amann M, Borken-Kleefeld J, Cofala J, et al (2014a) Summary of the Bilateral Consultations with National Experts on the GAINS Input Data. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Amann M, Borken-Kleefeld J, Cofala J, et al (2014b) Updates to the GAINS Model Databases after the Bilateral Consultations with National Experts in 2014. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Amann M, Borken-Kleefeld J, Cofala J, et al. (2012a) Future emissions of air pollutants in Europe – Current legislation baseline and the scope for further reductions. TSAP Report #1. International Institute for Applied Systems Analysis, Laxenburg, Austria

Amann, M. (Ed.) (2012b) TSAP-2012 Baseline: Health and environmental impacts. TSAP report no.6, International Institute for Applied Systems Analysis, Laxenburg, Austria

Amann, M. (Ed.) (2012c) Scenarios of cost-effective emission controls after 2020. TSAP report no.7, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Amann, M. (Ed.) (2013) Policy scenarios for the revision of the Thematic Strategy on Air Pollution. March 2013. TSAP report no.10, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Amann, M. (Ed.) (2014) The final policy scenarios for the revision of the EU Clean Air Package. February 2014. TSAP report no.11, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Amann, M., Bertok I., Borken-Kleefeld, J., et al (2015) Adjusted historic emission data, projections, and optimized emission reduction targets for 2030 - A comparison with COM data 2013. Part A: Results for EU-28 - TSAP#16A Version 1.1. IIASA

American Lung Association (2013) Trends in COPD (chronic bronchitis and emphysema): mortality and morbidity

Anton, B. and J. R. Morgan (2014) Coal power plant emission exposure and its effect on education access. Journal of Public Health (Germany) 22(4): 313-321.

Auermann, E., Bigl, S., Hajduk, F., Meyer, R. and Lippmann, R. (1992) Effect of air pollutants on the health of the Annaberg district population with special reference to acute respiratory tract diseases. [German] Kinderarztliche Praxis, 60(4), 137-141.

Bener, A., Kamal, M. and Shanks, N. J. (2007) Impact of asthma and air pollution on school attendance of primary school children: are they at increased risk of school absenteeism? Journal of Asthma, 44, 249-252.

Birchby, D. et al (2014) Valuing the impacts of air quality on productivity. Report for the UK Dept. of Environment, Food and Rural Affairs. https://uk-air.defra.gov.uk/assets/documents/reports/cat19/1511251135_140610_Valuing_the_impacts_of_air_quality_on_productivity_Final_Report_3_0.pdf.

Björkenstam, E., et al. (2014) Associations between number of sick-leave days and future all-cause and cause-specific mortality: a population-based cohort study. BMC Public Health 14(733): (18 July 2014)-(2018 July 2014).

Brabin, B., Smith, M., Milligan, P., Benjamin, C., Dunne, E. and Pearson, M. (1994), Respiratory morbidity in Merseyside schoolchildren exposed to coal dust and air pollution. Archives of Disease in Childhood, 70(4), 305-12.

Brauer, M. and Brook, J. R. (1997) Ozone personal exposures and health effects for selected groups residing in the Fraser Valley. Atmospheric Environment, 31(14), 2113-2121

Britton, M. (2003) The burden of COPD in the U.K.: results from the Confronting COPD survey. Respir Med. Mar;97 Suppl C:S71-9.

Brink, C. and W. Smeets (2017). Europese doelen voor lucht, klimaat en energie in 2030: gevolgen voor economie en emissies. Een analyse voor de Europese Unie en Nederland met het algemeen-evenwichtsmodel WorldScan. Beleidsstudie Planbureau voor de Leefomgeving Nederland

Burton, W. N., et al. (2004) Caregiving for ill dependents and its association with employee health risks and productivity. Journal of Occupational & Environmental Medicine 46(10): 1048-1056.

Capros, P., D. Van Regemorter, L. Paroussos, P. Karkatsoulis, T. Revesz, C. Fragkiadakis, S. Tsani, I. Charalampidis, (authors); M. Perry, J. Abrell, J. C. Ciscar, J. Pycroft, B. Saveyn, (editors) (2013). GEM-E3 Model Documentation, JRC Scientific and Technical Reports.

California Environmental Protection Air Resources Board, (2016): Physical activity: health benefits, the role of the built environment and impacts of air pollution. https://www.arb.ca.gov/research/vprp/physical_activity_and_health_final_161216.pdf.

CBI (1998) Missing out: 1998 absence and labour turnover survey. Confederation of British Industry, London.

CBI (2011) Healthy returns? Absence and workplace health survey, 2011. Confederation of British Industry, London. http://www.cbi.org.uk/media/955604/2011.05-healthy_returns_-_absence_and_workplace_health_survey_2011.pdf

CBI (2013) Fit for purpose: Absence and workplace health survey 2013. Confederation of British Industry, London. http://www.cbi.org.uk/media/2150120/cbi-pfizer_absence___workplace_health_2013.pdf

Chanel, O and Luchini, S. (2014) Monetary values for risk of death from air pollution exposure: a context-dependent scenario with a control for intra-familial altruism. Journal of Environmental Economics and Policy, 3, 67-91.

Chang, T, J Graff Zivin, T Gross, M Neidell (2016): The effect of pollution on worker productivity: evidence from call-center workers in China, NBER Working Paper 22328, http://www.nber.org/papers/w22328.

Charante, A. W. M. van and Mulder, P. G. (1996) Effects of smog on absenteeism in forestry workers. Archives of Environmental Health, 51, 34-41.

Chen, L. and Omaye, S. T. (2001) Air pollution and health effects in northern Nevada. Reviews on Environmental Health, 16, 133-149.

Chen, L., Jennison, B. L., Yang, W. and Omaye, S. T. (2000) Elementary school absenteeism and air pollution. Inhalation Toxicology, 12(11), 997-1016.

Cifuentes, L., Borja-Aburto, V. H., Gouveia, N., Thurston, G. and Davis, D. L. (2001) Assessing the health benefits of urban air pollution reductions associated with climate change mitigation (2000-2020): Santiago, São Paulo, México City, and New York City. Environmental Health Perspectives, 109, 419-425.

COMEAP (2010) Mortality effects of long-term exposure to particulate air pollution in the UK. Committee on the Medical Effects of Air Pollutants. https://www.gov.uk/government/publications/comeap-mortality-effects-of-long-term-exposure-to-particulate-air-pollution-in-the-uk.

Concawe (2012) Evaluating the Value of a Life Year (VOLY). Concawe Review, 21/2, 13-15. https://www.concawe.eu/DocShareNoFrame/docs/1/FJNDLCHBNLPNDCMBONJBDKML5CIT3G5C5JPYP3PDW69D/CEnet/docs/DLS/CONCAWE_CR212-2013-00753-01-E.pdf.

Concawe (2013a) Concentration response functions for morbidity endpoints under the project HRAPIE. Concawe, The oil companies' European association for environment, health and safety in refining and distribution. https://www.concawe.eu/content/default.asp?PageID=580&DocID=43272

Concawe (2013b) CONCAWE Comments on the Key Submissions Associated with 5th Stakeholder Expert Group of the Air Quality Policy Review held in Brussels, 3rd April 2013. Cost Benefit Analysis under the Microscope. Concawe, The oil companies' European association for environment, health and safety in refining and distribution. https://www.concawe.eu/content/default.asp?PageID=580&DocID=43615

Crippa M. et al (2016) Forty years of improvement in European air quality: regional policy-industry interactions with global impacts, Atmospheric Chemistry and Physics vol 16 p 3825-3841

Currie, J., et al. (2009) Does pollution increase school absences? Review of Economics and Statistics 91(4): 682-694.

Dal Negro R, Rossi A, Cerveri I. (2003) The burden of COPD in Italy: results from the Confronting COPD survey. Respir Med. Mar;97 Suppl C:S43-50.

Dekker T, HRJ Vollebergh, FP de Vries,CA Withagen (2012) Inciting Protocols – how international environmental agreements trigger knowledge transfers, Journal of Environmental Economics and Management, vol 64, pp 45-67

Desaigues, B., et al (2011) Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY). Ecological Indicators 11 (2011) 902–910.

Dickie, M. and Ulery, V.L. (2001), "Valuing Health in the Household: Are Kids Worth More Than Parents?" Paper presented at the Association of Environmental and Resource Economists 2001 Workshop: "Assessing and Managing Environmental and Public Health Risks", June.

Ding Li, Yan Zhang & Shuang Ma (2017): Would Smog Lead to Outflow of Labor Force? Empirical Evidence from China, Emerging Markets Finance and Trade, 53:5, p1122-1134, http://dx.doi.org/10.1080/1540496X.2017.1282858

Duki, M. I., Sudarmadi, S., Suzuki, S., Kawada, T. and Tri-Tugaswati, A. (2003) Effect of air pollution on respiratory health in Indonesia and its economic cost. Archives of Environmental Health, 58, 135-143.

EC (2013a) Proposal for a Directive of the European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants and amending Directive 2003/35/EC. European Commission (EC), Brussels, Belgium

EC (2013b) Impact Assessment accompanying the documents Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions -a Clean Air Programme for Europe. European Commission (EC), Brussels, Belgium

EC4MACS (European Consortium for the Modelling of Air Pollution and Climate Strategies), 2013, Baseline Projections of Greenhouse Gases and Air Pollutants in the European Union up to 2030 (pp 84-85)

ECLAIRE, 2015, Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems, Seventh Framework Programme; D18.3 Elaboration of the Modelling Approach for Benefits Analysis, Including Illustrative Examples

ECLAIRE, 2015b, Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems, Seventh Framework Programme; D20.8: Policy recommendations and advice to other interest groups

European Commission (2013), Impact Assessment, SWD(2013)531 Accompanying the Communication on a Clean Air Programme for Europe

European detailed mortality database: http://data.euro.who.int/dmdb/

European health for all database: http://data.euro.who.int/hfadb/

European hospital morbidity database: http://www.euro.who.int/en/what-we-do/data-and-evidence/databases/european-hospital-morbidity-database-hmdb2

European mortality database (MDB): http://data.euro.who.int/hfamdb/

Eurostat (2013) Employment rate data. http://epp.eurostat.ec.europa.eu/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=tsdec420&language=en accessed 21/09/2013.

Eurostat (2017) Employment statistics. http://ec.europa.eu/eurostat/statistics-explained/index.php/Employment_statistics#Employment_rates_by_sex.2C_age_and_educational_attainment_level accessed 27/9/2017.

ExternE (1995) Volume 2: methodology. ExternE: Externalities of Energy. http://www.externe.info/externe_d7/?q=node/37.

ExternE (1999) DGXII (JOULE Programme) Externalities of Energy, ExternE Project, Report Number 7, Methodology: Update 1998. Holland, M.R. and Forster, D. (eds.).

ExternE (2005) Methodology, 2005 update. ExternE: Externalities of Energy. http://www.externe.info/externe_d7/?q=node/30.

Gill, I.S. et al (1977) Acute effects of air pollutants on healthy outdoor workers. American Review of Respiratory Disease, 115(4 II), 215.

Gilliland, F. D., Berhane, K., Rappaport, E. B., Thomas, D. C., Avol, E., Gauderman, W. J., London, S. J., Margolis, H. G., McConnell, R., Islam, K. T. and Peters, J. M. (2001) The effects of ambient air pollution on school absenteeism due to respiratory illnesses. Epidemiology, 12, 43-54.

Graff Zivin, J, M Neidell (2012): The Impact of Pollution on Worker Productivity, The American Economic Review, Vol. 102, No. 7 (Dec 2012), pp. 3652-3673 Stable URL: http://www.jstor.org/stable/41724649

Hoek G et al. (2012). PM10, and children's respiratory symptoms and lung function in the PATY study. European Respiratory Journal, 40(3):538–547.

Hoek G, Brunekreef B (1995). Effect of photochemical air pollution on acute respiratory symptoms in children. American Journal of Respiratory and Critical Care Medicine, 151(1):27–32.

Holland, M. (2012) Cost-benefit Analysis of Scenarios for Cost-Effective Emission Controls after 2020, Version 1, Corresponding to IIASA TSAP Report #7. November 2012.

Holland, M. (2013a) Cost-benefit Analysis of Scenarios for Cost-Effective Emission Controls after 2020, Version 1, Corresponding to IIASA TSAP Report #10. March 2013.

Holland, M. and King, K. (1998) Economic Evaluation of Air Quality Targets for Tropospheric Ozone. Part C: Economic Benefit Assessment. http://ec.europa.eu/environment/enveco/air/pdf/tropozone-c.pdf

Holland, M. Pye, S., Jones, G., Hunt, A. and Markandya, A. (2013b) EC4MACS Modelling Methodology: The ALPHA Benefit Assessment Model. http://www.ec4macs.eu/content/report/EC4MACS_Publications/MR_Final%20in%20pdf/Alpha_Methodologies_Final.pdf.

Holland, M., Hunt, A., Hurley, F., Navrud, S., Watkiss, P. (2005a) Methodology for the Cost-Benefit analysis for CAFE: Volume 1: Overview of Methodology. http://www.cafe-cba.org/assets/volume_1_methodology_overview_02-05.pdf

Holland, M., Hurley, F., Hunt, A. and Watkiss, P. (2005b) Methodology for the Cost-Benefit analysis for CAFE: Volume 3: Uncertainty in the CAFE CBA. Available at: http://www.cafe-cba.org/assets/volume_3_methodology_05-05.pdf

Holland, M., Wagner, A., Hurley, F., Miller, B. and Hunt, A. (2011) Cost Benefit Analysis for the Revision of the National Emission Ceilings Directive: Policy Options for revisions to the Gothenburg Protocol to the UNECE Convention on Long-Range Transboundary Air Pollution. http://ec.europa.eu/environment/air/pollutants/pdf/Gothenburg%20CBA1%20final%202011.pdf

Holland, M.R., Forster, D. and King, K. (1999) Cost-Benefit Analysis for the Protocol to Abate Acidification, Eutrophication and Ground Level Ozone in Europe. Report Number: Air and

Energy 133, Ministry of Housing, Spatial Planning and Environment (MVROM), Directorate Air and Energy, ipc 640, P.O. Box 30945, 2500 GX The Hague, The Netherlands.

Houghton, F., Gleeson, M. and Kelleher, K. (2003) The use of primary/national school absenteeism as a proxy retrospective child health status measure in an environmental pollution investigation. Public Health, 117, 417-423.

HRAPIE (see WHO, 2013b)

Hubbell, B. J., Hallberg, A., McCubbin, D. R. and Post, E. (2005) Health-related benefits of attaining the 8-hr ozone standard. Environmental Health Perspectives, 113, 73-82.

Hunt, A., Navrud, S., Maca, V. and Scasny, M. (2011) Monetary values for health end-points used in the HEIMTSA/INTARESE Common Case Study. Thematic Priority 6.3, Deliverable 4.1.2. HEIMTSA (Health and Environment Integrated Methodology and Toolbox for Scenario Development. Sixth Framework Programme of the European Commission. http://www.heimtsa.eu/LinkClick.aspx?fileticket=Z79uJ1ZKuX8%3d&tabid=2937&mid=6403&language=en-GB.

Hurley, F., Cowie, H., Hunt, A., Holland, M., Miller, B., Pye, S., Watkiss, P. (2005) Methodology for the Cost-Benefit analysis for CAFE: Volume 2: Health Impact Assessment. Available at: http://www.cafe-cba.org/assets/volume_2_methodology_overview_02-05.pdf

Hwang, JingShiang, Chen, YiJu, Wang, JungDer, Lai, YuMin, Yang, ChunYuh and Chan, ChangChuan (2000) Subject-domain approach to the study of air pollution effects on schoolchildren's illness absence. American Journal of Epidemiology, 152, 67-74.

IEA (2016) World Energy Outlook, Paris IIASA, 2014, The Final Policy Scenarios of the EU Clean Air Policy Package, TSAP Report #11 Version 1.1a, p40

IIASA (2017)

Isen A, M Rossin-Slater, W Reed Walker (2017): Every Breath You Take—Every Dollar You'll Make: The Long-Term Consequences of the Clean Air Act of 1970, Journal of Political Economy, 2017, vol. 125, no. 3. Se also http://www.nber.org/papers/w19858.pdf.

Izquierdo, J.L. (2003) The burden of COPD in Spain: results from the Confronting COPD survey. Respir Med. Mar;97 Suppl C:S61-9.

Jakubiak-Lasocka, J. et al (2015) Impact of traffic related air pollution on health. Advances in Experimental Medicine and Biology, 834, 21-29.

Jerrett M, Burnett R, Pope A C, Ito K, Thurston G. (2009). Long-term ozone exposure and mortality. N Engl J Med 360 (11) 1085-1095.

Jones, A. Y., Lam, P. K. and Dean, E. (2006) Respiratory health of bus drivers in Hong Kong. International Archives of Occupational & Environmental Health, 79, 414-418.

Krupnick, A., Ostro, B. and Bull, K. (2005) Peer review of the methodology of cost-benefit analysis of the Clean Air For Europe Programme. http://www.cafe-cba.org/assets/cafe_peer_review.pdf

Kunzli, N. (2002) The public health relevance of air pollution abatement, European Respiratory Journal, 20, 198-209.

Kunzli, N., Kaiser, R. and Seethaler, R. (2001) Air pollution and health: Quantification of the public health impact. [German] Umweltmedizin in Forschung und Praxis, 6, 202-212.

Kunzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., Herry, M., Horak, F., Jr., Puybonnieux-Texier, V., Quenel, P., Schneider, J., Seethaler, R., Vergnaud, J. C. and Sommer, H. (2000 Public-health impact of outdoor and traffic-related air pollution: a European assessment. Lancet, 356, 795-801.

Kunzli, N., Kaiser, R., Rapp, R., Sommer, H., Wanner, H. U., Seethaler, R. and Ackermann-Liebrich, U. (1997) Air pollution in Switzerland: Quantification of health effects and use of epidemiologic data. [German] Schweizerische Medizinische Wochenschrift, 127(34), 1361-1370.

Laforest, L., et al. (2004) Association between asthma control in children and loss of workdays by caregivers. Annals of Allergy, Asthma & Immunology 93(3): 265-271.

Lemos, M., et al. (2011) Correlation between respiratory events in asthmatic children and passive sampling of pollutants. American Journal of Respiratory and Critical Care Medicine 183 (1 MeetingAbstracts).

Levy, D. E., et al. (2011) School absenteeism among children living with smokers. Pediatrics 128(4): 650-656.

Levy, J. I., Carrothers, T. J., Tuomisto, J. T., Hammitt, J. K. and Evans, J. S. (2001) Assessing the public health benefits of reduced ozone concentrations, Environmental Health Perspectives, 109, 1215-1226.

Lu, R., et al. (2013) Study on the effect of air pollution on respiratory system health of students in Fengtai District of Beijing. Occupation and Health 29(21): 2754-2757.

Makino, K. (2000) Association of school absence with air pollution in areas around arterial roads. Journal of epidemiology / Japan Epidemiological Association, 10, 292-299.

Marcon, A., et al. (2014) Association between PM10 concentrations and school absences in proximity of a cement plant in northern Italy. International Journal of Hygiene and Environmental Health 217(2/3): 386-391.

Michael Porter and Claas van der Linde (1995) Toward a new conception of the environment-competitiveness relationship, Journal of Economic Perspectives, vol 9, no 4, pp97-118

Miller, B., Hurley, J.F. and Shafrir, A. (2011) Health Impact Assessment for the National Emissions Ceiling Directive (NECD) – Methodological Issues http://ec.europa.eu/environment/air/pollutants/pdf/IOM%20Report%20methodology%20NECD%20HIA.pdf

Milligan, P. J. M., Brabin, B. J., Kelly, Y. J., Pearson, M. G., Mahoney, G., Dunne, E., Heaf, D. and Reid, J. (1998) Association of spatial distribution of childhood respiratory morbidity with environmental dust pollution, Journal of Toxicology and Environmental Health, 55(3), 169-184.

Mills, G. and Harmens, H. (Eds.) (2011) Ozone Pollution: A hidden threat to food security. http://icpvegetation.ceh.ac.uk/publications/documents/ozoneandfoodsecurity-ICPVegetationreport%202011-published.pdf

Mohai, P., et al. (2011) Air pollution around schools is linked to poorer student health and academic performance. Health Affairs 30(5): 852-862.

Morales-Lage R, A Bengochea-Morancho, I Martínez-Zarzoso (2016) Does environmental policy stringency foster productivity in OECD countries? Center for European Governance and Economic Development Research, discussion paper nr 282, Göttingen

Muller NZ, A Jha (2017), Environmental policy, pollution and economic growth, Science Daily, 9 August 2017, DOI: 10.1371/journal.pone.0181407

Netten, A. and Curtis, L. (2000) Unit costs of Health and Social Care 2000. Personal Social Services Research Unit (PSSRU). http://www.pssru.ac.uk/index.htm.

Nordic competition authorities, 2010, Competition Policy and Green Growth,

OECD (2006) Economic Valuation of Environmental Health Risks to Children. OECD, Paris.

OECD (2012) Mortality Risk Valuation in Environment, Health and Transport Policies. OECD, Paris.

OECD (2016): The economic consequences of outdoor air pollution, CIRCLE project. http://www.oecd.org/env/the-economic-consequences-of-outdoor-air-pollution-9789264257474-en.htm.

OECD, 2017, Employment Implications of Green Growth: Linking Jobs, Growth, and Green Policies, Paris

Ostro BD (1987). Air pollution and morbidity revisited: a specification test. Journal of Environmental Economics Management, 14(1):87–98.

Ostro BD, Rothschild S (1989). Air pollution and acute respiratory morbidity: an observational study of multiple pollutants. Environmental Research, 50:238–247.

Ostro, B. D. (1987) Air pollution and morbidity revisited: A specification test. Journal of Environmental Economics and Management, 14(1), 87-98.

Ostro, B. D., Tran, H. and Levy, J. I. (2006) The health benefits of reduced tropospheric ozone in California. Journal of the Air & Waste Management Association, 56, 1007-1021.

Park, H., Lee, B., Ha, E. H., Lee, J. T., Kim, H. and Hong, Y. C. (2002) Association of air pollution with school absenteeism due to illness, Archives of Pediatrics and Adolescent Medicine, 156, 1235-1239.

Peters, A., Dockery, D. W., Heinrich, J. and Wichmann, H. E. (1997) Short-term effects of particulate air pollution on respiratory morbidity in asthmatic children. European Respiratory Journal, 10(4), 872-9.

Piperno D, Huchon G, Pribil C, Boucot I, Similowski T. (2003) The burden of COPD in France: results from the Confronting COPD survey. Respir Med. Mar;97 Suppl C:S33-42.

Ponka, A. (1990) Absenteeism and respiratory disease among children and adults in Helsinki in relation to low-level air pollution and temperature. Environmental Research, 52(1), 34-46.

Pope, C.A. III (1996) Adverse health effects of air pollutants in a nonsmoking population, Toxicology, 111(1-3), 149-155

Pope, C.A. III (1996) Particulate pollution and health: a review of the Utah valley experience. Journal of Exposure Analysis and Environmental Epidemiology, 6(1), 23-34

Pothikamjorn, S. L., Ruxrungtham, K., Thampanitchawong, P., Fuangthong, R., Srasuebkul, P., Sangahsapaviriyah, A., Suttithavil, W., Klaewsongkram, J., Parisuthikul, V., Viravan, T., Rumsaeng, V., Kana, K., Direkwattanachai, C., Kamchaisathien, V. and Phanupak, P. (2002) Impact of particulate air pollutants on allergic diseases, allergic skin reactivity and lung function. Asian Pacific Journal of Allergy & Immunology, 20, 77-83.

Raaschou-Nielsen, O., Palmgren, F., Solvang Jensen, S., Wahlin, P., Berkowicz, R., Hertel, O., Vrang, M. L. and Loft, S. H. (2002) Health effects of ambient particulate matter - A quantitative assessment. [Danish] Ugeskrift for Laeger, 164, 3959-3963.

Ransom, M. R. and Pope, C. A. III, (1992) Elementary school absences and PM10 pollution in Utah Valley, Environmental Research, 58(2), 204-19.

Rayment M, et al (2009) The economic benefits of environmental policy, final report under framework contract ENV.G.1/FRA/2006/0073-2nd

RCP (2016) Every breath we take: the lifelong impact of air pollution. Royal College of Physicians and Royal College of Paediatrics and Child Health.

REVIHAAP (see WHO, 2013a)

Ricardo / IOM (2014) Valuing the impacts of air quality on productivity. Report for the UK Dept. of Environment, Food and Rural Affairs. https://uk-air.defra.gov.uk/assets/documents/reports/cat19/1511251135_140610_Valuing_the_impacts_of_air_quality_on_productivity_Final_Report_3_0.pdf

Rindel, A. K., et al. (1992) Morbidity of children attending day care centers in Copenhagen illustrated by social, physical, environmental and hygienic factors. [Danish]. Ugeskrift for Laeger 154(31): 2140-2146.

Romieu, I., Lugo, M. C., Velasco, S. R., Sanchez, S., Meneses, F. and Hernandez, M. (1993) Air pollution and school absenteeism among children in Mexico City. American Journal of Epidemiology, 136(12), 1524-1531.

Rosales-Castillo, J. A., Torres-Meza, V. M., Olaiz-Fernandez, G. and Borja-Aburto, V. H. (2001) Acute effects of air pollution on health: Evidence from epidemiological studies. [Spanish] Salud Publica de Mexico, 43, 544-555.

Scapecchi, P. (2008) The Health Costs of Inaction with Respect to Air Pollution, OECD Environment Working Papers, No. 2, OECD Publishing, Pari, http://dx.doi.org/10.1787/241481086362

Schindler C et al. (2009). Improvements in PM10 exposure and reduced rates of respiratory symptoms in a cohort of Swiss adults (SAPALDIA). American Journal of Respiratory and Critical Care Medicine, 179(7):579–587.

Seethaler, R., Sommer, H. and Kunzli, N. (2002) Monetisation of air pollution-related health effects. [German] Umweltmedizin in Forschung und Praxis, 7, 17-25.

Sih, T. M. (1997) Lower airways and pollution. [Portuguese] Jornal de pediatria, 73(3), 166-170.

Stieb DM et al. (2002). Air pollution and disability days in Toronto: results from the national population health survey. Environmental Research, 89(3):210–221.

Stieb, D. M., Civita, P. de, Johnson, F. R., Manary, M. P., Anis, A. H., Beveridge, R. C. and Judek, S. (2002) Economic evaluation of the benefits of reducing acute cardiorespiratory morbidity associated with air pollution. Environmental Health: A Global Access Science Source, 1(7), 18 December 2002.

Studnickal, M., Oberfeld, G., Horak, F., Jr., Kaiser, R. and Kunzli, N. (2001) Health consequences of traffic-related air pollution in Austria. Austrian report of the tri-lateral WHO project (participating countries Austria, France and Switzerland) on quantifiable costs of road traffic. [German] Atemwegs- und Lungenkrankheiten, 27, 439-456.

Terzano, C. and Allegra, L. (2006) Effects of atmospheric gaseous pollution and fine particles on respiratory and cardiovascular function and disease. [Italian] GIMT - Giornale Italiano delle Malattie del Torace, 60, 393-416.

Tessier, J. F., Coudray, P. and Bernadou, M. (1977) Atmospheric pollution in Bordeaux and absenteeism in schoolchildren due to respiratory causes. [French] Bordeaux Medical, 10(20), 1361-1370.

Toma, Tudor (2000) Outdoor air pollution has a large impact on public health. Bulletin of the World Health Organization, 78, 1371.

USEPA (2011) Benefits and Costs of the Clean Air Act 1990-2020, the Second Prospective Study. https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act-1990-2020-second-prospective-study.

USEPA (2011) The Benefits and Costs of the Clean Air Act from 1990 to 2020. Final Report – Rev. A. U.S. Environmental Protection Agency, Office of Air and Radiation. http://www.epa.gov/air/sect812/feb11/fullreport_rev_a.pdf.

Van Der Lende, R., Huygen, C. and Jansen Koster, E. J. (1975) The lungs and air pollution; results of an epidemiological study in the Netherlands. Prax.Pneumol, 29(9), 505-512.

Vrontisi Z, J Abrell, F Neuwahl, B Saveyn, F Wagner, 2016, Economic impacts of EU clean air policies assessed in a CGE framework, Environmental Science & Policy 55 pp54-64

Ward DJ, Ayres JG (2004). Particulate air pollution and panel studies in children: a systematic review. Occupational and Environmental Medicine, 61(4):e13.

WHO (2013a) REVIHAAP: Review of evidence on health aspects of air pollution – REVIHAAP project: final technical report. World Health Organization, Regional Office for Europe, Bonn, Germany. http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report.

WHO (2013b) HRAPIE: Health risks of air pollution in Europe – HRAPIE project Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide. World Health Organization, Regional Office for Europe, Bonn, Germany. http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/health-risks-of-air-pollution-in-europe-hrapie-project-recommendations-for-concentrationresponse-functions-for-costbenefit-analysis-of-particulate-matter,-ozone-and-nitrogen-dioxide.

WHO databases. Copenhagen, WHO Regional Office for Europe:

Wilson, J. G., et al. (2011) Air pollution and restricted activity days among New Zealand school children and staff. International Journal of Environment and Pollution 41(1/2): 140-154.

Wong, E. Y., Gohlke, J., Griffith, W. C., Farrow, S. and Faustman, E. M. (2004) Assessing the health benefits of air pollution reduction for children. Environmental Health Perspectives, 112, 226-232.

World Bank and Institute for Health Metrics and Evaluation, (2016): The Cost of Air Pollution; Strengthening the Economic Case for Action. http://documents.worldbank.org/curated/en/781521473177013155/The-cost-of-air-pollution-strengthening-the-economic-case-for-action.

Wouters, E.F. (2003) The burden of COPD in The Netherlands: results from the Confronting COPD survey. Respir Med. Mar;97 Suppl C:S51-9.