Technical Policy Briefing Note 6

Technical Policy Briefing Note 6: Ancillary Air Quality Benefits

The Reduction in Air Quality Impacts and Associated Economic Benefits of Mitigation Policy:

Summary of Results from the EC RTD Climate Cost Project

Mike Holland, Markus Amann, Chris Heyes, Peter Rafaj, Wolfgang Schöpp, Alistair Hunt and Paul Watkiss

ClimateCost

SEVENTH FRAMEWORK PROGRAMME

Key Messages

- Mitigation policy has a beneficial effect in reducing greenhouse gas (GHG) emissions, because it introduces cleaner fuels and improves energy efficiency. These mitigation measures also reduce emissions of air pollutants such as oxides of nitrogen (NOx), sulphur dioxide (SO_2) and fine particles (PM), and as a result, they improve air quality.

- Despite large improvements in Europe in recent decades, current air quality (air pollution) levels are responsible for adverse health and environmental impacts, including a significant shortening of life expectancy. These impacts have large economic costs. The air quality improvements from mitigation policy will reduce these costs, and therefore lead to economic co-benefits.

- These ancillary co-benefits are important when comparing the costs and benefits of mitigation. Whilst the full benefit of European GHG reductions may only be experienced by future generations and occur at the global level, the ancillary benefits of air quality improvements occur in the short-term and lead to direct (local) benefits in Europe.

- The ClimateCost study has assessed the health, environmental and economic air quality benefits of mitigation policy. The analysis used the GAINS and ALPHA models to assess a mitigation policy scenario that is consistent with the EC's 2 degrees target, and compared this to a baseline medium-high emissions scenario.

- The estimated benefits of the 2 degrees stabilisation (mitigation) scenario, over and above the baseline scenario, are substantial.

- Under the mitigation scenario, there are large reductions in EU air pollutant emissions, with a 60% reduction in sulphur dioxide (SO_2) and

480,000

years of life (expectancy) gained annually in the EU27 by 2050, due to the improvement in air quality under a mitigation scenario

€44 to €95bn

annual air quality co-benefit in the EU27 in 2050 under a mitigation scenario

€24

air quality co-benefit per tonne of CO_2 abated (EU27 in 2050)

€36bn/yr

avoided air quality abatement costs in 2050 (EU27) under a mitigation scenario a 46% reduction in oxides of nitrogen (NOx) when compared to the baseline in 2050. There is also a 19% reduction in emissions of particulate matter (PM).

- These emission reductions – and the associated improvement in air quality – lead to large health benefits. Under the mitigation scenario, average life expectancy in Europe (EU27) is extended by 1 month of life by 2050: equivalent to an annual benefit of 480,000 years of life.

- In addition, the mitigation scenario reduces the number of ozone related deaths in the EU27 by 3400 fatalities a year by 2050, as well as reducing the annual number of cases of chronic bronchitis and hospital admissions by 27,000 and 20,000 respectively. It also leads to an estimated reduction of 127 million minor symptom days each year by 2050.

- The economic benefits of these health improvements are estimated at €43 billion per year in 2050 in the EU27 (current prices, undiscounted), based on a value of life years lost approach for the change in mortality risk. Using an alternative valuation metric of the value of a statistical life, the benefits of the mitigation scenario increase to €94 billion per year by 2050.

- When expressed against the CO_2 reductions achieved, the air quality co-benefits of the mitigation scenario are around €24 for each tonne of CO_2 reduced over the period investigated.

- GHG mitigation policies also reduce the need to implement air quality pollution measures and equipment required by legislation. These avoided costs have also been considered in ClimateCost, using the GAINS model. Under the mitigation scenario, the regulatory air quality costs in the EU27 are reduced by €36 billion per year by 2050, mostly due to avoided costs of NOx and PM control in the transport sector.

- The mitigation scenario also leads to important co-benefits for managed and unmanaged ecosystems, reducing acidification and eutrophication. Under the mitigation scenario, the area of forest in the EU27 that exceeds the critical loads for acid deposition is reduced by 42 thousand km^2 by 2050, a 15% reduction on the baseline. The area of ecosystems in the EU27 that exceeds the critical load for nitrogen deposition and eutrophication is reduced by 144 thousand km^2 by 2050.

- The study has also considered the air quality benefits of global mitigation policy in other world regions using the GAINS model, which reveals even larger health benefits. Under the mitigation scenario, the average life expectancy gain is estimated at 19 months in China and nearly 30 months in India by 2050, compared to the baseline, and would also reduce ozone related mortality by more than 75 thousand cases per year across the two countries.

- The magnitude of the co-benefits above demonstrates they are very relevant to the policy discussion on the costs and benefits of mitigation. It also emphasises the importance of exploiting synergies in the fields of climate and air pollution.

1. Introduction

The objective of the ClimateCost project is to advance knowledge on the economics of climate change, focusing on three key areas: the economic costs of climate change (the costs of inaction), the costs and benefits of adaptation, and the costs and benefits of long-term targets and mitigation. The project has assessed the impacts and economic costs of climate change in Europe and globally. This included a bottom-up sectoral impact assessment and analysis of adaptation for Europe, as well as a global economic modelling analysis with sector-based impact models, computable general equilibrium models and global economic integrated assessment models.

This technical policy briefing note (TPBN)[1] provides an overview of the air quality benefits work undertaken in the project, which has assessed the avoided impacts and economic ancillary benefits of mitigation policy, focusing on Europe (EU27), though with discussion of the benefits for China and India. The paper is based on ClimateCost reports by Rafaj et al (2011) and Holland et al (2011a)[2].

1.1 Background

Air pollution has a number of important impacts on human health, as well as on the natural and man-made environment. These include impacts of short-term and long-term exposure to air pollution on our health, damage to building materials, effects on crops, and impacts on natural and semi-natural ecosystems (both terrestrial and aquatic). These are described in the box below. These impacts have a number of important economic costs – known as external costs or externalities – as they are not included in the price of goods or services that lead to air pollution.

Concerns over these impacts have led to the introduction of major air quality policies in Europe over the past few decades. These were initially driven by the need to reduce impacts on natural or semi-natural ecosystems (acidification and eutrophication) and were implemented as international agreements to reduce emissions. More recently, they have focused on reducing the significant impacts of air quality concentrations on human health and the wider environment. These have been translated through to a set of policies, which includes the Thematic Strategy on Air Pollution (CEC, 2005). These policies have led to substantial reductions in emissions – and improvement of air quality – since the late 1970s.

Nevertheless, air pollution still leads to widespread health and environmental impacts in Europe. Recent reports for the European Commission (Amann et al, 2011; Holland et al, 2011b) estimate that across Europe as a whole, as far east as the European regions of Russia, nearly 5 million life years will be lost annually as a result of emissions in 2020, and 37% of ecosystems will be at risk of damage from nitrogen deposition.

At the same time that air pollution policy continues to target these impacts, it has become apparent that mitigation policy can lead to very large reductions in the air pollutant emissions – and thus large improvements in air quality. These arise because the use of cleaner fuels (e.g. renewables) or reduced demand (e.g. through energy efficiency) reduces fossil fuel use and the associated combustion emissions of oxides of nitrogen (NOx), sulphur dioxide (SO_2) and fine particles (PM). These provide additional benefits that should be considered when weighing up the potential costs and benefits of mitigation policy directed at GHG control.

[1] The research leading to these results received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° 212774. This TPBN was written by Mike Holland and Alistair Hunt from Metroeconomica, Markus Amman, Chris Heyes, Peter Rafaj and Wolfgang Schöpp from the Mitigation of Air Pollution & Greenhouse Gases (MAG) Program of IIASA, and Paul Watkiss from Paul Watkiss Associates (UK). The citation should be: Holland, M., Amann, M., Heyes, C., Rafaj, P., Schöpp, W. Hunt, A., and Watkiss, P. (2011). (2011). The Reduction in Air Quality Impacts and Associated Economic Benefits of Mitigation Policy. Summary of Results from the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

[2] This note is a summary of two ClimateCost reports, from Work Package 5.1.

– Co-benefits of post-2012 global GHG-mitigation policies. Peter Rafaj, Wolfgang Schöpp, Peter Russ‡, Chris Heyes, Markus Amann. Mitigation of Air Pollution & Greenhouse Gases (MAG) Program, IIASA. ‡Institute for Prospective Technological Studies (IPTS), Joint Research Centre (JRC), Seville, Spain.

– Quantification and monetisation of the co-benefits from control of regional air pollutants. Mike Holland, Alistair Hunt, Fintan Hurley, Brian Miller, Anne Wagner, Ritu Mathur, Atul K, Anil Ramaprasad.

These are summarised in the final deliverable, which is available from the ClimateCost website.

The impacts of air pollution

Studies of early air pollution episodes (such as the London smog episodes of the 1950s) revealed that very high levels of ambient air pollution are associated with strong increases in **health impacts**. Recent studies also reveal smaller increases at the current levels of air pollution typical of Europe. The health effects associated with short-term (acute) exposure include premature mortality (deaths brought forward), respiratory and cardio-vascular hospital admissions, and probably exacerbation of asthma and other respiratory symptoms. The evidence for these effects is strongest for particulates (usually characterized as PM_{10} or $PM_{2.5}$) and for ozone. There is also now strong evidence that long-term (chronic) exposure to particulates damages health and that these effects, measured through reduced life expectancy, are substantially greater than the effects of acute exposure. These health impacts have major economic costs because of the additional burden they impose on the health service, the lost time at work, and the pain and suffering of affected individuals.

Air pollution also impacts on other receptors. The effects of atmospheric pollutants on **buildings** provide some of the clearest examples of air pollution damage. Air pollution is associated with a number of impacts including acid corrosion of stone, metals and paints in 'utilitarian' applications; acid impacts on materials of cultural merit (including stone, fine art, etc.); ozone damage to polymeric materials, particularly natural rubbers; and soiling of buildings. SO_2 is the primary pollutant of concern in building corrosion. The analysis of building soiling is concerned with the deposition of particles on external surfaces and the dis-colouration of stone and other materials.

Ozone is recognised as the most serious regional air pollutant problem for **agriculture** in Europe at the present time, though some air pollutants other than ozone have been linked in the literature to crop damages (e.g. SO_2, NO_2, HF), though generally at higher levels than are currently experienced.

Air pollution also impacts on **natural and semi-natural ecosystems.** The effects of SO_2 and secondary pollutants on ecosystems ranging from forests to freshwaters are well known, and have been the prime concern until recently in international negotiations. Emissions of NO_X are also known to be responsible for a range of impacts on ecosystems particularly through their contribution to acidification, eutrophication and the generation of tropospheric ozone. Recent analysis shows that the problem of eutrophication from N deposition is far more extensive than current problems from acidification.

These ancillary air quality benefits are different to the benefits of mitigation in reducing global climate change. While the benefit of GHG reductions from mitigation are mostly experienced by future generations at the global level, the ancillary air quality benefits accrue to the current generation and are local or regional in nature. They therefore provide immediate and tangible benefits to those who reduce GHG emissions.

Mitigation policy therefore has potential to generate large co-benefits for Europe. Moreover, there are potentially even greater benefits for other major emitters, notably in major developing countries which have much higher baseline levels of air pollution, such as China and India. These countries are increasingly suffering air quality pollution levels that are similar to historic European levels, with the health and environmental impacts. Reducing GHG emissions in these countries will thus produce large, immediate and localised benefits, and provide an extra justification for a low carbon transition.

Against this background, the ClimateCost project has quantified the benefits of mitigation policy, in terms of physical impacts and the monetary values. This technical briefing note summarises the approach and findings.

2. Socio-Economic Projections and Scenarios

In the assessment of the future effects of mitigation policy, assumptions have to be made about future conditions, which require socio-economic scenarios. In scientific terms, a scenario is a plausible future ('storyline') of environmental and anthropogenic change as informed by expert judgement, but it does not mean that this future will necessarily occur.

The most widely used in the context of climate change are the emissions scenarios of the IPCC Special Report on Emission Scenarios (the SRES scenarios, Nakicenovic et al., 2000). These define a set of future self-consistent and harmonised socio-economic conditions and emissions futures that, in turn, have been used to assess potential changes in climate through the use of global and regional climate models. There is a wide range of future drivers and emissions paths associated with the scenarios.

The ClimateCost project focused on a number of scenarios. This included consideration of SRES medium-high (A1B) and a mitigation scenario consistent with the EU 2 degree target, based on ENSEMBLES E1 scenario (van der Linden et al., 2009).

In the analysis of air quality co-benefits reported in this technical briefing note, a slightly updated set of emission scenarios has been used, based on projections of energy use data provided by the POLES model (Russ et al, 2009). These include consideration of current air quality legislation. They are broadly consistent with the SRES A1B and ENSEMBLES E1 scenarios, but with some minor differences, notably in the emission profile in recent years and in the immediate future. These updated scenarios are particularly important here because of the greater analytical focus on the short-term and on local impacts (in Europe), i.e. to ensure the analysis matches a current profile consistent with current emissions and air quality concentrations.

2.1 Scenarios used

The **Baseline scenario** used in this analysis explores a baseline situation in which no further climate and air pollution policies are implemented beyond that in place in the year 2010, thus energy consumption from 2010 through to 2050 is driven by population and economic growth. Note that this does take into account the existence of the emission trading scheme (ETS) market in the EU and the prospect of future climate policies in other countries. It also includes the consequences of the financial crisis in 2008/2009, and the evolution of the oil prices, but it excludes the implementation of the unilateral GHG reduction target (20% compared to 1990 by 2020) and the renewables target (20% by 2020) as proposed in the EU energy and climate change package (EC, 2008).

The **Mitigation scenario** used in this analysis was provided by the POLES model. It is a greenhouse gas reduction scenario with global CO_2 emissions reduced by 60% in 2050 compared to 1990. These reductions, together with those in agriculture and in land-use change and forestry (de-forestation), contribute to achieving a global mean temperature increase of less than 2 degrees above pre-industrial levels. The scenario assumes developed countries take on a collective emission reduction target and set up a trading system such as the EU ETS or similar policy measures that establish a carbon price for the energy intensive industrial sectors, including the power sector. Energy intensive sectors in developing countries are exposed to a low carbon price, simulating the limited penetration or visibility of a carbon price for all individual firms through policy instruments such as the CDM.

Further details of both scenarios are available from Rafaj et al (2011).

The project has assessed these two scenarios, reported as the baseline and the 2 degrees target, and has assessed the difference between them to provide the economic benefits of mitigation. The assessment has been undertaken for the future decades from today through to 2050. It is stressed that benefits would continue to accrue beyond this time so long as policies remained in place.

3. Methods

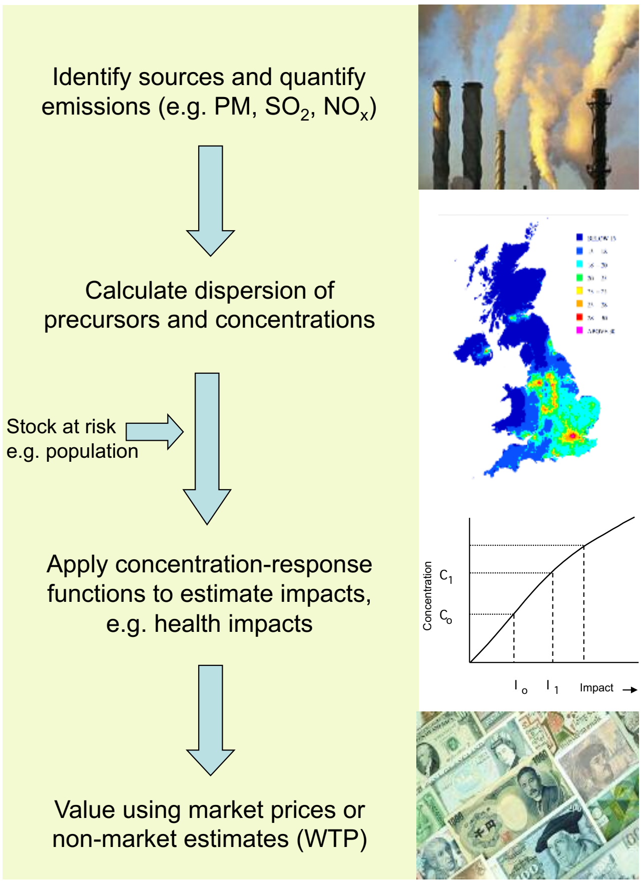
The usual approach taken for the detailed quantification of the benefits of air pollution emissions through to monetisation is often referred to as the 'impact pathway approach'. This is a logical progression from emissions, through the estimation of the modelled dispersion and change in air quality concentrations, to exposure and quantification of impacts and their valuation. This approach was advanced through the series of EC Research projects under the ExternE series (EC, 1995, 1999).

The approach is shown in Figure 1 below.

ClimateCost has used this impact pathway approach through the following series of steps:

1. Quantification of emissions;
2. Analysis of pollutant dispersion and chemistry across

Figure 1. Impact Pathway Approach



Source: Watkiss et al, 2008.

Europe (and also China and India) and assessment of the change in air pollution concentrations;

3. Quantification of the exposure of people, environment and buildings that are affected by air pollution, i.e. linking pollution with the 'stock at risk' e.g. using population data;

4. Quantification of the impacts of air pollution, using relationships from studies that link pollution concentrations with physical impacts such as crop damages or health impacts;

5. Valuation of the impacts. This is undertaken from the perspective of 'willingness to pay' (WTP). For some effects, such as damage to crops, this approach can be carried out using market data. For non-market effects such as on health, the assessment uses a combination of the 'market' data (e.g. the cost of medicines and care) combined with estimates of people's willingness to pay from stated and revealed preference techniques.

The analysis used two models to undertake this analysis, working within a Geographical Information Systems (GIS) framework: the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model and the ALPHA model. Both are described in the box below.

The two models are complementary as they focus on different aspects of the steps in Figure 1 above. Both the GAINS model (SERI, 2004, also 2007, 2009)[3] and the CAFE CBA method (Krupnick et al, 2004) have been extensively peer reviewed, and applied previously in EC policy impact assessment (CEC, 2005b).

[3] See http://gains.iiasa.ac.at/index.php/documentation-of-model-methodology/model-reviews/gains-review-2009.

Greenhouse Gas and Air Pollution Interactions and Synergies – GAINS

The Greenhouse and Air pollution Interactions and Synergies (GAINS) model explores cost-effective strategies to reduce emissions of greenhouse gases (GHG) and conventional air pollutants. The GAINS model (http://gains.iiasa.ac.at) produces emission scenarios for all major air pollutants for any exogenously supplied projection of future economic activities, abatement potentials, and costs as well as interactions in abatement between various pollutants (Amman et al., 2011).

It includes detailed atmospheric chemistry and transport models which allow the atmospheric modelling of emissions and the estimation of pollution concentrations, including both primary and secondary pollutants. These concentrations are combined with other necessary data such as critical loads and levels, relative risk factors, population, ecosystems areas, etc. This then allows the estimation of the effects on human health from the exposure of fine particles and ground-level ozone, and the ecosystems damage to vegetation via excess deposition of acidifying and eutrophying compounds.

The model also has a detailed abatement module which allows the analysis of abatement control to reduce these impacts, using a cost-effectiveness framework that can address multiple targets of health and ecosystem protection, as well as reducing GHG emissions. Thereby, GAINS allows for a comprehensive and combined analysis of air pollution and climate change mitigation strategies, which reveals important synergies and trade-offs between these policy areas.

Within the ClimateCost study the global version of GAINS was run to estimate the air pollution changes associated with the emission reduction scenarios, and the associated benefits to ecosystems and health.

CAFE CBA and the ALPHA model

The Atmospheric Long-range Pollution Health/environment Assessment (ALPHA) model (Holland et al, 2008) was developed to provide a detailed quantification of benefits of pollution controls in Europe. It has been used extensively for European policy assessments including work on the National Emission Ceilings Directive and the UN/ECE Gothenburg Protocol under the Convention on Long Range Transboundary Air Pollution, directives on air quality including the Clean Air For Europe (CAFE) Directive, directives on fuel quality and directives on emission limits for industry.

The model takes dispersion data from the EMEP or GAINS models and provides a detailed quantification of effects on health, including various morbidity impacts (on chronic bronchitis, hospital admissions, etc.) and mortality, and effects on building materials and crops. Extension of the model for quantification of effects on ecosystem services is currently under consideration.

Analysis then continues to monetization of quantified effects, permitting final results to be used in cost-benefit analysis using information on abatement costs from models such as GAINS. The model can be applied at any desired geographic scale and over any area of interest provided that appropriate pollution and population data are available.

Further information on the methods, data, and assumptions that underpin the GAINS and ALPHA models are available on the website of the EC4MACS Project[4].

3.1 Emissions Analysis and Inputs

The analysis first investigated the reduction in emissions of greenhouse gases in the EU and the associated reductions in emissions of sulphur dioxide (SO_2), oxides of nitrogen (NO and NO_2, together referred to as NOx), and fine particles

[4] http://www.ec4macs.eu/home/index.html?sb=1.

($PM_{2.5}$), but excluding the greenhouse gas nitrous oxide (N_2O) and volatile organic compounds (VOCs).

The analysis was undertaken for two scenarios, a reference (baseline) scenario out to 2050 and a mitigation scenario designed to limit global temperature to 2°C compared to pre-industrial levels. The emission scenarios are described in the box below.

Emission Scenarios

The scenarios assessed in ClimateCost were originally developed by Russ et al (2009) using the POLES (Prospective Outlook for Long term Energy System) world energy sector model and the GEM-E3 (General Equilibrium Model: Energy, Economy, Environment) multi-sector general equilibrium model. The scenarios were developed to assess the technological and economic effects of a 50% likelihood of limiting global temperature increase to 2°C. Within the analysis, POLES provided analysis of the technologies of the energy sector at a global scale, computing the direct cost of reducing emissions in the energy sector, while the GEM-E3 model used a multi-sector perspective that allows assessment of the economic consequences in the whole economy, therefore assessing the direct and indirect effects of mitigation policies.

In setting emission levels by country under the Mitigation Scenario, the modelling accounted for both efficiency and equity to prescribe alternative burden sharing options, through consideration of: GDP per capita as an indicator of wealth and ability to pay; the energy intensity of the economy as an indicator of the potential to reduce emissions; GHG emission trends as an indicator of those that have taken early action (and constrain subsequent ability to reduce emissions); and recent levels of population growth.

These four criteria were brought together to provide a central scenario, which has been adopted in this analysis. This scenario includes an assumption of imperfect operation of global carbon markets (as opposed to perfect trading or no trading at all), in which international trading gradually develops over time, bringing in more and more countries. The modelling includes some account of the 2008/9 economic crisis through IMF forecasts made in 2008, though this seems likely to have been too optimistic in terms of economic recovery in the USA and Europe.

The GHG reductions in the Mitigation Scenario are primarily from energy efficiency measures (accounting for roughly half of the global reduction in 2020-2030). Significant reductions in GHG emissions are also made through use of carbon capture and storage and fuel switching. The latter covers a move from (e.g.) coal and oil to lower carbon fossil fuels or to renewables and nuclear. The sectors contributing most to emission reductions are power generation followed by other industries, with a modest contribution from the transport and domestic sectors. Projected total emissions of CO_2 for the EU27 in the Baseline and Mitigation Scenarios are shown in Figure 2.

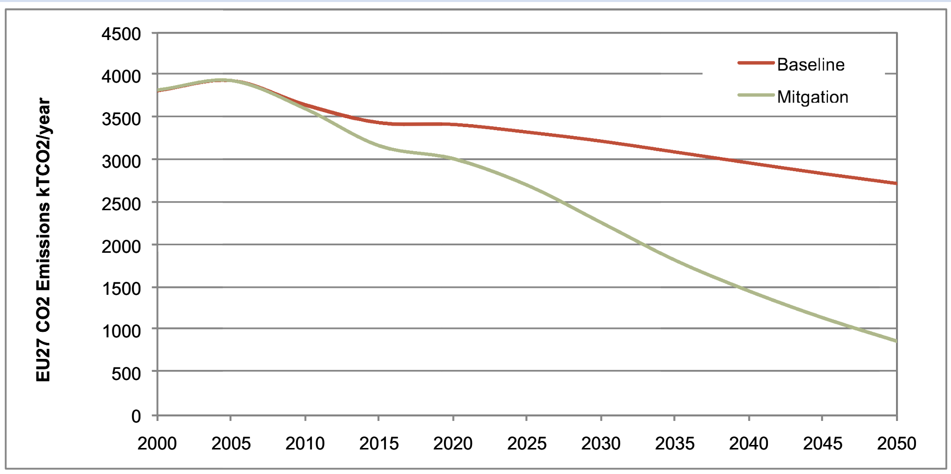


Figure 2. Projected total emissions of CO_2 for the EU27, 2005 to 2050.

3.2. Assessment of Impacts

The analysis of co-benefits has undertaken a multi-pollutant, multi-effect analysis up to the year 2050. The pollutants covered were SO_2, NO_x, VOC, NH_3, $PM_{2.5}$ and the effects considered were human health, acidification and eutrophication, as shown in Table 1 below.

The first step was to assess the effects of economic development and emissions from the POLES scenario (see box above) on air quality concentrations in Europe through to 2050. This was undertaken in the GAINS model (Amann, 2008), which assesses the formation and dispersion of pollutants in the atmosphere. The GAINS model was then used to assess the key health impacts from fine particulate matter and ground-level ozone, as well as a number of ecosystem impacts from acidification and eutrophication. This was complemented with the use of the ALPHA model which covers a wider set of health and environmental impacts, and also undertakes monetary valuation.

Health
The health impact assessment used here is based on methods and quantification steps developed over a number of years. There is a good level of consistency in the methods between different groups undertaking this work for example in Europe, the USA, and globally for the World Health Organization (WHO). These methods have been subject to extensive review (e.g. Krupnick et al, 2005) and found to be fit for purpose and reflective of the current state of science[5].

Mortality: Following the advice of an earlier expert group convened by WHO-Europe under the CAFE Programme[6], the Health Impact Assessment was performed against exposure to ozone and fine particles, considering the acute effects on mortality – as reflected by premature mortality (ozone) – and the longer-term changes in life expectancy (sometimes termed chronic mortality) from particles. Note that the particles considered include primary particulate emissions (emitted directly) and secondary particulates that form in the atmosphere following the release of SO_2, NOx and NH_3. In line with WHO advice, the analysis treats all particles, irrespective of source and chemical composition, as equally harmful.

The outputs are reported as the cumulative years of life lost (YOLL) from PM pollution and the additional cases of premature mortality from ozone pollution. For acute mortality from ozone, the analysis quantifies the number of 'premature deaths' (deaths brought forward)[7].

Table 1 Pollutants and Effects Considered.

	Emissions Reduced and Coverage Against Effects				
Air Pollutants and Effects	**SO_2**	**NOx**	**NH_3**	**VOCs**	**Primary $PM_{2.5}$**
Fine particles – health	✓	✓	✓	✓	✓
Ozone – health		✓		✓	
Acidification	✓	✓	✓		
Eutrophication		✓	✓		

[5] The health impact assessment has been further substantiated by recent epidemiological research, e.g. by Smith et al (2009, a paper that also demonstrates links between climate and air quality policies), Pope et al (2009a, b), and others.
[6] The recommendations of WHO-CLRTAP Task Force on Health (TFH) (http://www.unece.org/env/documents) and the WHO "Systematic Review of Health Aspects of Air Quality in Europe" (http://www.euro.who.int/document/e79097.pdf) were key to the development of quantification methods for assessing health impacts of air pollution, the WHO-sponsored meta-analyses of the acute effects of PM and ozone based on studies in Europe (http://www.euro.who.int/document/e82792.pdf). The process also drew on the answers to follow-up questions (http://www.euro.who.int/document/e82790.pdf) of the CAFE Steering Group.
[7] This wording signifies that many people whose deaths are brought forward by acute exposure to ozone in particular have serious pre-existing cardio-respiratory disease and so in at least some of these cases, the actual loss of life is likely to be small – the death might have occurred within the same year and, for some, may only be brought forward by a few days.

Other health impacts. The health impact assessment in GAINS addresses mortality only. For other non-fatal health effects (morbidity), the ALPHA model is used. This model also assesses mortality and morbidity impacts in monetary terms.

The method used here was based on the CAFE CBA methodology (Holland et al, 2005a; b; Hurley et al, 2005) and response functions developed as part of the EC CAFE programme[8].

For PM and ozone morbidity, impact functions were used to assess the health effects of acute exposures (from observation of response to day-to-day variations in ambient PM) and long-term (chronic) exposures. A list of the health impacts covered is provided in the Appendix.

Other environmental impacts. The study used the ALPHA model to quantify and monetise impacts to building materials and crops, focusing on the two major categories of impact in Europe: crop losses from ozone exposure; and damage to building materials from acidic deposition.

Air pollution has a significant influence on agricultural and horticultural production. The analysis used the results of previous studies (Holland and Watkiss, 2002: Holland et al, 2005c) that have considered the effects of ozone on crop yield. The valuation of impacts on agricultural production is reasonably straightforward, and estimated yield losses are valued using world market prices, as published by the UN's Food and Agriculture Organization[9]. It is highlighted that these do not consider changes in the productivity of grassland and hence of livestock.

Air pollution is also associated with a number of impacts on materials (see Box 1). The analysis again used the results of previous studies (Holland and Watkiss, 2002: Holland et al, 2005c) that have quantified these impacts using dose-response (damage function) relationships from the UNECE ICP Task Force on Materials programme[10]. It is highlighted that these only consider quantification of 'utilitarian' material damage, and do not consider particle emission on building soiling or buildings of historic or cultural value.

Ecosystems. The GAINS model was used to assess the impacts of air pollutant deposition on ecosystems. The analysis considered the area of forests and ecosystems that exceed 'critical loads' for acidification and nutrient nitrogen deposition. These critical loads represent a quantitative exposure, below which no significant harmful effects on (specific) sensitive elements occur. In the analysis here, the area exceeding these critical threshold levels is assessed.

The study did not attempt the economic valuation of ecosystem impacts. Such an analysis would require knowledge of specific effects (change in species richness, productivity, etc.) over extended time scales and appropriate models are not available. Data for valuation of most impacts to ecosystems are also unavailable, or so specific that generalisation to the broader environment cannot be carried out with confidence. Consideration was given to various recent studies (NEEDS, 2006; Hettelingh et al, 2009; Jones et al, 2011). These approaches, which address the change in ecosystem services, provide a promising avenue for future quantification, but they are difficult to apply at the scale considered here.

More details of the impact methods (for health, environmental impacts and ecosystems) are described in the reports from CAFE and the EC4MACS study (Holland et al, 2005a, 2008; Amann et al, 2008). It is highlighted that these methods continue to evolve, and there are some recent developments which could be used in future assessments[11].

3.3. Monetary Valuation and reporting of economic values

The impacts on human health are more difficult to value, because there are no observed market prices. However, it is possible to derive monetary values for this non-market sector, by considering the total effect on society's welfare. This requires analysis of three components which each capture different parts of the total effect. These are:

[8] The methodology developed was the subject of intense consultation in 2003 and 2004 with stakeholders from the European Union Member States, academic institutes, environment agencies, industry and non-governmental organisations. It was also subject to formal peer review by senior experts in the USA and Europe.
[9] World market prices are used as a proxy for shadow price on the grounds that they are less influenced by subsidies than local European prices.
[10] ICP Materials. Dose-response functions. http://www.corr-institute.se/ICP-Materials/html/dose_response.html
[11] As highlighted by Hurley, Miller and Shafrir (2011) the future health impact assessment could include a cause-specific approach (Pope et al, 2009; Krewski et al, 2009; Amann and Schopp, 2011), use country specific life tables, consider long term exposure to ozone on mortality (Jerrett et al, 2009) and use European chronic bronchitis studies (Schindler et al, 2009).

- The resource costs i.e. medical treatment costs;
- The opportunity costs, in terms of lost productivity; and
- Dis-utility i.e. pain or suffering, concern and inconvenience to family and others.

The first two components can be captured relatively easily. Techniques are also available to capture the third component, by assessing the 'willingness to pay' or the 'willingness to accept compensation' for a particular health outcome. These are derived using survey-based "stated" preference methods and/or "revealed" preferences methods that are based on observed expenditures such as on consumer safety.

ClimateCost has made use of existing unit estimates for health based impacts, and adopts established benefit value transfer procedures to apply these values.

However, there is substantial debate concerning the correct approach to valuation of mortality risks in the context of air pollution. These can be valued using a long-established metric, the value of statistical life (VSL – also known as the value of a prevented fatality, VPF), but changes in life expectancy can also be valued using the value of a life year (VOLY), which provides a way of accounting for differing lengths of remaining life expectancy. Both approaches are used in the literature and both have strengths and weaknesses. ClimateCost has therefore used both for valuation. This is also the approach used in the European Commission's Clean Air For Europe (CAFE) Programme, following peer review guidance.

The main results reported below use a VOLY of €60,000, which is consistent with the (low) value used in EC CAFE assessment. The VSL is also applied, using values of €1.1 million and €3.8 million. The lower figure is also broadly consistent with the EC CAFE analysis. In the sections below, numbers are first presented for the VOLY, using the mid value of €60,000. Results are then provided in a later section based on the VSL.

For morbidity (non-fatal) impacts, a literature review has assessed the most appropriate values. Note that for acute mortality from ozone, the analysis quantifies the number of 'premature deaths' (deaths brought forward) and these cases are valued using a VOLY approach, assuming that on average, each premature death leads to the loss of 12 months of life.

The same monetary values for mortality risk and morbidity are used across all European countries.

Consistent with all sector-based analysis in ClimateCost, the economic valuation results below are presented in terms of constant 2005 prices in Euros over future years, without any adjustments or discounting. The results are presented in this way to facilitate direct comparison, over time, and between sectors. However, subsequent policy analysis that looks at the costs and benefits of mitigation policy would need to work with present values (i.e. values that are adjusted and discounted as with standard economic appraisal). This analysis is included in other parts of the ClimateCost study

3.4 What is included and excluded in the analysis?

When considering the results in this technical briefing note, it is important to be explicit about what is included or excluded, and on the areas of uncertainty covered.

The results below only present the effects of mitigation policy on air quality – they do not include analysis of how climate change might affect air quality concentrations more generally. Climate change has the potential to increase future ambient background ozone concentrations in summer months, and also influence the frequency and intensity of high concentration (ozone episodes). However, the evidence for these effects is by no means well understood, and the current evidence indicates there could be potential positive as well as negative effects of climate change on ozone formation. Similarly, climate change could affect the formation, transport or (wet) deposition rates of particulate species, though both positive and negative effects are possible.

The impacts for building materials are monetised using repair and replacement costs. While a similar approach could, in theory, be applied to historic and cultural buildings, there is a lack of data on the stock at risk (number of such buildings and an inventory of the materials in them), and also the relevant valuation of building damage, thus the numbers reported here only include utilitarian buildings.

Finally, despite the large, well-documented literature available on these effects, it is not currently possible to conduct an economic analysis of the effects on ecosystems. The omission of these effects therefore significantly underestimates the total reported benefits, and it is recommended that the physical benefits to ecosystems are considered directly alongside the economic values presented in the findings.

4. Results – impacts and economic costs of air pollution

4.1 European Emissions

The emission trends for the EU under the Baseline and Mitigation Scenarios are summarised Table 2 (and plotted in Figure 3) based on data generated by GAINS. The analysis includes current policies and so there are large emission reductions in the baseline scenario up to 2030, which thereafter remains broadly constant. Note that the baseline includes all emission limit values and fuel quality standards, as used in the analysis for the revision of the National Emission Ceilings (NEC) Directive (Amann et al., 2008).

The results in Table 2/Figure 3 show:

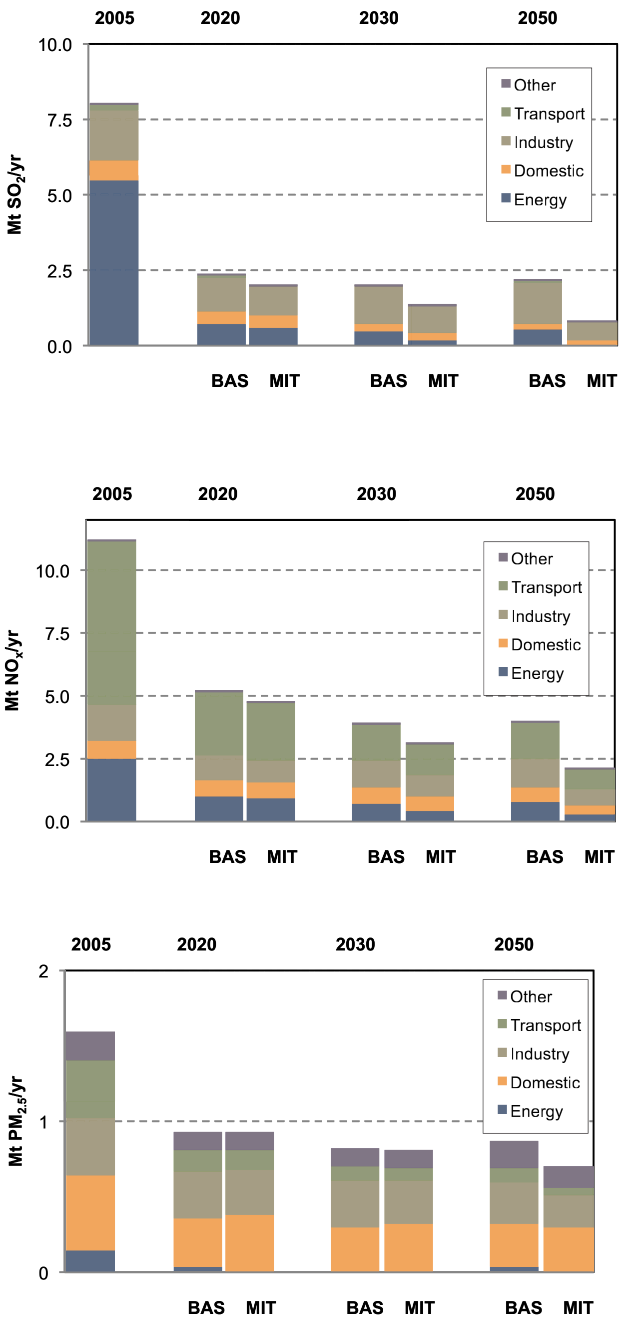
- The pollutants that show the greatest reductions under the mitigation scenario are SO_2 and NOx. This is not surprising as these pollutants are closely linked with CO_2 emissions, as they are products of fossil fuel combustion.

Table 2. Emissions (million tonnes/year) 2005 to 2050 in Europe (EU27), under the baseline and mitigation scenarios, and the benefits of mitigation (Mtonnes and % reduction in year of emission).

Million tonnes per year in EU27, Baseline scenario				
	2005	**2020**	**2030**	**2050**
SO_2	8053	2411	2083	2239
NOx	11221	5219	3991	4034
$PM_{2.5}$	1595	931	831	877
Million tonnes per year in EU27, Mitigation (2°C) scenario				
	2005	**2020**	**2030**	**2050**
SO_2	8053	2086	1440	906
NOx	11221	4854	3200	2190
$PM_{2.5}$	1595	932	813	710
Net benefits of Mitigation – million tonnes and % reduction from the baseline				
	2005	**2020**	**2030**	**2050**
SO_2	0	325 (14%)	643 (31%)	1333 (60%)
NOx	0	365 (7%)	791 (20%)	1844 (46%)
$PM_{2.5}$	0	-1 (0%)	18 (2%)	167 (19%)

Source GAINS, Rafaj et al (2011).

Figure 3. European (EU27) emissions of SO_2, NO_x, and $PM_{2.5}$, annual Million tonnes, from 2005 to 2050 under the Baseline and Mitigation Scenarios. (Source GAINS, Rafaj et al (2011)).



Key to the figures:
The graphs show the emissions of three main air pollutants SO_2 (top) NO_x (middle) and $PM_{2.5}$ (bottom) in 2005, 2020, 2030 and 2050, for a baseline scenario (BAS) and the mitigation scenario (MIT), with each bar also showing the breakdown of emissions by sector.

- There is little difference between the Baseline and Mitigation Scenario emissions through to 2020. This is due to the existing legislation that targets air quality, such as the Euro standards for motor vehicles, the Large Combustion Plant Directive, and measures to improve fuel quality such as the Directive on the sulphur content of certain liquid fuels.
- A significant difference for emissions of $PM_{2.5}$ is only apparent for 2050.
- There is very little change in the Baseline Scenario after 2030, as legislation currently in place will have taken its full effect by then.

For the other major air pollutants, VOC and NH_3 (not shown in the Table and Figure above) the emission reductions are much lower because these pollutants are less affected by decarbonisation of the energy system. For VOCs, emission benefits are estimated to be 2% in 2030 rising to 9% in 2050. For ammonia, emissions are similar in the baseline and mitigation scenario.

The mitigation scenario is most effective in reducing oxides of sulphur and nitrogen, with reductions of 60% and 46% respectively in 2050 in Europe, while reductions in particulate matter are lower at 19%.

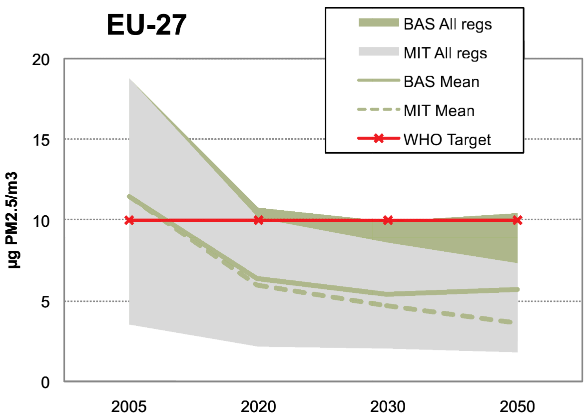
4.3 Health

The reduction in air quality concentrations in Europe has large potential health benefits. The analysis has quantified and monetised these benefits, comparing the projected impacts from air pollution under the baseline and mitigation scenario.

The first step in this analysis is to estimate the change in air quality concentrations, and link this with population to estimate the population-weighted-exposures.

Figure 4 below shows the ambient concentrations of $PM_{2.5}$ up to 2050 in the EU, showing the baseline (BAS) and mitigation scenario (MIT) over time. This is compared against the WHO target guideline levels on PM, shown in red (WHO, 2005). At the current time there is still widespread non-compliance, but by 2050 most countries will be below the target levels. Nonetheless, under the mitigation scenario, all EU countries fall within the WHO target level. Mitigation target therefore has the benefit of ensuring European wide compliance. Furthermore, there are still residual health impacts that are thought to occur below the target level. Under the mitigation scenario, average ambient concentrations of $PM_{2.5}$ in the EU are by 36% lower than the Baseline projections by 2050.

Figure 4 Ambient concentrations of $PM_{2.5}$ (population weighted, annual mean) for the Baseline and the Mitigation scenarios in the EU27. Ranges indicate variations over EU countries.



Key:
The figure shows the mean EU27 population weighted PM concentrations under the — baseline and – - – mitigation scenarios. These can be compared to the WHO target guideline levels for PM, shown as -x-. The grey and green shaded areas show the upper range for individual countries. Note that under the mitigation scenario, all EU countries in 2050 are within the WHO target level, while under the baseline, some still remain above.
Source GAINS, Rafaj et al (2011).

Table 3 presents the statistical loss of life expectancy estimated in the GAINS model from air pollution. This shows that across Europe, the population currently loses an average of 7 months of life expectancy (on average) from air pollution. By 2020, this fall to around 4 months of life lost on average, for both the baseline and mitigation scenario.
However, under the mitigation scenario, the loss of life expectancy continues to fall from 2030 to 2050, down to 2 months on average, and thus mitigation achieves a benefit of a month of life expectancy compared to the baseline in 2050 (a 35% reduction in the loss of life expectancy compared to the Baseline).

A full breakdown by Member State is provided in the Appendix. It is stressed that is an average across the whole population, and the population as a whole will vary in their sensitivity to air pollution.

Air pollution currently has a significant impact in reducing life expectancy in Europe, by 7 months on average. While current air pollution legislation is expected to halve this by 2050, mitigation policy would increase life expectancy by 1 month on average.

Figure 5 shows the variation in these impacts across Europe, for 2030 and 2050 under the baseline and mitigation scenario. The largest losses of average life expectancy are in Belgium and the Netherlands. The smallest are in the fringes of Europe, for example in Finland, Ireland and Sweden. These differences are due to trans-boundary pollution.

Table 3. Statistical loss of life expectancy in months (Source GAINS, Rafaj et al (2011)) under the baseline and mitigation scenarios, and the benefits of mitigation.

Loss of life expectancy from air pollution – months, Baseline scenario				
	2005	**2020**	**2030**	**2050**
Baseline	7.3	3.7	3.1	3.1
Loss of life expectancy from air pollution – months, Mitigation (2°C) scenario				
	2005	**2020**	**2030**	**2050**
Mitigation (2C)	7.3	3.5	2.6	2.0
Net benefits of Mitigation				
	2005	**2020**	**2030**	**2050**
Benefits of mitigation scenario		0.2	0.5	1.1

Notes values are for adults older than 30 years and attributable to exposure to $PM_{2.5}$ from anthropogenic sources

Figure 5. Statistical loss of life expectancy due to anthropogenic $PM_{2.5}$, (months), left baseline, right mitigation scenario (Source GAINS, Rafaj et al, 2011).

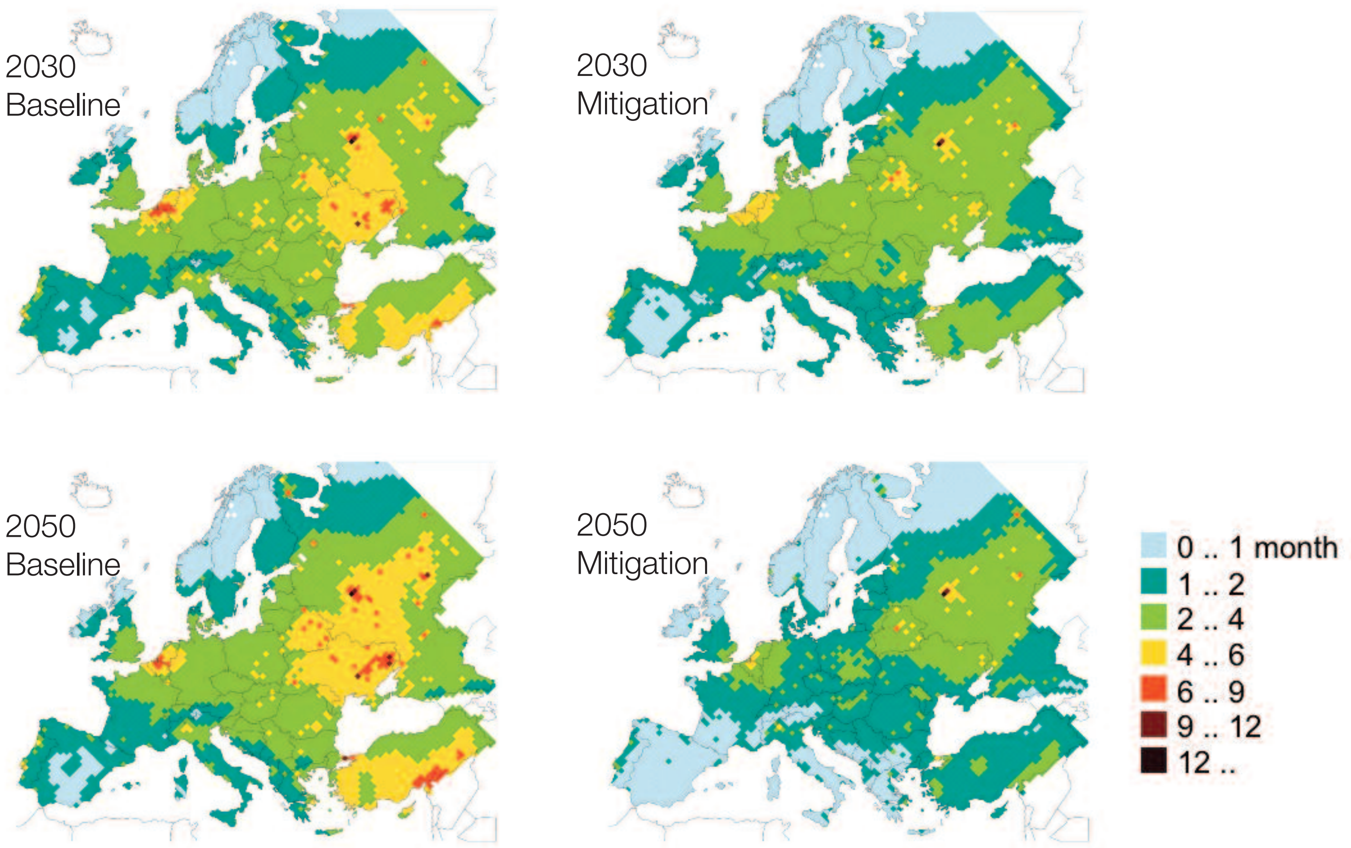


Table 4. Health impacts (cases per year) for the EU27 in the Baseline and Mitigation Scenario in 2050, and Co-Benefits of Mitigation.

Results for 2050		Cases per year		
		Baseline	Mitigation	Co-benefit
Acute mortality (all ages) deaths	O3	24,259	20,884	3,374
Respiratory hospital admissions (65yr +)	O3	27,869	24,075	3,794
Minor restricted activity days (15-64yr)	O3	36,150,820	31,214,804	4,936,016
Respiratory medication use (adults 20yr +)	O3	16,688,648	14,411,345	2,277,303
Chronic mortality, life years lost	PM	1,387,251	904,805	482,446
Infant Mortality (1 month - 1yr) deaths	PM	201	129	72
Chronic bronchitis (27yr +) new incidence	PM	76,839	50,282	26,556
Respiratory hospital admissions (all ages)	PM	28,933	18,968	9,965
Cardiac hospital admissions (all ages)	PM	17,844	11,698	6,146
Restricted activity days (RADs 15-64yr)	PM	124,127,047	81,419,761	42,707,287
Respiratory medication use (children 5-14yr) days	PM	1,391,384	917,130	474,254
Respiratory medication use (adults 20yr +) days	PM	13,643,560	8,933,242	4,710,318
Lower respiratory symptom days (children 5-14yr)	PM	71,501,674	47,130,298	24,371,376
Lower respiratory symptom days (15yr +)	PM	137,690,472	90,189,476	47,500,996

As Figure 5 shows, under the mitigation scenario (bottom right), the life expectancy losses are reduced over all of Europe. Under the baseline (bottom left), Belgium, the Netherlands and central and eastern Europe still have particularly high life expectancy losses in some areas.

The **study** has also estimated the health impact of ozone related mortality. Note that this only considers the reduction in ozone precursor emissions with mitigation: it does not consider the effects of climate change directly on ozone formation. Under the Mitigation scenario, there is a reduction in the number of premature fatalities from ozone, by 6% in 2030 and 15% in 2050 relative to the Baseline. In absolute terms, the mitigation scenario leads to 2800 fewer premature deaths from ozone in Europe by 2050 compared to the Baseline.

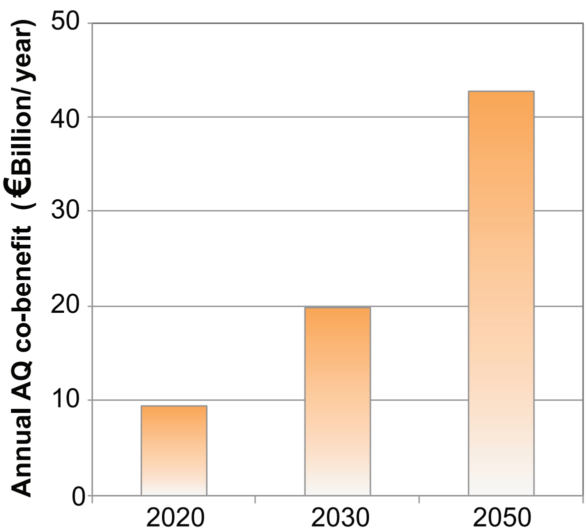
The ALPHA model provides a more extensive quantification of health impacts, including a number of effects on morbidity, as well as valuing all health outcomes in monetary terms.

The results for the Baseline and Mitigation Scenarios for 2050 are presented in Table 4, in terms of the physical health effects (outcomes or cases per year). The table also shows the difference between the two scenarios (i.e. the 'co-benefit'). Values for 2020, 2030 and 2050 are presented in the Appendix

By 2050 the results for the EU27 in Table 4 reveal that:

- For fine particles, the annual co-benefits are estimated at 480,000 fewer life years lost to air pollution[12], 72 fewer cases of infant mortality, 27,000 fewer new cases of chronic bronchitis, 16,000 fewer hospital admissions and in total around 120 million fewer person days of restricted activity, respiratory medication use and lower respiratory symptoms.
- For ozone, the Mitigation Scenario leads to 3,400 fewer deaths brought forward each year, 3,800 fewer hospital admissions and a reduction of around 7 million person days of 'minor restricted activity' and respiratory medication use.

Figure 6. Annual Health Co-benefit (Net benefit of the Mitigation Scenario relative to the Baseline) (source ALPHA). All figures in €Billions/year (current prices, undiscounted, VOLY estimate).



The mitigation scenario leads to an estimated annual benefit of 480,000 life years gained, as well as 27,000 avoided cases of chronic bronchitis, 20,000 fewer annual hospital admissions and around 127 million avoided minor symptom days each year by 2050 in the EU27.

These benefits are then converted to monetary equivalents. The values for 2050 presented below in Table 5. Full results are presented in the Appendix. The value of a life year lost metric has been used in these table, using a VOLY of €60,000. The impact on the estimates with the use of the value of statistical life is presented in a later section. The greatest impacts – and co-benefits – arise from the chronic effects on mortality and chronic bronchitis and the acute effects on restricted activity days, which are all associated with exposure to fine particles.

Figure 6 shows how the total co-benefits increase over time. The EU27 benefits total €9 billion, €20 billion and €43 billion/year respectively in 2020, 2030 and 2050 (current prices, no discounting). The benefit of €43 billion in 2050 equates to over €78 for each EU citizen.

The co-benefits over time are shown in Figure 7 at the country level.

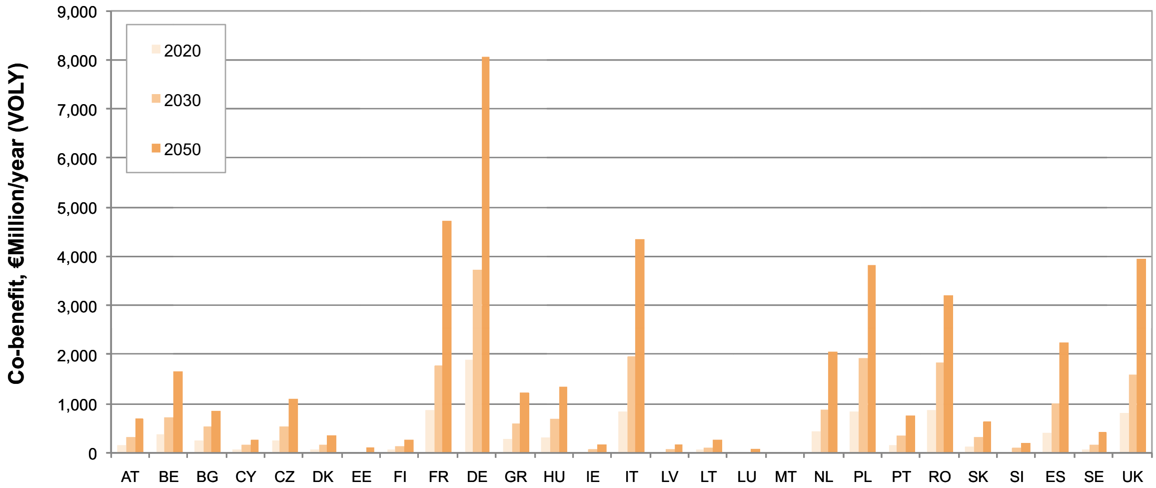
For an explanation of the country abbreviations, see Appendix 1.

[12] Note that under the GAINS analysis, the change in life expectancy is calculated for the population as a whole over the lifetime of the individuals (assuming similar pollution exposure). In the ALPHA analysis this metric is estimated in an annualised form to give an annual number of life years lost which can then be monetised.

Table 5. Monetised health effects for the EU27 for the Baseline and Mitigation Scenario for 2050, and Co-Benefits of Mitigation. All figures in €millions/year (current prices, undiscounted). VOLY estimates for mortality. Source ALPHA.

Results for 2050		€millions/year		
		Baseline	Mitigation	Co-benefit
Acute mortality (all ages) deaths	O3	1,456	1,253	202
Respiratory hospital admissions (65yr +)	O3	64	55	9
Minor restricted activity days (15-64yr)	O3	1,591	1,373	217
Respiratory medication use (adults 20yr +)	O3	17	14	2
Chronic mortality, life years lost	PM	83,235	54,288	28,947
Infant Mortality (1 month - 1yr) deaths	PM	1,147	737	410
Chronic bronchitis (27yr +) new incidence	PM	16,597	10,861	5,736
Respiratory hospital admissions (all ages)	PM	67	44	23
Cardiac hospital admissions (all ages)	PM	41	27	14
Restricted activity days (RADs 15-64yr)	PM	11,916	7,816	4,100
Respiratory medication use (children 5-14yr) days	PM	1	1	0
Respiratory medication use (adults 20yr +) days	PM	14	9	5
Lower respiratory symptom days (children 5-14yr)	PM	3,146	2,074	1,072
Lower respiratory symptom days (15yr +)	PM	6,058	3,968	2,090
Total		125,350	82,521	42,828

Figure 7. Annual Health Co-benefit by Country (Net benefit of the Mitigation Scenario relative to the Baseline) (source ALPHA). All figures in €Millions/year (current prices, undiscounted, VOLY estimate).



The economic health cobenefits of the mitigation scenario in Europe (EU27) are estimated at €9 billion/year by 2020, rising to €20 billion/year by 2030 and €43 billion/year by 2050 (VOLY approach).

As highlighted earlier, two approaches can be used for valuing the change in risk of mortality – the VOLY and the VSL. In ClimateCost both have been used. To further reflect uncertainty, the following ranges have been used:

- VOLY: €37,500 to €215,000 with the best estimate of €60,000
- VSL: €1.1 million, €3.8 million and €5.6 million.

The values in the Tables and Figures above use the VOLY mid estimate (€60,000). Table 6 presents the effects on the total results (all health impact) with the different values for mortality valuation above. It is highlighted that the use of a low VSL estimate (of just over €1 million) increases the co-benefits to €94 billion in 2050, while using values from the recent literature increases this significantly.

It is also possible to assess these co-benefits against the GHG emission reductions, to estimate the co-benefit per tonne of GHG reduced. This provides a useful way for communicating the size of the benefits.

The emissions of CO_2 for the EU27 were shown in Figure 2. Current 2005 emissions were just under 4 billion tonnes/year, and fall to under 1 billion tonnes/year by 2050 under the mitigation scenario (around an 80% reduction on the 2005 baseline).

Using the values presented in Figure 6, the air quality co-benefits are estimated at €24 a tonne of CO2 mitigated in 2020, €21/tCO2 in 2030, and €24/tCO2 by 2050. As elsewhere, these figures are estimated using the mid-estimate of the VOLY (€60,000). The values would be higher with the use of VSL estimates."

When expressed against the CO_2 reductions achieved, the air quality co-benefits of the mitigation scenario are around €24 a tonne of CO_2 across the period.

Table 6. Mitigation Co-benefits in the EU27 based on different mortality valuation approaches and unit values. All figures in €millions/year (current prices, undiscounted).

Valuation metric and unit cost	Net benefits of Mitigation – €millions/year (current prices, undiscounted). 2020	2030	2050
VOLY low (€37,500)	6,893	14,556	31,606
VOLY mid (€60,000)	9,450	19,865	42,828
VOLY high (€215,000)	26,560	55,504	118,325
VSL low (€1.1 million)	15,680	36,142	94,025
VSL mid (€3.8 million)	47,425	110,305	292,009
VSL high (€5.6 million)	68,652	159,901	424,471

4.3 Crops and Materials

Analysis of the effects of changes in emissions on materials has focused on SO_2 and its impact on materials used in 'utilitarian' buildings. The material results are shown in Table 7 below, and can be seen to be a small fraction (0.4%) of the health co-benefits in Table 6. Note that the analysis of materials damage omits damage to cultural heritage and damage from pollutants other than SO_2 (e.g. effects of other acidifying gases).

The results of the effects of ozone on crops are presented in Table 8 below. Given the non-linearities in ozone chemistry, the approach used only gives a very approximate result of the change over time. However, total co-benefits of reduced crop damage are again a small fraction of the health impacts quantified in Table 6 above.

Table 7. Damage to building materials from SO_2 emissions for the EU27 under the Baseline and Mitigation Scenario (€Million/year, current prices, undiscounted).

	€Million/year 2020	2030	2050
Total: Baseline Scenario	509	434	447
Total: Mitigation Scenario	442	303	183
Co-benefit (difference between the two scenarios)	67	131	264

Table 8. Damage to crops from emissions of ozone precursors for the EU27 (€M/year, current prices, undiscounted)

	€Million/year		
Effects of NOx	**2020**	**2030**	**2050**
Total: Baseline Scenario	1,621	1,208	1,209
Total: Mitigation Scenario	1,510	969	642
Co-benefit (difference between the two scenarios)	111	239	567
Effects of VOCs	2020	2030	2050
Total: Baseline Scenario	886	857	884
Total: Mitigation Scenario	884	842	813
Co-benefit (difference between the two scenarios)	2	15	71
Total co-benefit	113	254	638

4.4 Ecosystems (Critical Loads Exceedance)

The protection of ecosystems has been the main stimulus for tackling transboundary air pollution in Europe, particularly concerns about 'acid rain' in the 1970s and 1980s, which was responsible for acidification of freshwater ecosystems and forest decline.

Since then, there have been significant reductions in the acid burden to ecosystems, particularly in emissions of SO_2. There have also been large reductions in emissions of NOx, but the fall in NH_3 emissions has been more modest.

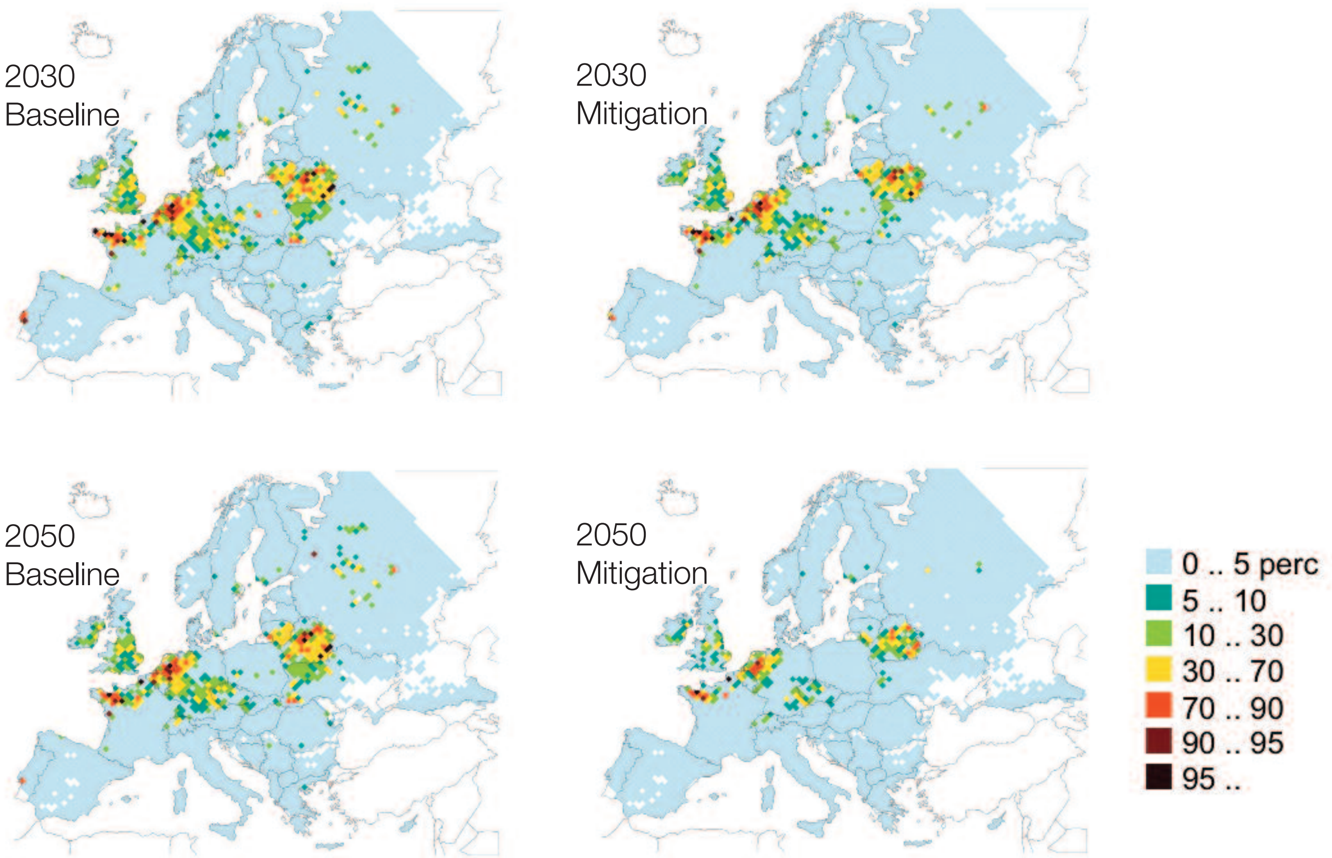
One result of such action is that the area of ecosystems subject to exceedance of the critical load for acidification has declined substantially since the 1970s. Table 9 shows the area of forest in excess of the critical loads for acidification. In 2005, 20% of the forest area of the EU27 was subject to critical load exceedance for acidification. By 2020 this is projected to fall to 7% under the Baseline Scenario, because of existing legislation. However, under the Mitigation Scenario the area subject to exceedance more than halves between 2020 and 2050, to less than 3%, and the mitigation scenario reduces the forest area exposed to acidification deposition by 42 thousand km^2.

Figure 8 shows the distribution of the Baseline and Mitigation scenario exceedences over Europe. These are concentrated in a band running across Northern Europe from the west of France to Ukraine.

Table 9. Area of forest (and % of total forest) in excess of the critical loads for acidification in the EU27 (2005-2050), for the Baseline and the Mitigation scenarios.

Baseline scenario	**2005**	**2020**	**2030**	**2050**
Forest area with acid deposition	253	89	73	78
exceeding critical load (thousand km^2) (20%)	(7%)	(6%)	(6%)	
and % of total area				
Mitigation (2°C) scenario	**2005**	**2020**	**2030**	**2050**
Forest area with acid deposition	253	77	53	36
exceeding critical load (thousand km^2) (20%)	(6%)	(4%)	(3%)	
and % of total area				
Net benefits of Mitigation	**2005**	**2020**	**2030**	**2050**
Forest area with acid deposition		11	21	42
exceeding critical load (thousand km^2)		(1%)	(2%)	(3%)
and % of total area				

Figure 8. Percentage of forest area (%) affected by exceedance of the critical load for acidification



Source GAINS, Rafaj et al (2011).

Table 10 reports the extent of exceedance of the critical load for **eutrophication**. In the Baseline this falls from 72% in 2005 to 56% by 2050. Under the Mitigation Scenario, the extent of exceedance falls to 48% by 2050 – an improvement, but there is still a high level of residual exceedance.

Table 10. Area of ecosystems (and % of total) in excess of the critical loads for eutrophication in EU27 (2005-2050), for the Baseline and the Mitigation scenarios.

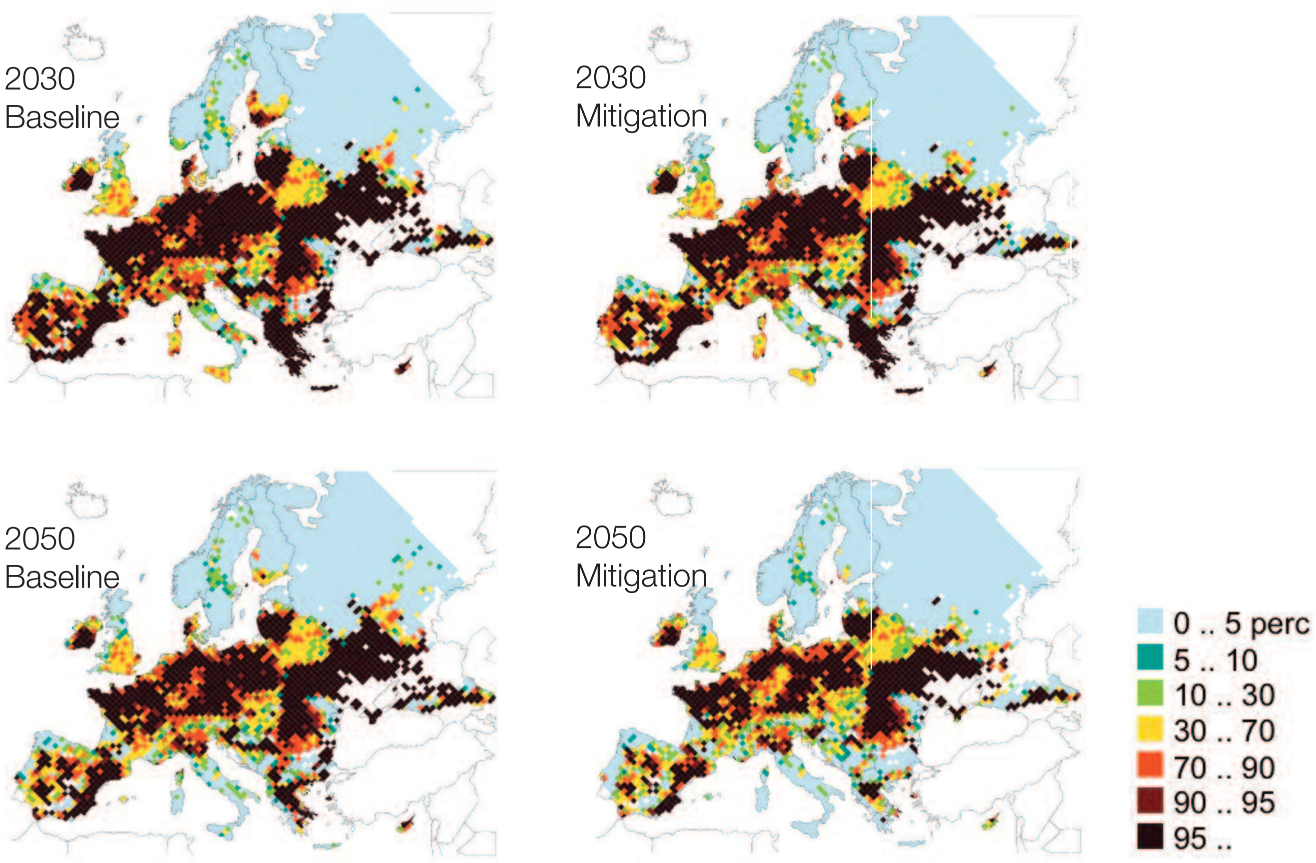
Baseline scenario	**2005**	**2020**	**2030**	**2050**
Ecosystem area with nutrient nitrogen deposition exceeding critical load (thousand km^2) and % of total area	1176 (73%)	949 (59%)	908 (56%)	926 (57%)
Mitigation (2°C) scenario	**2005**	**2020**	**2030**	**2050**
Ecosystem area with nutrient nitrogen deposition exceeding critical load (thousand km^2) and % of total area	1176 (73%)	926 (57%)	850 (53%)	783 (48%)
***Net benefits* of Mitigation**	**2005**	**2020**	**2030**	**2050**
Ecosystem area with nutrient nitrogen deposition exceeding critical load (thousand km^2) and % of total area		23 (1%)	58 (4%)	144 (9%)

Source GAINS, Rafaj et al (2011).

In percentage terms, the difference between the two scenarios is lower than for acidification. This is to be expected as ammonia emissions – which contribute to eutrophication – are not affected much under the mitigation case. Nonetheless, the total area that falls below the critical load for eutrophication is significant under the mitigation scenario, estimated at 145 thousand km^2 by 2050. The pattern of exceedances across Europe is shown in Figure 9.

The extent of the eutrophication problem at a national level is shown in Figure 10. In 2005, slightly more than half of the EU's Member States were estimated to have eutrophication exceedance across more than 95% of their ecosystem area. By 2050 this falls to seven Member States under the Baseline Scenario and five under the Mitigation Scenario. However, it is notable that in 2050 there are still more than half of the EU27 countries which have exceedances over more than 50% of their ecosystem area.

Figure 9. Percentage of ecosystem area affected by exceedance of the critical load for nutrient nitrogen (Source GAINS, Rafaj et al, 2011).



Source GAINS, Rafaj et al (2011).

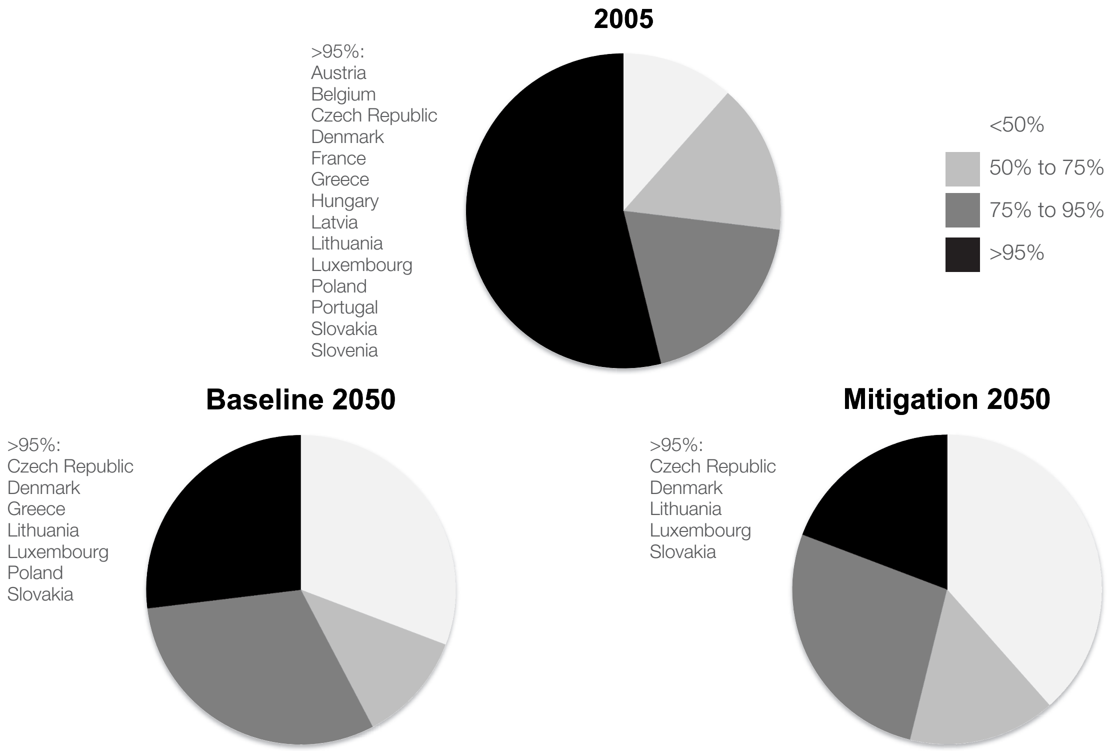
The mitigation scenario reduces the forest area exposed to acidification deposition exceeding critical loads by 42 thousand km² in 2050 and the sensitive ecosystem area exposed to eutrophication by 144 thousand km².

4.5 Avoided Abatement Costs

Mitigation policies also have an additional ancillary benefits through avoiding the need to implement air pollution measures required by legislation. The mitigation scenario will reduce the costs of air pollution abatement because of the lower levels of fossil fuels, which in turn requires fewer installations of air-pollution control equipment.

In Europe, the legislation in the Euro standards and the Industrial Emissions Directive (IED) lead to additional costs on polluters (consistent with the polluter pays principle) and requires equipment to reduce pollution. For example, under the IED, coal fired power stations need to be fitted with technologies such as bag filters or electrostatic precipitators to reduce emissions of particles, flue gas desulphurisation to reduce SO_2 releases and NOx controls such as selective

Figure 10. Proportion of countries with varying levels of exceedance of the critical load for eutrophication by ecosystem area.



Data source: GAINS, Rafaj et al (2011).

catalytic/non-catalytic reduction (SCR/SNCR). These technologies incur capital expenditure and operating costs for manpower, reagents, waste material disposal, etc.

The GAINS model has calculated the difference in abatement costs (for each pollutant) between the Baseline and Mitigation Scenarios. These are estimated as the annual savings (in 2005 prices) in future years[13].

The costs of implementing current legislation within the EU – through to 2050 – are estimated at about 76 billion $€_{2005}$ per year (undiscounted) in the baseline scenario. The GAINS calculation suggests that this cost can be halved by 2050 under a mitigation scenario, with the savings (co-benefits) estimated at €36 billion/year by 2050 for the EU27. The results are shown in Table 11.

The breakdown by sector is shown in Figure 11. The largest part of these savings is related to the transport sector. In respect of emissions, the largest reduction in abatement costs is for NOx control, at about three quarters of the total, with most of the remainder associated with savings for SO_2 controls. Savings for control of PM[14], VOCs and NH_3 are much more modest, reflecting the nature of the mechanisms for reducing GHGs in the Mitigation Scenario.

The benefits by country are shown in Figure 12 below. The country codes are listed in Appendix 1.

At the global level, the annual savings are much greater, and are estimated by the GAINS model to be more than 250 billion Euros/year by 2050 (€2005, undiscounted). A significant proportion of these – around one fifth – are in the USA. Most of these benefits (in relative terms) arise in the power sector, where control costs are reduced very significantly, followed by the transport sector, which has the highest absolute reductions.

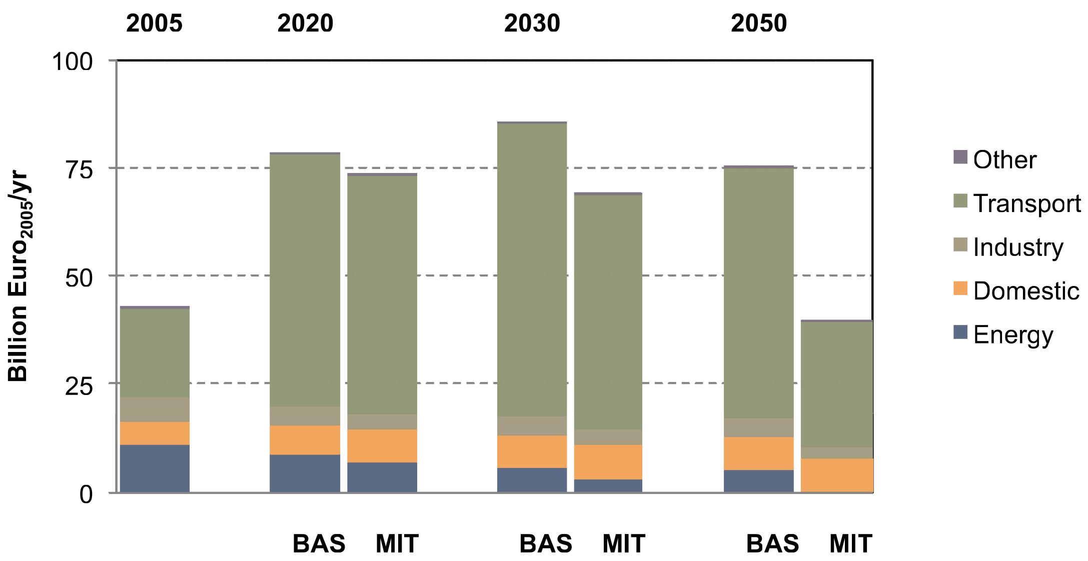
While care needs to be taken in applying these cost savings in any policy impact assessment to avoid double counting,

[13] These are estimated as annualised costs (investment and fixed operating costs) in current prices for future years, using a 4% discount rate which is consistent with the GAINS analysis. These are not discounted back to the current year i.e. to 2010.

Table 11. Potential abatement costs, 2005 to 2050, under the baseline and mitigation scenarios. Source GAINS, Rafaj et al (2011). All figures in €billions/year (2005 prices, undiscounted).

Cost of abatement – billions of Euros per year in EU27, Baseline scenario	**2005**	**2020**	**2030**	**2050**
Costs of abatement EU27 – baseline	46.8	85.1	92.2	82.0
Costs of abatement – billions of Euros per year in EU27, Mitigation (2°C) scenario	**2005**	**2020**	**2030**	**2050**
Costs of abatement EU27 – mitigation	46.8	80.2	75.8	46.3
Net benefits of Mitigation	**2005**	**2020**	**2030**	**2050**
Benefits of mitigation scenario	0	4.9	16.4	35.7

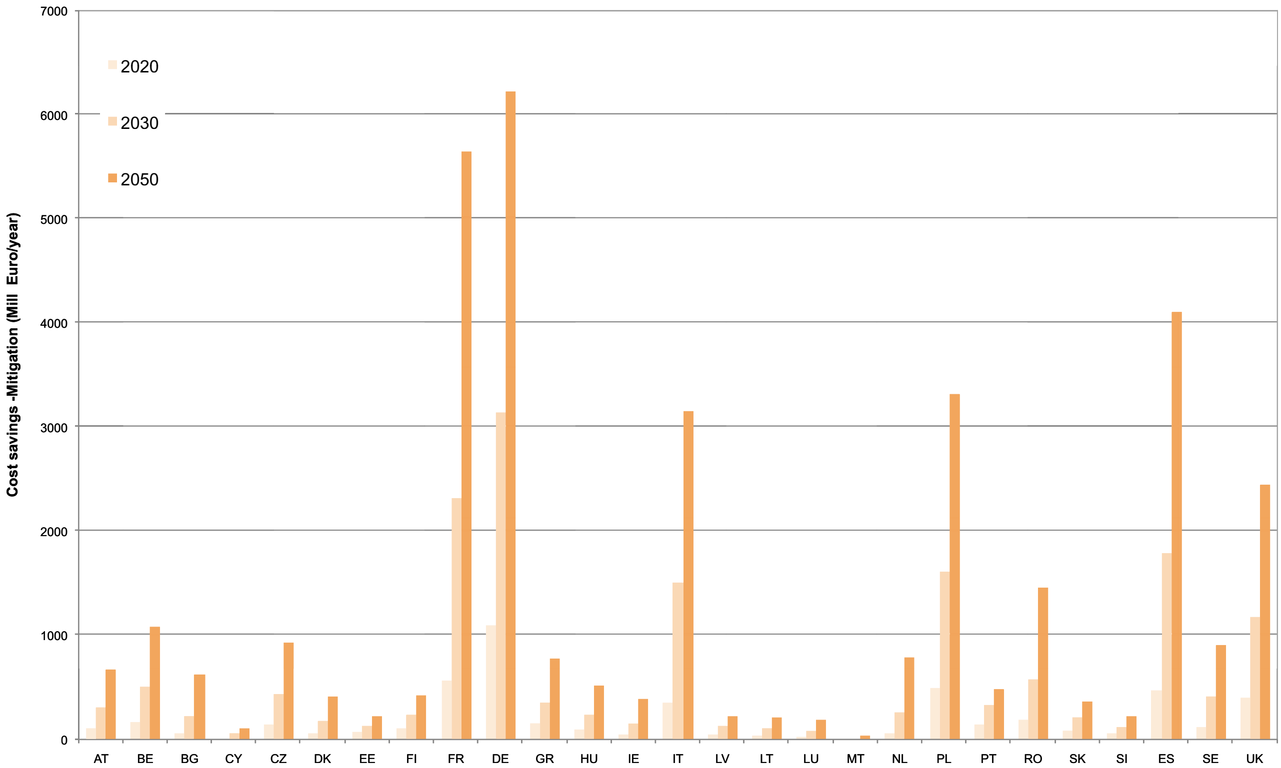
Figure 11. Abatement costs total (billion) for sectors, 2005 to 2050, from climate policies (2005 prices, undiscounted).



Source GAINS, Rafaj et al, 2011).

[14] Note that many of the technologies that abate NOx also abate PM_{10}, but in the analysis, the costs are counted against NOx reductions

Figure 12. Abatement savings in 2030 to 2050, from climate policies. Source GAINS, Rafaj et al (2011). All figures in €millions/year (2005 prices, undiscounted).



For an explanation of the abbreviations, see Appendix 1.

they demonstrate that climate policy can reduce the regulatory burden on business in some ways.

Mitigation also reduces the air pollution abatement required by legislation, leading to cost savings for business. In the EU27, these savings are estimated at €36 billion/year by 2050.

4.6 Other Effects

The main measures for reducing emissions under the Mitigation Scenario are improvements to energy efficiency, fuel switching and the use of carbon capture and sequestration (CCS). These have a broad range of effects beyond the effects on greenhouse gas emissions and the air pollutants considered in this TPBN (and the economic consequences assessed by Russ et al in their 2009 paper on the scenarios). Most of these are beneficial for society, though there is some potential for negative impacts. The following illustrates the additional benefits. These have not been assessed in the ClimateCost project, but should be considered in the wider discussion of mitigation co-benefits.

Energy security: Climate policies that reduce the use of fossil fuels through fuel switching or energy efficiency provide important energy security benefits. These policies reduce the demand for imports of fossil fuels and provide important

macro-economic benefits associated with reduced energy imports. This is important as 55% of Europe's primary energy is imported (CEC, 2011) and this figure will increase slightly in future years under the baseline scenario. Second, by reducing reliance on fossil fuels, these policies potentially provide greater price stability (lower volatility). This is particularly important given oil price fluctuations and price spikes in recent years, and because fossil reserves are primarily in regions with higher geopolitical risks.

Risk of major accidents and legacy issues: A switch from fossil fuels will reduce the risk of some types of major accident. These include coal mining accidents, of which there have been a number of events in recent years, particularly in China, but also in the USA, New Zealand and the UK (amongst others). They also include accidents associated with oil and gas extraction and transport. These are very varied in type, including oil spills from tankers, accidents from rigs such as Piper Alpha in the North Sea and Deepwater Horizon in the Gulf of Mexico. However, some low carbon technologies are also not without risk of accident, most notably the use of nuclear power during operation, as at Fukushima, and from the storage of waste over extended periods. Advocates of all these technologies tend to argue that major accidents affecting their favoured technology are not typical of the advanced technologies that would be installed today, but nonetheless, accidents still happen, despite the existence of sophisticated management and inspection protocols intended to avoid them. These risks are therefore important in balancing the overall ancillary effects of alternative future pathways. Alongside the issues of major accidents are legacy issues associated with nuclear waste, and CO_2 storage.

Landscape and amenity: Widespread deployment of some renewable technologies, notably wind turbines, could have a significant impact on landscapes. Widespread deployment of wind turbines will have an immediate and possibly large effect on the amenity value of landscapes in the short to medium term.

The examples provided above only represent a short-list of co-benefits/trade-offs of climate policies. There are other potential areas that could also be added, notably possible employment or growth opportunities (CEC, 2011). However, they underline the fact that the consequences of climate controls are far reaching and monetisation of these additional issues is a priority for future analysis.

5. Co-Benefits in China and India

While mitigation policy has potentially large co-benefits in Europe, there are potentially even greater benefits for other major emitters with higher current baseline pollution levels, notably in China and India. These countries are increasingly suffering air pollution problems similar to historic European levels, and there is a growing awareness of the associated health and environmental impacts.

The ClimateCost study has therefore assessed the potential co-benefits of mitigation in these countries. This has used the GAINS model analysis, using a similar approach to that outlined for Europe above.

Figure 13 below illustrates the baseline population weighted concentrations of $PM_{2.5}$ up to 2050 in China and India,

Figure 13. Ambient concentrations of $PM_{2.5}$ (population weighted, annual mean) for the Baseline and the Mitigation scenarios. Ranges indicate variations over provinces/states.

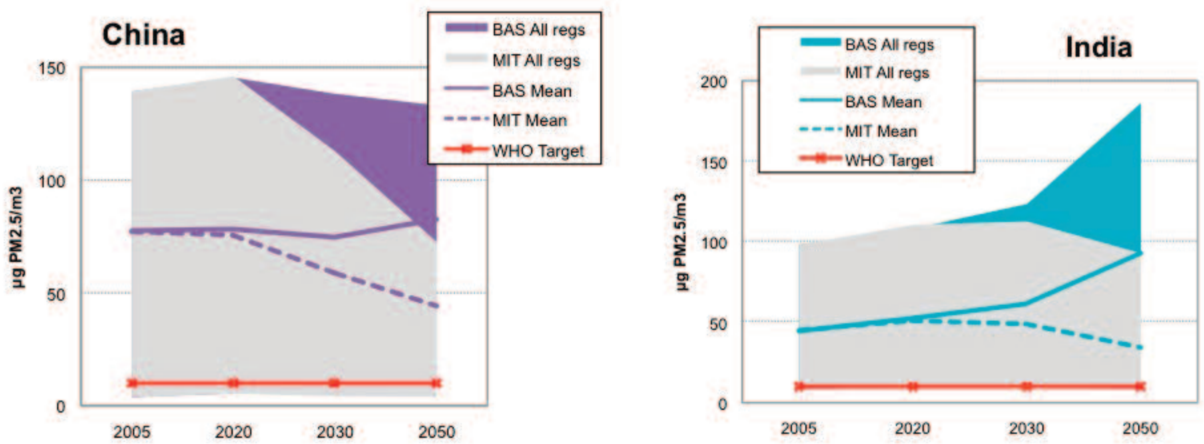
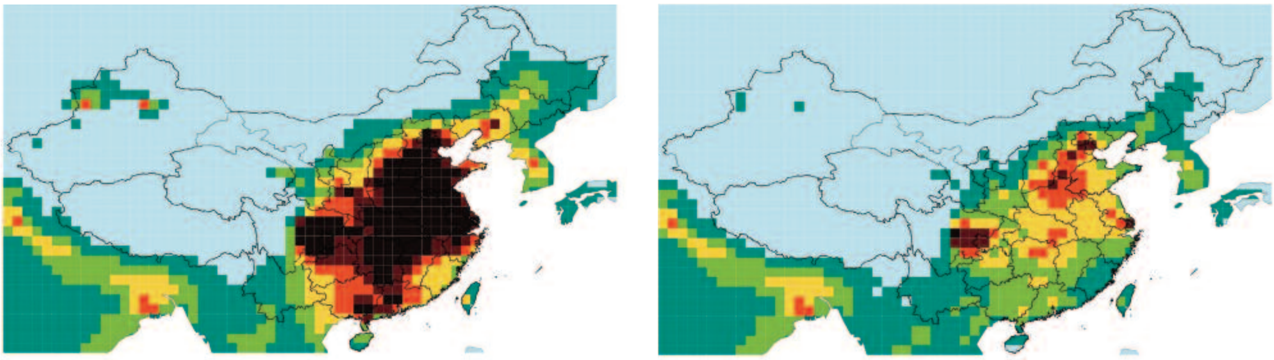
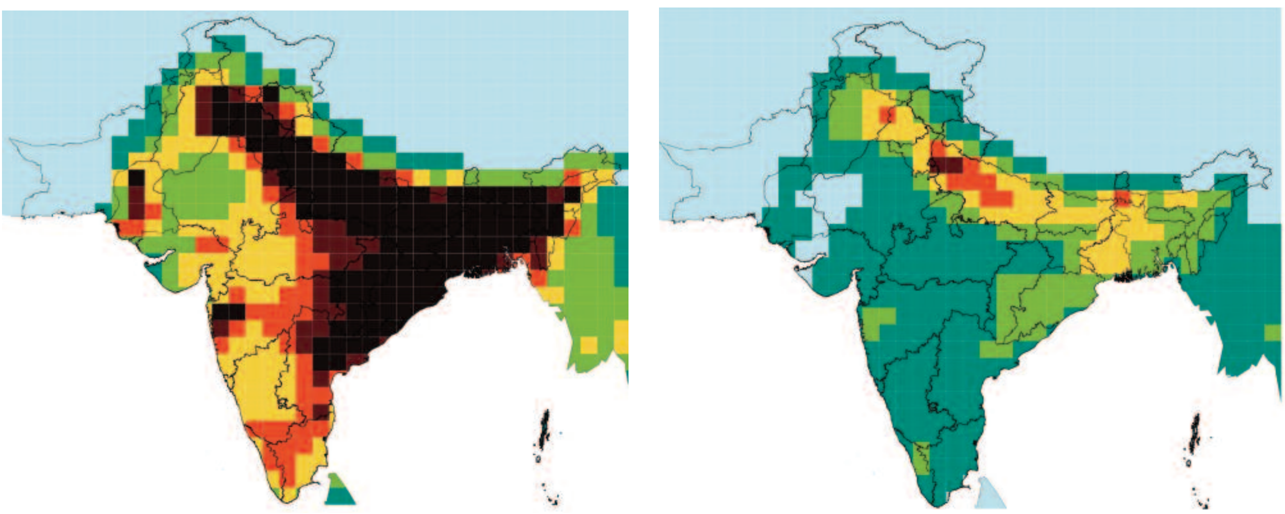


Figure 14. Statistical loss of life expectancy (months) in China due to anthropogenic $PM_{2.5}$ for the Baseline (left panel) and Mitigation (right panel) scenarios in 2050.



Source GAINS, Rafaj et al (2011).

Figure 15. Statistical loss of life expectancy (months) in India due to anthropogenic $PM_{2.5}$ for the Baseline (left panel) and Mitigation (right panel) scenarios in 2050.



Source GAINS, Rafaj et al (2011).

showing the comparison of baseline (BAS) and mitigation scenario (MIT) over time set against the WHO target guideline levels on PM (WHO, 2005). Note these values can be directly compared against the same plot for Europe in Figure 4.

Unlike Europe, most of the regions of China and India have concentrations that far above the WHO guideline level of 10 µg $PM_{2.5}/m^3$. Under the mitigation scenario, average ambient concentrations of $PM_{2.5}$ in China and India are 47% and 63% lower, respectively, when compared to the Baseline projections in 2050. In turn, these air quality improvements lead to very large health benefits.

In China, large health benefits start to arise in 2030, in line with the changes in emissions of air pollutants between the mitigation and baseline scenarios. By 2050, the loss in statistical life expectancy due to $PM_{2.5}$ is halved under the Mitigation scenario, as shown in Figure 14, and compared to the Baseline scenario, it increases life expectancy by nearly 20 months. The premature deaths attributable to ozone are also reduced annually by 20,000 cases with mitigation.

Similarly, in India, the mitigation scenario brings major improvements after 2030. The gain in the statistical life expectancy from mitigation policies is estimated at 30 months by 2050 (see Figure 15), while the projected premature death-rates due to ground-level ozone are reduced by 55,000 cases per year by 2050, relative to the Baseline case.

The pollution reductions in the mitigation scenario would also have very dramatic benefits in reducing acidification and eutrophication loads in these countries, which are an increasingly recognised problem.

7. Discussion

The total co-benefits (health, materials and crops) of reducing emissions under a mitigation scenario (consistent with the EU 2 degrees target) are estimated to reach €44 to €95 billion/year by 2050 (current prices, undiscounted).

These benefits are significant when compared to the underlying costs of mitigation, and accrue to the Member States that are undertaking emissions reductions, with benefits arising in the short-term.

When expressed against the CO_2 reductions achieved, the air quality co-benefits of the mitigation scenario are around €24 per tonne of CO_2 across the period (mid estimate VOLY, current prices).

It is highlighted that there remains some uncertainty over the valuation of mortality. There is almost a factor of 10 variation in the total health co-benefits between the most and least conservative positions on mortality valuation (Table 6) though there is much less difference (less than a factor of 2) between the central values in use in policy (€60 000 VOLY and €1.1 million VSL). While many experts in health impact assessment (see Rabl et al, 2011) believe that the VSL is poorly suited to the specific case of air pollution and the underlying method for deriving life expectancy changes, there remains support for its use.

There are also some limitations to the analysis presented here, principally in relation to the omission from the monetised damage estimates of impacts on ecosystems, and possibly the omission of effects of long-term exposure to ozone on mortality. Inclusion of these impacts would increase our estimates of co-benefits, noting in particular the extensive exceedance of the critical load for nutrient nitrogen.

Nonetheless, it is clear that given the size of these co-benefits, they warrant much greater consideration in the discussion of mitigation policy than currently given. Further work to monetise additional co-benefits, such as energy security, are also highlighted as a priority.

Finally, despite the significant fall in emissions of the regional pollutants under the Baseline, described above, and despite the further reductions in emissions associated with the Mitigation Scenario, there remains a loss of 905,000 million life years annually across the EU27 by 2050. Along with the still widespread exceedance of the critical load for eutrophication by 2050, this demonstrates both the severity of the problems of regional air pollution and the difficulties in addressing them. This, in turn, emphasises the need to exploit opportunities that exist in the synergies between climate and air quality policies.

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Table A1. Country codes

AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DK	Denmark
EE	Estonia
FI	Finland
FR	France
DE	Germany
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
LV	Latvia
LT	Lithuania
LU	Luxembourg
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SK	Slovakia
SI	Slovenia
ES	Spain
SE	Sweden
UK	United Kingdom

List of health impacts quantified

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

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

Table A2. Estimated average loss of life expectancy (Months) (Source GAINS, Rafaj et al, 2011).

Country	Baseline Scenario				Mitigation Scenario		
	2005	2020	2030	2050	2020	2030	2050
Austria	6.7	3.2	2.6	2.6	3.0	2.1	1.6
Belgium	11.5	6.1	5.6	6.0	5.7	4.9	4.2
Bulgaria	8.2	3.4	3.0	3.2	3.1	2.1	1.5
Cyprus	4.1	4.1	3.9	4.4	3.2	2.1	1.5
Czech Rep.	8.2	4.1	3.3	3.3	3.9	2.7	2.0
Denmark	6.4	3.3	3.0	3.1	3.1	2.6	2.3
Estonia	5.2	2.8	2.5	2.6	2.5	2.0	1.6
Finland	2.9	1.6	1.5	1.7	1.5	1.2	1.0
France	6.9	3.5	2.9	2.9	3.3	2.5	2.0
Germany	8.7	4.4	3.8	3.9	4.1	3.2	2.5
Greece	7.8	3.7	3.0	3.2	3.4	2.3	1.9
Hungary	9.5	4.7	4.0	4.1	4.4	3.1	2.3
Ireland	3.4	1.8	1.5	1.5	1.8	1.3	1.1
Italy	6.6	3.4	2.5	2.7	3.2	2.1	1.7
Latvia	5.8	3.5	3.1	3.1	3.3	2.6	2.0
Lithuania	5.7	3.3	3.1	3.3	3.1	2.6	2.1
Luxembourg	8.6	4.4	3.9	4.2	4.2	3.4	2.9
Malta	5.1	3.9	2.1	2.1	3.8	1.8	1.6
Netherlands	11.1	5.8	5.4	5.8	5.5	4.7	4.2
Poland	9.0	4.6	3.7	3.7	4.3	3.1	2.3
Portugal	6.5	3.7	3.1	3.2	3.5	2.6	2.1
Romania	9.1	4.2	3.7	3.9	3.8	2.7	1.9
Slovakia	8.3	4.0	3.4	3.5	3.8	2.7	2.0
Slovenia	7.3	3.6	2.9	2.9	3.4	2.3	1.7
Spain	4.5	2.2	1.6	1.7	2.1	1.4	1.1
Sweden	3.4	1.8	1.7	1.8	1.7	1.5	1.3
United Kingdom	6.2	3.1	2.7	2.8	2.9	2.4	2.1
EU-27 average	**7.3**	**3.7**	**3.1**	**3.1**	**3.5**	**2.6**	**2.0**
Albania	5.0	2.4	1.9	2.1	2.3	1.5	1.2
Belarus	6.3	4.2	4.2	5.0	4.0	4.2	3.6
Bosnia-H	5.4	2.4	2.0	2.2	2.2	1.6	1.2
Croatia	7.5	3.8	3.0	3.2	3.5	2.3	1.8
FYR Macedonia	5.8	2.5	2.1	2.2	2.3	1.5	1.1
R Moldova	7.5	4.2	4.0	4.4	3.6	2.7	2.4
Norway	2.2	1.3	1.3	1.5	1.3	1.2	1.2
Russia	7.4	4.8	4.8		4.4	4.1	
Serbia-M	7.5	3.2	2.7	3.0	2.9	2.0	1.4
Switzerland	5.4	2.7	2.2	2.4	2.6	1.9	1.6
Turkey							
Ukraine	8.6	5.2	5.1	5.7	4.3	3.3	2.6
Non-EU average	7.3	4.5	4.4	4.1	4.1	3.6	2.1

Table A3. Health impacts (cases per year) for the EU27 of for the Baseline and the Mitigation Scenario for 2020, 2030 and 2050 (source ALPHA), and the Co-Benefits.

		Cases/year		
Results for 2020		Baseline	Mitigation	Co-benefit
Acute mortality (all ages) deaths	O3	19,911	19,455	456
Respiratory hospital admissions (65yr +)	O3	19,610	19,173	437
Minor restricted activity days (15-64yr)	O3	43,904,691	42,909,607	995,084
Respiratory medication use (adults 20yr +)	O3	16,671,412	16,295,076	376,335
Chronic mortality, life years lost	PM	1,793,840	1,684,260	109,580
Infant Mortality (1 month - 1yr) deaths	PM	304	284	20
Chronic bronchitis (27yr +) new incidence	PM	84,559	79,467	5,091
Respiratory hospital admissions (all ages)	PM	32,370	30,425	1,945
Cardiac hospital admissions (all ages)	PM	19,964	18,764	1,200
Restricted activity days (RADs 15-64yr)	PM	165,076,033	155,113,567	9,962,466
Respiratory medication use (children 5-14yr) days	PM	1,624,839	1,527,875	96,964
Respiratory medication use (adults 20yr +) days	PM	15,139,994	14,228,761	911,234
Lower respiratory symptom days (children 5-14yr)	PM	83,498,667	78,515,813	4,982,854
Lower respiratory symptom days (15yr +)	PM	153,110,816	143,899,871	9,210,946
Results for 2030				
Acute mortality (all ages) deaths	O3	20,067	18,958	1,109
Respiratory hospital admissions (65yr +)	O3	21,663	20,505	1,159
Minor restricted activity days (15-64yr)	O3	39,396,060	37,257,639	2,138,421
Respiratory medication use (adults 20yr +)	O3	15,952,748	15,090,715	862,033
Chronic mortality, life years lost	PM	1,443,492	1,215,323	228,170
Infant Mortality (1 month - 1yr) deaths	PM	223	186	37
Chronic bronchitis (27yr +) new incidence	PM	72,204	60,925	11,279
Respiratory hospital admissions (all ages)	PM	27,441	23,174	4,268
Cardiac hospital admissions (all ages)	PM	16,924	14,292	2,632
Restricted activity days (RADs 15-64yr)	PM	131,614,877	110,986,476	20,628,401
Respiratory medication use (children 5-14yr) days	PM	1,352,598	1,144,796	207,802
Respiratory medication use (adults 20yr +) days	PM	12,873,281	10,865,142	2,008,138
Lower respiratory symptom days (children 5-14yr)	PM	69,508,511	58,829,817	10,678,694
Lower respiratory symptom days (15yr +)	PM	130,378,109	110,050,954	20,327,155
Results for 2050				
Acute mortality (all ages) deaths	O3	24,259	20,884	3,374
Respiratory hospital admissions (65yr +)	O3	27,869	24,075	3,794
Minor restricted activity days (15-64yr)	O3	36,150,820	31,214,804	4,936,016
Respiratory medication use (adults 20yr +)	O3	16,688,648	14,411,345	2,277,303
Chronic mortality, life years lost	PM	1,387,251	904,805	482,446
Infant Mortality (1 month - 1yr) deaths	PM	201	129	72
Chronic bronchitis (27yr +) new incidence	PM	76,839	50,282	26,556
Respiratory hospital admissions (all ages)	PM	28,933	18,968	9,965
Cardiac hospital admissions (all ages)	PM	17,844	11,698	6,146
Restricted activity days (RADs 15-64yr)	PM	124,127,047	81,419,761	42,707,287
Respiratory medication use (children 5-14yr) days	PM	1,391,384	917,130	474,254
Respiratory medication use (adults 20yr +) days	PM	13,643,560	8,933,242	4,710,318
Lower respiratory symptom days (children 5-14yr)	PM	71,501,674	47,130,298	24,371,376
Lower respiratory symptom days (15yr +)	PM	137,690,472	90,189,476	47,500,996

Table A4. Monetised equivalent of health impacts for the EU27 of the Baseline and the Mitigation Scenario for 2020, 2030 and 2050, and Economic Co-benefits. All figures in €millions/year (current prices, undiscounted, VOLY estimates for mortality risks). Source ALPHA.

		€millions/year		
Results for 2020		Baseline	Mitigation	Co-benefit
Acute mortality (all ages) deaths	O3	1,195	1,167	27
Respiratory hospital admissions (65yr +)	O3	45	44	1
Minor restricted activity days (15-64yr)	O3	1,932	1,888	44
Respiratory medication use (adults 20yr +)	O3	17	16	0
Chronic mortality, life years lost	PM	107,630	101,056	6,575
Infant Mortality (1 month - 1yr) deaths	PM	1,731	1,617	114
Chronic bronchitis (27yr +) new incidence	PM	18,265	17,165	1,100
Respiratory hospital admissions (all ages)	PM	74	70	4
Cardiac hospital admissions (all ages)	PM	46	43	3
Restricted activity days (RADs 15-64yr)	PM	15,847	14,891	956
Respiratory medication use (children 5-14yr) days	PM	2	2	0
Respiratory medication use (adults 20yr +) days	PM	15	14	1
Lower respiratory symptom days (children 5-14yr)	PM	3,674	3,455	219
Lower respiratory symptom days (15yr +)	PM	6,737	6,332	405
Total		**157,209**	**147,759**	**9,450**
Results for 2030				
Acute mortality (all ages) deaths	O3	1,204	1,137	67
Respiratory hospital admissions (65yr +)	O3	50	47	3
Minor restricted activity days (15-64yr)	O3	1,733	1,639	94
Respiratory medication use (adults 20yr +)	O3	16	15	1
Chronic mortality, life years lost	PM	86,610	72,919	13,690
Infant Mortality (1 month - 1yr) deaths	PM	1,272	1,060	212
Chronic bronchitis (27yr +) new incidence	PM	15,596	13,160	2,436
Respiratory hospital admissions (all ages)	PM	63	53	10
Cardiac hospital admissions (all ages)	PM	39	33	6
Restricted activity days (RADs 15-64yr)	PM	12,635	10,655	1,980
Respiratory medication use (children 5-14yr) days	PM	1	1	0
Respiratory medication use (adults 20yr +) days	PM	13	11	2
Lower respiratory symptom days (children 5-14yr)	PM	3,058	2,589	470
Lower respiratory symptom days (15yr +)	PM	5,737	4,842	894
Total		**128,027**	**108,162**	**19,865**
Results for 2050				
Acute mortality (all ages) deaths	O3	1,456	1,253	202
Respiratory hospital admissions (65yr +)	O3	64	55	9
Minor restricted activity days (15-64yr)	O3	1,591	1,373	217
Respiratory medication use (adults 20yr +)	O3	17	14	2
Chronic mortality, life years lost	PM	83,235	54,288	28,947
Infant Mortality (1 month - 1yr) deaths	PM	1,147	737	410
Chronic bronchitis (27yr +) new incidence	PM	16,597	10,861	5,736
Respiratory hospital admissions (all ages)	PM	67	44	23
Cardiac hospital admissions (all ages)	PM	41	27	14
Restricted activity days (RADs 15-64yr)	PM	11,916	7,816	4,100
Respiratory medication use (children 5-14yr) days	PM	1	1	0
Respiratory medication use (adults 20yr +) days	PM	14	9	5
Lower respiratory symptom days (children 5-14yr)	PM	3,146	2,074	1,072
Lower respiratory symptom days (15yr +)	PM	6,058	3,968	2,090
Total		**125,350**	**82,521**	**42,828**

Technical Policy Briefing Note 06

Further information

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To find out more about the ClimateCost project, please visit: www.climatecost.eu

For further information on the ClimateCost project: contact Paul Watkiss at paul_watkiss@btinternet.com

For further information on the GAINS Model, contact Markus Amann, amann@iiasa.ac.at

For further information on the CAFE CBA analysis, contact Mike Holland, mike.holland@emrc.co.uk

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