Offshore wind farm construction noise can displace harbour porpoises

**Noise caused by construction** of Germany’s first offshore wind farm caused significant habitat disturbance for harbour porpoises, according to a recent study. Its results suggest that porpoises avoided areas up to 20 kilometres from the noise source during construction of the wind farm’s foundations.

Development of offshore wind farms plays a major role in the shift towards renewable energies. The construction of Germany’s first offshore wind farm began in the North Sea in September 2008. Offshore wind turbines require solid foundations; typically these are made of heavy posts driven into the seabed with a hydraulic hammer, a process known as pile-driving. With each hammer impact, energy is transmitted into the surrounding water as sound. Sound that causes negative effects, in this context, is referred to as ‘noise’.

Manmade marine noise has been found to have negative effects on some species, such as cetaceans (whales, dolphins, and porpoises), including hearing damage and displacement. Germany has only one resident cetacean, the harbour porpoise, a species considered particularly vulnerable to disturbance, injury or death from human activity. Marine noise is one of these disturbances, potentially capable of damaging hearing and driving away prey species that harbour porpoises feed upon.

Researchers used a combination of aerial surveys and static acoustic monitoring (SAM), a device which logs harbour porpoise echolocation clicks, to determine the effects of turbine-pile-driving noise on the porpoises. Aerial surveys, in an area of 10,900 km², were conducted before, during and after turbine installation between August 2008 and October 2010. SAM data were collected every three months from 12 sites between August 2008 and November 2011. Aerial surveys revealed major differences in harbour porpoise distribution before and during turbine construction. During construction, the porpoises appeared to be avoiding the area. SAM results agreed with aerial survey results, with significantly fewer porpoises detected within 10 kilometres of the pile-driving activity, particularly during longer construction periods. More porpoises were detected at 25 and 50 kilometres from the construction site during pile-driving activity.

The results show a substantial avoidance reaction to pile-driving, suggesting that noise is, at least, unpleasant for harbour porpoises. However, the researchers are unable to assess the level of harm that may result from noise and displacement, both in terms of physical damage to those animals closest to the pile-driving site, and long-term population effects caused by habitat displacement during construction. They suggest that some noise-blocking technologies, such as ‘air bubble curtains’ and ‘hydro sound dampers’ (curtains made of foam or balloons), could be used to reduce habitat displacement during pile-driving.

The authority responsible for licensing offshore wind farms in the German EEZ (Exclusive Economic Zone), the Federal Maritime and Hydrographic Agency, has set a threshold for pile-driving noise, based on advice given by the Federal Environmental Agency. Each offshore wind farm project is obliged to carry out an environmental impact study, in which the possible effects of noise emissions on the marine environment are described and assessed. Under the conditions of the license, during the installation of offshore wind turbines, the sound exposure level (SEL) must not exceed 160 dB (re 1 mPa) outside a 750 m radius. During noisy work, such as pile-driving, regular measurements of waterborne sound have to be taken.

As EU countries increasingly invest in renewable energy resources, these results may be important for discussions of regulations and policies concerning the construction of offshore wind farms. Following the 2011 Fukushima nuclear power plant catastrophe, Germany increased its focus on renewable energies further, with planned expansion of offshore wind power to provide up to 25GW by 2030. Denmark, The Netherlands, Belgium and the UK also have a large number of offshore wind farms planned or already in operation.
Acid emission controls ‘fail to protect habitats’

Conservation agencies in England and Wales say tighter controls on acid emissions from power stations set by the Environment Agency are not enough to protect habitats. Meanwhile, three power stations run by Npower and Scottish and Southern Energy have failed to meet the deadline to fit sulphur abatement. Natural England and the Countryside Council for Wales (CCW) say tighter controls on emissions of sulphur and nitrogen oxides, which came into force on 1 January under the large combustion plant Directive (LCPD), fail to protect sensitive habitats.

Under the LCPD, 13 coal- and oil-fired power stations have opted either to meet tighter emission limits on the acid gases $SO_x$ and $NO_x$, or enter a UK acid gas emissions trading scheme. Most have had to install expensive flue gas desulphurisation and overfire air abatement equipment to achieve the cuts.

Nine other stations have opted out of meeting these requirements and can only operate for limited hours before closing by the end of 2015 (ENDS Report 374, p 38).

The power sector also recently fell under the pollution prevention and control regime. This requires companies to use the ‘best available techniques’ to reduce emissions, potentially forcing them to go beyond the LCPD’s requirements.

Sites under PPC are required by the habitats Directive to assess the potential impact of their emissions on protected areas to ensure they have "no adverse effect".

But in its assessment of power station emissions, focusing on sulphur deposition, the Agency concluded they will have no adverse effect. The chief justification for this decision was the uncertainties involved in modelling critical load exceedances for habitats and the difficulty of attributing these to the power sector.

The Agency has sought to back up its decision by including a generic improvement condition in the PPC permits of all opted-in power stations, setting a total annual limit on $SO_2$ of 70,000 tonnes by 2020. It says this is an 89% reduction from 2003 emissions, with most of the cut coming in the next few months.

Operators must also monitor habitat acidification to track changes. The Agency says if this proves its decision was wrong, power stations will have to make further cuts.
Nevertheless, the conservation agencies do not support the Agency’s decision. They argue that, despite emission reductions by 2020, almost 40% of the UK’s sensitive ecosystems will still exceed critical loads for sulphur and nitrogen.

Simon Bareham, senior adviser at the CCW, said uncertainty over the impact of power stations’ emissions on habitats does not mean there are no adverse effects.

The Agency says nitrogen deposition from agriculture contributes more to exceedances than power stations.

The CCW is also concerned about weaker NO\textsubscript{x} limits at Npower’s Aberthaw station in South Wales. It is permitted to release 1,200 milligrams of NO\textsubscript{x} per cubic metre compared with 500mg/m\textsuperscript{3} at other coal-fired plants.

The Agency says the site’s boiler design means it is not possible to fit overfire air, which other power stations use to control NO\textsubscript{x}. It is requiring Npower to assess alternative ways of cutting NO\textsubscript{x}.

The Agency has also revealed that three power stations have failed to meet the 1 January deadline to fit flue gas desulphurisation. Scottish and Southern Energy’s Fiddlers Ferry and Ferrybridge stations and Aberthaw have fallen back on an LCPD derogation which allows them to operate at a reduced capacity - with a significant loss of income - until FGD is installed.

The sites were caught out by the failure of a long-running Environment Department (DEFRA) campaign to limit the impact of the LCPD, which meant some companies were uncertain how it would affect them (ENDS Report 372, p 37).

Scottish Power has also yet to fit FGD at its Longannet site. It has opted to comply with the LCPD through the national emissions reduction plan, which is an acid gas trading scheme (ENDS Report 386, p 49). This will require the firm to buy allowances to cover the site’s higher emissions. Some power companies have proposed a new generation of so-called clean coal power stations to replace ones closed as a result of the LCPD (see pp 26-29).
Air pollution linked to increased risk of anxiety and stroke

*New series of articles examine the association between air pollution and health*

Air pollution is linked to a higher risk of stroke, particularly in developing countries, finds a study published in *The BMJ* today. In a second article, new research also shows that air pollution is associated with anxiety.

Stroke is a leading cause of death and kills around 5 million people each year worldwide. Common risk factors include obesity, smoking and high blood pressure. But the effect of the environment, such as, air pollution is uncertain because evidence is lacking.

In a systematic review and meta analysis, a team of researchers from Edinburgh University looked at the association between short term air pollution exposure and stroke related hospital admissions and deaths. In total, they analysed 103 observational studies that covered 28 countries across the world.

Gaseous pollutants included in the analysis were carbon monoxide, sulphur dioxide, nitrogen dioxide and ozone. In addition, particulate matter was included: PM 2.5 (fine particles less than 2.5 µm in size) and PM 10 (coarse particles less than 10 µm in size).
Results showed an association between carbon monoxide (1.5% increased risk per 1 ppm), sulphur dioxide (1.9% per 10 ppb) and nitrogen dioxide (1.4% per 10 ppb) and stroke related hospital admissions or death. The weakest association was found for ozone.

Both PM 2.5 and PM 10 were associated with hospital admissions or deaths due to stroke, by 1.1% and 0.3% per 10 µg/m³ increment respectively. The first day of air pollution exposure was found to have the strongest association.

Low- to middle-income countries experienced the strongest associations compared to high-income countries. Only 20% of analysed studies were from low- to middle-income countries - mostly mainland China - despite these countries having the highest burden of stroke.

Higher concentrations of gaseous pollutants were measured in middle- to low- income countries when compared to high-income countries. These results suggest a need for policy changes to reduce exposure in such highly polluted regions, conclude the authors.

Previous research has shown that air pollution can affect the cells that line the circulatory system and increase activity of the sympathetic nervous system, which can lead to narrow blood vessels, an increase in blood pressure, the restriction blood supply to tissues and increase the risk of thrombosis.

A second study from researchers at The Johns Hopkins and Harvard Universities examined the association between particulate air pollution and anxiety.

Anxiety is the most common psychiatric disorder and globally affects around 16% of people at some point in life. It is associated with lessened productivity, increased medical care and risk of suicide.
Overall, 71,271 women, aged between 57 and 85 years, were included in the analysis. Data were taken from the US Nurses’ Health Study.

Exposure to particulate matter, PM 2.5 and PM 2.5-10 was determined from national geographic and meteorological data, and estimated from five periods (one month, three months, six months, one year and 15 years) before assessment of anxiety.

Distance from residence address to the nearest major road, a common indicator for traffic related air pollution exposure, was also analysed.

An anxiety questionnaire that included eight self-rated questions on symptoms including fearfulness, desire for avoidance and tendency to worry was completed by each participant.

Factors including socioeconomic status, education, age and marital status were all accounted for.

Findings showed that around 15% of women experienced high anxiety symptoms. Exposure to particulate matter was linked to a higher risk of anxiety. While PM2.5 was found to have a significant association with anxiety, no such link existed with PM 2.5 - 10.

Women who resided 50 to 200m from a major road were more likely to have higher anxiety symptoms than those living more than 200m away. But those living within 50m of a major road did not experience this association.

Recent exposure, on the other hand, was found to have a more significant association with anxiety- effects were strongest following the first month of exposure.

Particulate matter air pollution may trigger or worsen anxiety through oxidative stress and inflammation or deteriorate an
existing health condition, explain the authors.

Both studies were observational and no definitive conclusions can be drawn about cause and effect, and the teams of researchers call for more research.

In an accompanying editorial, Michael Brauer from the University of British Columbia, Canada, writes that these studies “confirm the urgent need to manage air pollution globally as a cause of ill health” and that reducing “air pollution could be a cost effective way to reduce the large burden of disease from both stroke and poor mental health.”

Research article: Short term exposure to air pollution and stroke: a systematic review and meta analysis
www.bmj.com/cgi/doi/10.1136/bmj.h1295

Research article: The relation between exposure to fine particulate air pollution and anxiety: a cohort study
www.bmj.com/cgi/doi/10.1136/bmj.h1111

Editorial: Air pollution, stroke and anxiety
www.bmj.com/cgi/doi/10.1136/bmj.h1510

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Media Coverage

**Air Pollution Raises Stroke Risk** - New York Times

**Air pollution 'link to stroke risk'** - BBC News

**Air Pollution Could Trigger 'Disabling Strokes' Or Increase The Likelihood That You'll Suffer Anxiety, Research Shows** - Huffington Post

# CABINET MEMBERS DELEGATED DECISION

<table>
<thead>
<tr>
<th>Open/Exempt</th>
<th>Would any decisions proposed:</th>
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<tbody>
<tr>
<td></td>
<td>Be entirely within Cabinet’s powers to decide</td>
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<td></td>
<td>Need to be recommendations to Council</td>
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<td></td>
<td>Is it a Key Decision</td>
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<tr>
<th>Any especially affected Wards</th>
<th>Mandatory/ Discretionary/ Operational</th>
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<tbody>
<tr>
<td>All coastal wards in the Borough</td>
<td></td>
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</table>

**Lead Member:** Cllr Brian Long  
**E-mail:** cllr.brian.long@west-norfolk.gov.uk  
**Other Cabinet Members consulted:** None  
**Other Members consulted:** None

**Lead Officer:** Alan Gomm  
**E-mail:** alan.gomm@west-norfolk.gov.uk  
**Direct Dial:** 01553 616237  
**Other Officers consulted:** Executive Director Planning and Environment

<table>
<thead>
<tr>
<th>Financial Implications</th>
<th>Policy/Personnel Implications</th>
<th>Statutory Implications</th>
<th>Equal Impact Assessment</th>
<th>Risk Management Implications</th>
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<tbody>
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<td>YES/NO</td>
<td>YES/NO</td>
<td>YES/NO</td>
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**Date meeting advertised:** 9 April 2015  
**Date of meeting decision to be taken:** 15 April 2015  
**Deadline for Call-In:** 22 April 2015

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## DRAFT MEMORANDUM OF AGREEMENT FOR WASH & NORTH NORFOLK COAST EUROPEAN MARINE SITE MANAGEMENT SCHEME

**Summary**
- The Borough Council has a statutory responsibility for aspects of the Wash and North Norfolk Coast European Marine Site and has for a number of years discharged this along with other bodies through the Wash and North Norfolk Coast European Marine Site Management Scheme.  
- The current Management Scheme is about to expire and consideration has been given to whether this should be extended.

**Recommendation**
- The proposal is that it should be extended for a further three years at a cost of £2700 p.a. to the Borough Council.

**Reason for Decision**
- In order to discharge a statutory function which falls to the Borough Council.

---

1. **Background and statutory considerations**
1.1 The Wash and North Norfolk Coast European Marine Site consists of a Special Area of Conservation (SAC) designated under the “Habitats Directive” and three Special Protection Areas (SPA) designated under the Birds Directive which created a network of protected wildlife areas across the European Union, known as the Natura 2000 series.

1.2 The parties to the current agreement fully recognise the nature conservation importance of the Wash and North Norfolk Coast (referred to below as “the W&NNC”) and the statutory obligations placed upon them by the legislation referred to above. In order to assist in meeting these obligations the “Wash and North Norfolk Coast Management Group” jointly prepared “The Wash and North Norfolk Coast European Marine Site Management Scheme”. Dedicated staff time is required to implement the management scheme and a Project Manager will be employed by Eastern Inshore Fisheries and Conservation Authority (EIFCA) and financially supported by the partners.

1.3 Project Objectives - The purpose of the Project is to deliver the requirements placed upon Relevant Authorities and local agencies to implement the U.K. Habitats Regulations as these affect the W&NNC, in particular to maintain/achieve favourable conservation status for the interest features for which the area has been designated, and also to contribute to the sustainable development of the area. This should be achieved by working with all stakeholders for the area to implement The Management Scheme. There are several strategic goals which provide a framework for the tasks of the Project:

- Implementing and reviewing a Management Scheme for the area.
- Reporting as appropriate on the achievements of the Project.
- Delivering Natural England (NE) conservation objectives for the marine site interest features.
- Undertaking a condition monitoring programme.
- Promoting the Project and the sustainable use of the area, including the exercising of traditional activities. (See paragraph 1.6 of the Management Scheme.)

1.4 This agreement aims to establish the funding of the Wash and North Norfolk Coast European Marine Site Management Project to implement the Wash and North Norfolk Coast European Marine Site Management Scheme and sets out the arrangements for running the Project.

1.5 EIFCA is to take the lead and employ the Project Manager to implement the Project. The Project is to be funded by those “Relevant Authorities” listed below.

1.6 The Project will work closely with other complementary initiatives, for example The Norfolk Coast Project.
The area within which the Project will operate is the statutorily designated areas of the European Marine Site, (stretching from Flamborough Head to Blakeney Point) but on occasions will also include the wider adjoining areas in relation to specific issues, for example water quality, where a wider working area may be required to maintain favourable condition of an interest feature within the Project’s area.

2. Options Considered

2.1 To not continue with the partnership working would render the Borough Council open to individual responsibilities that would be more onerous and costly than through joint working.

3. Policy Implications

3.1 The FMB will be chaired by the lead authority, be serviced by the Project Manager and consist of the following listed below:-

- one elected Member of the Boston Borough Council
- one elected Member of the East Lindsey District Council
- one representative of Natural England
- one elected Member of the King’s Lynn and West Norfolk Borough Council
- one elected Member of the Lincolnshire County Council
- one representative of the Environment Agency
- one elected Member of the Norfolk County Council
- one elected Member of the South Holland District Council
- one elected Member of Fenland District Council
- one elected Member of Internal Drainage Boards
  (to represent all other Lincolnshire and Norfolk IDBs relevant to the European Marine Site)
- one representative of EIFCA
- one elected member of the North Norfolk District Council
- two ports representatives (to represent the King’s Lynn Conservancy Board, the Port of Boston, and the Wells Harbour Commissioners)
- one representative of Defence Infrastructure Organisation
- one representative of the Marine Management Organisation

all of whom will be entitled to vote, or can delegate their vote to a named substitute on all issues affecting the Project.
Full Management Board (FMB)

**Composition:** Officers, elected members, representatives of user groups & other partner organisations, plus project manager. Chaired by the lead authority (or other elected body.) Meets twice a year.

**Role:** Accountable under legislation & protocols
Agrees policy and direction
Bids for project support within relevant authority/other partner organisations
Represents project within same
Responsible for management scheme & its Progress

Core Management Group (CMG)

**Composition:** A subgroup of the relevant authorities within FMB, plus the project manager. Chair as for FMB. Meets 2 times a year, or as required.

**Role:** A working group taking forward functions delegated from FMB
Sets programme & manages project manager
Reports to & advises Full Management Board

4. Financial Arrangements

4.1 The Project’s annual cost for core and output funding will be shared between the various participants to this Memorandum of Agreement, as set out below:

- Boston Borough Council £2,700
- East Lindsey District Council £2,700
- King’s Lynn and West Norfolk Borough Council £2,700
- Lincolnshire County Council £2,025
- Norfolk County Council £2,700
- South Holland District Council £2,700
- Fenland District Council £2,700
- North Norfolk District Council £2,700
- Internal Drainage Boards (5 x £306 excluding Kings Lynn Consortium) £1,530
- Defence Estates £500

Total income 2015-18 £22,955

5. Personnel Implications - Employment of Project Manager

5.1 The Project will be implemented through a Project Manager appointed to the staff of the EIFCA (They will be an employee of EIFCA) and funded through the project.
6. Statutory Considerations

6.1 See 2.1 above.

7. Equality Impact Assessment (EIA)

7.1 Pre-screening report attached.

8. Risk Management Implications

8.1 The risk of failing to discharge relevant duties should we not continue in membership of the partnership would open the Borough Council to legal proceedings.

9. Declarations of Interest / Dispensations Granted

9.1 None sought.

10. Background Papers

10.1 Memorandum of Agreement for the Wash and North Norfolk Coast European Marine Site Management Scheme 2015-18
# Pre-Screening Equality Impact Assessment

## Name of policy/service/function
Memorandum of Agreement for the Wash and North Norfolk Coast European Marine Site Management Scheme 2015-18

## Is this a new or existing policy/ service/function?
New / Existing (delete as appropriate)

## Brief summary.description of the main aims of the policy/service/function being screened.
Discharge of statutory responsibilities regarding the European Marine Site.

## Question

<table>
<thead>
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<th>Question</th>
<th>Answer</th>
<th>Positive</th>
<th>Negative</th>
<th>Neutral</th>
<th>Unsure</th>
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</thead>
<tbody>
<tr>
<td>1. Is there any reason to believe that the policy/service/function could have a specific impact on people from one or more of the following groups according to their different protected characteristic, for example, because they have particular needs, experiences, issues or priorities or in terms of ability to access the service?</td>
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<td>Disability</td>
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<td>Gender Re-assignment</td>
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<td>Marriage/civil partnership</td>
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<td>Pregnancy &amp; maternity</td>
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<td>Race</td>
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<td>Religion or belief</td>
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<td>Sexual orientation</td>
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<td>Other (eg low income)</td>
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NB. Equality neutral means no negative impact on any group.

## Question

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<tr>
<th>Question</th>
<th>Answer</th>
<th>Comments</th>
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<tbody>
<tr>
<td>2. Is the proposed policy/service likely to affect relations between certain equality communities or to damage relations between the equality communities and the Council, for example because it is seen as favouring a particular community or denying opportunities to another?</td>
<td>Yes / No</td>
<td></td>
</tr>
<tr>
<td>3. Could this policy/service be perceived as impacting on communities differently?</td>
<td>Yes / No</td>
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<tr>
<td>4. Is the policy/service specifically designed to tackle evidence of disadvantage or potential discrimination?</td>
<td>Yes / No</td>
<td></td>
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<tr>
<td>5. Are any impacts identified above minor and if so, can these be eliminated or reduced by minor actions? If yes, please agree actions with a member of the Corporate Equalities Working Group and list agreed actions in the comments section</td>
<td>Yes / No</td>
<td>Actions: Actions agreed by EWG member: …………………………………………</td>
</tr>
</tbody>
</table>

## Assessment completed by:
Name: Alan Gomm
Job title: LDF Manager
Date: 8 April 2015
Short term exposure to air pollution and stroke: systematic review and meta-analysis

Anoop S V Shah,1 Kuan Ken Lee,1 David A McAllister,2 Amanda Hunter,1 Harish Nair,2 William Whiteley,3 Jeremy P Langrish,1 David E Newby,1 Nicholas L Mills1

ABSTRACT

OBJECTIVE
To review the evidence for the short term association between air pollution and stroke.

DESIGN
Systematic review and meta-analysis of observational studies

DATA SOURCES
Medline, Embase, Global Health, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Web of Science searched to January 2014 with no language restrictions.

ELIGIBILITY CRITERIA
Studies investigating the short term associations (up to lag of seven days) between daily increases in gaseous pollutants (carbon monoxide, sulphur dioxide, nitrogen dioxide, ozone) and particulate matter (<2.5 µm or <10 µm diameter (PM$_{2.5}$ and PM$_{10}$)), and admission to hospital for stroke or mortality.

MAIN OUTCOME MEASURES
Admission to hospital and mortality from stroke.

RESULTS
From 2748 articles, 238 were reviewed in depth with 103 satisfying our inclusion criteria and 94 contributing to our meta-estimates. This provided a total of 6.2 million events across 28 countries. Admission to hospital for stroke or mortality from stroke was associated with an increase in concentrations of carbon monoxide (relative risk 1.015 per 1 ppm, 95% confidence interval 1.004 to 1.026), sulphur dioxide (1.019 per 10 ppb, 1.011 to 1.027), and nitrogen dioxide (1.014 per 10 ppb, 1.009 to 1.019). Increases in PM$_{2.5}$ and PM$_{10}$ concentration were also associated with admission and mortality (1.011 per 10 µg/m$^3$ (1.010 to 1.012) and 1.003 per 10 µg/m$^3$ (1.002 to 1.004), respectively). The weakest association was seen with ozone (1.001 per 10 ppb, 1.000 to 1.002).

WHAT IS ALREADY KNOWN ON THIS TOPIC
Stroke is a major cause of disability worldwide with an increasing incidence, particularly in low and middle income countries
While exposure to outdoor air pollution is strongly associated with acute cardiac events, the relation between air pollution and stroke is less clear

WHAT THIS STUDY ADDS
Our findings suggest a strong association between short term exposure to both gaseous (except ozone) and particulate air pollution, and admission to hospital for stroke and mortality from stroke
These associations were strongest in low and middle income countries, suggesting the need for policy changes to reduce personal exposure to air pollutants especially in highly polluted regions

Strongest associations were observed on the day of exposure with more persistent effects observed for PM$_{2.5}$.

CONCLUSION
Gaseous and particulate air pollutants have a marked and close temporal association with admissions to hospital for stroke or mortality from stroke. Public and environmental health policies to reduce air pollution could reduce the burden of stroke.

SYSTEMATIC REVIEW REGISTRATION
PROSPERO-CRD42014009225.

Introduction
Outdoor air pollution is an important risk factor for cardiovascular disease throughout the world, with particulate air pollution alone responsible for over three million deaths each year. Increases in concentrations of daily air pollution are associated with acute myocardial infarction and admission to hospital or death from heart failure. These associations could be mediated through direct and indirect effects of exposure to air pollutants on vascular tone, endothelial function, thrombosis, and myocardial ischaemia.

Stroke accounts for five million deaths each year and is a major cause of disability. The incidence of stroke is increasing, particularly in low and middle income countries, where two thirds of all strokes occur. The global burden of stroke related disability is therefore high and continues to rise. This has been primarily attributed to an ageing population in high income countries and the accumulation of risk factors for stroke, such as smoking, hypertension, and obesity, in low and middle income countries. The impact of environmental factors on morbidity and mortality from stroke, however, might be important and is less certain. Given similarities in the pathophysiology of acute coronary syndrome and ischaemic stroke, it is plausible that air pollution is also an important and modifiable risk factor.

To provide global policy makers with the best estimates of the effect of short term exposure to air pollution on risk of stroke, we systematically reviewed studies examining the association between air pollution and admission to hospital for stroke or mortality from stroke.

Methods
Databases, sources, and searches
We searched Medline and Embase (from 1948 to 21 January 2014), Global Health, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Web of Science with detailed search terms for: “stroke”, “cerebrovascular
disease”, “air pollution”, “carbon monoxide”, “sulphur dioxide”, “nitrogen dioxide”, “ozone”, and “particulate matter” (see appendix 1 for detailed search strategy). We also hand searched the bibliographies of all the included studies and relevant review articles to identify any remaining studies.

Selection of articles and extraction of data
Original studies were included if they evaluated short term associations (up to a lag of seven days) between carbon monoxide, sulphur dioxide, nitrogen dioxide, ozone, and particulate matter PM$_{2.5}$ (fine particles $<$2.5 μm in size) or PM$_{10}$ (coarse particles $<$10 μm in size) and admission to hospital for stroke or mortality from stroke (appendix 2). Admission or mortality had to be recorded as an end point. Our search criteria imposed no language restrictions. We did not include studies that evaluated association of long term exposure to air pollution and stroke (appendix 2) or abstracts, but we did include short reports.

One investigator (ASVS) performed the initial screening of titles and abstracts. A second investigator (KKL) assessed a random sample of 200 initial titles and abstracts during the initial screening process, and no cases of disagreement were found. Two investigators (ASVS and KKL) were involved in the examination of the full text reports for eligibility of studies according to our prespecified review protocol (PROSPERO registration CRD42014009225). The inter-rater agreement for eligibility of studies was 0.95 (95% confidence interval 0.91 to 0.99). ASVS and KKL independently extracted the required parameters of each study, and conflicts were adjudicated by a third author (AH). We contacted authors for additional data or clarification for our meta-analysis where these were not presented.

Study design
We included both case crossover and time series studies (appendix 3). The case crossover design uses conditional logistic regression to compare exposure in a case period when the event occurred with exposure in specified control periods, with adjustment for individual characteristics such as age, sex, and comorbidity as well as secular trends and seasonal patterns with a time stratified approach. It assumes that short term time varying risk factors (such as smoking) are constant within reference periods and therefore do not confound rapidly fluctuating parameters such as concentrations of air pollution and other meteorological parameters.

Time series studies measure the association between exposure and outcome with regression analysis to adjust for confounding factors, such as meteorological variables, but are less effective at controlling for secular trends such as seasonality.

Data synthesis
We pooled relative risks for a standardised increment in pollutant concentration as follows: 10 μg/m$^3$ for PM$_{2.5}$ and PM$_{10}$, 10 ppb (parts per billion) for nitrogen dioxide (NO$_2$), sulphur dioxide (SO$_2$), and ozone (O$_3$), and 1 ppm (parts per million) for carbon monoxide (CO). These increments were used in most studies and in previous meta-analysis. We calculated standardised risk estimates for each study using the following formula:

Five studies reported natural log of relative risk and the corresponding statistic value or standard error of mean. Studies that expressed substratified risk estimates by age, location, season, sex, and type of stroke rather than an overall risk estimate were pooled separately.

Additional analysis
We used the shortest lag presented to derive the overall estimates consistent with previous studies. The temporal association between air pollution and admission to hospital for stroke or mortality from stroke were further stratified according to time lags. Summary estimates for lag 0 (days) refer to the risk of an event per increment in air pollution on the day of the event. Lag 1 refers to risk estimates per increment in air pollution concentrations one day before the event. Most studies presented single lag analysis but only a few studies explicitly reported use of distributed lag models (appendix 4). We were therefore unable to further stratify studies reporting single lag analysis using distributed lag models. Several studies reported data based on pollutant concentrations over cumulative lags (for example lag 0–1 or lag 0–2) and were not suitable for pooling in single lag analysis.

We performed additional prespecified analysis stratified by study design, age, sex, outcome, and type of stroke. For nitrogen dioxide and PM$_{10}$ we further provided pooled estimates stratified by the nation’s income status as defined by the World Bank using the gross national income per capita. We provided pooled estimates for stratified variables where at least three or more estimates were available.

Risk of bias
We assessed each individual study for risk of bias across three parameters: selection bias, assessment of exposure, and adjustment for confounders. We then carried out sensitivity analysis eliminating those studies with high risk of bias.

Selection bias
We did not have access to primary data and therefore were reliant on the case definitions used by the authors of the individual studies. Most studies (83%, 86/103 studies), however, used ICD-9 (international classification of diseases, ninth revision) codes 430–438 and ICD-10 (international classification of diseases, 10th revision) codes I60–I69 (appendix 4). Studies that used all clinical information, including brain imaging, to define stroke or those that used an inclusive definition of stroke (ICD-9 codes 430–437 and ICD-10 codes I60-I68) were considered to be at low risk of selection bias. Studies that used a less inclusive definition were considered to be at increased risk of selection bias.
Exposure assessment

Accuracy of the measurement of exposure was difficult to assess because of variable reporting in the primary studies. The frequency of measurement (daily or intermittent monitoring), however, was reported to a high standard, and we considered studies that used daily measurement to be at low risk of bias.

Adjustment of confounders

Adjustment for meteorological parameters, time trends, seasonality, and influenza outbreaks are summarised in the data supplement (appendix 4). Studies that adjusted for at least three confounders were considered to be at low risk of bias.

Statistical analysis

Based on our previous analysis, we anticipated a larger degree of variation and heterogeneity in the overall effect estimates between studies because of different study designs, methods of analysis, different exposure lags, and geographical and population differences. As we did not assume that the “true effect” estimate would be the same across all studies, we used a prespecified random effects model (maximum likelihood approach) for our analysis to account for heterogeneity both within and between studies. We conducted prespecified subgroup analysis by study design, age, sex, outcome, and type of stroke to explore any underlying source for heterogeneity.

We constructed funnel plots to examine publication bias (appendix 5) and assessed them for asymmetry using Egger’s regression test. We then corrected for asymmetry using the trim and fill method, with adjusted relative risks and the number of studies adjusted presented for each pollutant.

Summary statistics are presented as relative risk per given increment in pollutant concentration. The analysis was performed with comprehensive meta-analysis (Biostat, Englewood, NJ) and RStudio (RStudio 2013, version 0.98.501). Significance for pooled estimates was taken as a two sided P<0.05.

Results

We assessed the abstracts of 2748 articles and reviewed 238 relevant studies in depth. Of these, we identified 103 that fulfilled the inclusion criteria (appendix 2 and 3). Of these 103 studies, 36 used a case control design, 45 used a time series design, 33 used a case crossover design, and one used both study designs incorporating over 6.2 million events across 28 countries (appendix 3). Twenty five (24%) studies presented analyses stratified by type of stroke (haemorrhagic and ischaemic), though only a minority of studies reported on haemorrhagic strokes (15 studies, 15%). Most studies presented risk estimates for stroke defined from administrative databases using the ICD-9 and ICD-10 codes (appendix 4). Most studies adjusted for other meteorological parameters including time trends, seasonality, and temperature (appendix 4). Not all studies provided risk estimates across all pollutants (appendix 3).

Of the 103 studies that met the inclusion criteria, we excluded nine studies from meta-analysis. Of these nine studies, five presented estimates as a subset of the parent study and therefore only estimates from the parent study were included. Twenty studies were excluded as risks were presented per category of pollutant concentration rather than per unit increment, the increment was not defined, or the effect estimates were not presented as either relative risks or odds ratios.

There was a positive association between all gaseous and particulate air pollutants and admission to hospital for stroke or mortality from stroke, with the weakest association seen for ozone (fig 1). Individual forest plots for each of the pollutants are presented in appendix 6.

Particulate pollutants

Both PM2.5 and PM10 were positively associated with admission to hospital for stroke or mortality from stroke, with a stronger association for PM2.5. The increase in relative risk was 1.011 (95% confidence interval 1.011 to 1.012) per 10 µg/m³ increase in PM2.5 concentration (fig 1). The association between PM2.5 and stroke was evident on the day of the event (lag 0) and was present for up to two days (lag 2) before the event.

These associations persisted when we stratified by outcome (admission or death), sex, age (>65), or study design.

---

**Table:**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Increment</th>
<th>Lag</th>
<th>N of events</th>
<th>N of estimates</th>
<th>Relative risk (95% CI)</th>
<th>I²</th>
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<td>CO</td>
<td>per 1 ppm</td>
<td>Overall</td>
<td>2 010 272</td>
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<td>1.015 (1.004 to 1.026)</td>
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<td></td>
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<td></td>
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<td>1 515 116</td>
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<td>1.002 (0.993 to 1.010)</td>
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<td>SO₂</td>
<td>per 10 ppb</td>
<td>Overall</td>
<td>1 791 159</td>
<td>52</td>
<td>1.019 (1.011 to 1.027)</td>
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<td>711 955</td>
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<td>30</td>
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<td></td>
<td></td>
<td>Lag 2</td>
<td>654 676</td>
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<td>1.004 (0.989 to 1.019)</td>
<td>34</td>
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<tr>
<td>NO₂</td>
<td>per 10 ppb</td>
<td>Overall</td>
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<td>1.014 (1.009 to 1.019)</td>
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<td></td>
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<td>Lag 0</td>
<td>1 175 010</td>
<td>40</td>
<td>1.012 (1.008 to 1.016)</td>
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<td>1.005 (0.999 to 1.011)</td>
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<tr>
<td>O₃</td>
<td>per 10 ppb</td>
<td>Overall</td>
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<td>53</td>
<td>1.001 (1.000 to 1.002)</td>
<td>58</td>
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<tr>
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<td>PM₁₀,₅</td>
<td>per 10 µg/m³</td>
<td>Overall</td>
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<td>Lag 0</td>
<td>1 961 515</td>
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<td></td>
<td>Lag 1</td>
<td>803 394</td>
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<td>1.013 (1.011 to 1.015)</td>
<td>66</td>
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<tr>
<td></td>
<td></td>
<td>Lag 2</td>
<td>697 365</td>
<td>15</td>
<td>1.013 (1.010 to 1.015)</td>
<td>70</td>
</tr>
<tr>
<td>PM₁₅,₅</td>
<td>per 10 µg/m³</td>
<td>Overall</td>
<td>2 607 993</td>
<td>78</td>
<td>1.003 (1.002 to 1.004)</td>
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<tr>
<td></td>
<td></td>
<td>Lag 0</td>
<td>1 405 957</td>
<td>43</td>
<td>1.002 (1.001 to 1.003)</td>
<td>17</td>
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<tr>
<td></td>
<td></td>
<td>Lag 1</td>
<td>864 448</td>
<td>33</td>
<td>1.001 (1.000 to 1.002)</td>
<td>19</td>
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<tr>
<td></td>
<td></td>
<td>Lag 2</td>
<td>694 772</td>
<td>24</td>
<td>1.001 (1.000 to 1.002)</td>
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**Fig 1** | Association between gaseous and particulate air pollutants and admission for stroke or mortality from stroke stratified by time lag (days)
Gaseous pollutants

Nitrogen dioxide was the most commonly measured gaseous pollutant, with a 1.014 (95% confidence interval 1.009 to 1.019) relative increase in risk of admission to hospital for stroke or mortality from stroke per 10 ppb increment across two million events (fig 1). Both sulphur dioxide (1.019 (1.011 to 1.027) per 10 ppb) and carbon monoxide (1.015 (1.004 to 1.026) per 1 ppm) were also positively associated with admission and mortality. Ozone however, showed only a weak association (1.001 (1.000 to 1.002) per 10 ppb; fig 1).

These associations persisted when we stratified by outcome, age, and study design. All gaseous pollutants except ozone showed a positive and consistent relation with ischaemic stroke (appendix 7). Nitrogen dioxide exposure showed a consistent association with both ischaemic and haemorrhagic stroke (1.024 (95% confidence interval 1.010 to 1.038, F=56%) and 1.024 (1.003 to 1.045, F=42%), respectively; see appendix 7).

The association between gaseous pollutants and stroke was related to lag in exposure (days), with the strongest associations evident for pollutant concentrations on the day of the event (lag 0) and diminishing with longer lag periods (fig 1).

Stratification by category of national income

Most studies (80%) originated from high income countries, with only 21 (20%) originating from low or middle income countries. Both nitrogen dioxide and particulate matter (PM$_{2.5}$) were commonly measured across high and low to middle income countries. Studies for these pollutants originated from Latin America (including Brazil, Chile, and Mexico), South Africa, China, Thailand, Iran, and South Africa (fig 3). Most studies from low and middle income countries originated from mainland China (14 studies).

Pooled estimates from studies originating in low and middle income countries showed a stronger association than high income countries for nitrogen dioxide (1.019 (95% confidence interval 1.011 to 1.027) v 1.012 (1.006 to 1.017)) and PM$_{10}$ (1.004 (1.002 to 1.006) v 1.002 (1.001 to 1.003)) (fig 3). The median pollutant concentrations for nitrogen dioxide and PM$_{2.5}$, were higher in low and middle income countries (median pollutant concentration 27.6 ppb (interquartile range 23.8–29.6 ppb) for nitrogen dioxide and 50.2 µg/m$^3$ (32.6–65.7 µg/m$^3$) for PM$_{2.5}$) than in high income countries (median pollutant concentration 22.6 ppb (19.4–28.3 ppb) for nitrogen dioxide and 25.3 µg/m$^3$ (23.8–29.6 µg/m$^3$) for PM$_{10}$).

Bias and heterogeneity

There was no difference in our overall effect estimates when we removed studies at increased risk of bias (appendix 8). Publication bias (Egger’s test for asymmetry P<0.05) was observed for all pollutants except sulphur dioxide and PM$_{10}$ (table; appendix 4). Adjustment for asymmetry with the trim and fill method did not alter the effect direction but, as expected, did attenuate the effect size. We observed heterogeneity across all pollutants, and this was most evident with PM$_{2.5}$ (I²=86%) and least evident with PM$_{10}$ (I²=24%).

Discussion

In this systematic review and meta-analysis, we evaluated the effects of short term exposure to gaseous and particulate matter.
particulate air pollution on admission to hospital for stroke or mortality from stroke. We made several important observations. Firstly, in over 6.2 million events across 28 countries throughout the world, our pooled analysis showed robust and clear associations between both gaseous and particulate air pollution and stroke admission or mortality. Secondly, the strongest associations between air pollution and admission or mortality were observed from studies originating in low to middle income countries. Thirdly, these associations persisted when we stratified our pooled analyses by study design, age, or outcome. Thus, we have shown that gaseous and particulate air pollutants have a robust and close temporal association with admission to hospital for stroke or stroke death. We suggest that improvements in air quality could reduce the burden of stroke.

Evidence of short term exposure to air pollution and stroke

Over the past three decades, epidemiological studies including pooled analyses have shown that cardiac, rather than pulmonary, disease is the primary cause of morbidity and mortality associated with exposure to air pollution. Long term exposure studies have already shown strong associations between air pollution and stroke. While the short term effects of air pollution on cardiac disease, including heart failure and myocardial infarction, have received much attention, it is less certain whether acute exposure to air pollution is a trigger for cerebrovascular disease, especially stroke.

This is partly because the results of many short term exposure studies evaluating the effect of air pollution on stroke have been inconclusive, reflecting both the nature of the condition and the size of individual studies. Recently meta-analyses, including 12 and 45 studies, reported an association between particulate air pollution and stroke. To our knowledge, our study is the first comprehensive prespecified pooled analysis to examine the short term effects after exposure to gaseous or particulate air pollution and admission to hospital for stroke or mortality from stroke across both time series and case crossover study designs.

Particulate matter and gaseous pollutants both showed a strong temporal relation with mortality from stroke and admission to hospital for stroke. The lag effects of exposure and stroke have to be interpreted with caution. Unlike other cardiac conditions such as acute myocardial infarction, decompensated heart failure, and sudden cardiac death, the timing of onset of stroke symptoms and subsequent admission to hospital or mortality might differ substantially.

Lokken and colleagues showed that in cases of acute ischaemic stroke, onset of symptoms occurred at a median of one calendar day before admission, and this delay in presentation is likely to underestimate the overall association between exposure to pollutant and stroke.

Aetiology of stroke and exposure to air pollution

While our analysis showed consistent associations for ischaemic stroke and air pollution, the association for haemorrhagic stroke was more variable with larger imprecision. Our results were similar to those from a smaller meta-analysis that showed identical patterns with type of stroke and exposure to PM$_{2.5}$ and PM$_{10}$. While haemorrhagic and ischaemic stroke share similar risk factors and have a similar clinical presentation, they are different clinical entities. Heterogeneity in the association between air pollution and stroke subtype might be caused by many factors. Firstly, the mechanisms linking exposure to air pollution and haemorrhagic stroke might differ for ischaemic stroke. Secondly, there were fewer estimates for haemorrhagic stroke, reflecting the lower incidence of this subtype, and therefore wider confidence intervals for these
Particulate pollution and stroke

Exposure to PM<sub>2.5</sub> showed weaker associations with admission to hospital for stroke or mortality from stroke than PM<sub>10</sub>, consistent with observations from other meta-analyses for stroke and acute myocardial infarction. This could reflect differences in particle size, with larger particles more likely to exert local pulmonary effects whereas fine or ultrafine particles (PM<sub>0.3</sub>) or gaseous pollutants could cause additional systemic cardiovascular effects. In contrast, the adverse effect of larger particles in patients with heart failure was more striking, possibly reflecting indirect biological pathways such as the adverse effect of sympathetic nervous activation on the failing heart. We noticed greater heterogeneity for PM<sub>10</sub> than for PM<sub>2.5</sub>. These differences in heterogeneity persisted after subgroup analysis and could reflect variation in study design. We were able to meta-analyse twice as many estimates for PM<sub>10</sub> than for PM<sub>2.5</sub>, with an overall less marked but more consistent effect of exposure on stroke with PM<sub>10</sub>. There are several biologically plausible reasons for this. While there is a close correlation between PM<sub>2.5</sub> and PM<sub>10</sub> concentrations, epidemiological studies have shown that the association between PM<sub>10</sub> and acute cardiovascular events is primarily driven by the PM<sub>2.5</sub> fraction. This fraction is enriched with ultrafine particles derived from the combustion of fossil fuels, which toxicology studies have suggested are the most potent component of particulate matter. These particles are potentially small enough to translocate from the lungs into the circulation and are therefore perhaps more likely to trigger acute cardiovascular episodes. Interestingly, all three gaseous pollutants derived from combustion (nitrogen dioxide, sulphur dioxide, and carbon monoxide) were associated with stroke, and this was consistent with reported associations with admission for heart failure and acute myocardial infarction.

Possible mechanisms explaining relation between stroke and air pollution

Several large cohort studies have shown a positive association between long term exposure to ambient air pollution and coronary and cerebrovascular events. Staffogr and colleagues showed that even in high income countries, where annual mean air pollution concentrations meet current international standards, small increases in PM<sub>2.5</sub> were associated with a 19% increase in the risk of cerebrovascular disease, including both ischaemic and haemorrhagic events. Long term exposures to PM<sub>2.5</sub> accelerate carotid atherosclerosis. The underlying pathophysiological mechanisms after acute exposure to air pollutants in triggering stroke, however, remain unclear and might differ for haemorrhagic and ischaemic stroke. Previous controlled exposure studies have shown that air pollution can adversely affect the vascular endothelium and increase activity of the sympathetic nervous system, resulting in vasoconstriction, increases in blood pressure, ischaemia, and risk of thrombosis. Indeed, even minor increases in PM<sub>2.5</sub> concentrations are associated with changes in cerebrovascular haemodynamics, including increased cerebrovascular resistance and reduced cerebral blood flow. Another potentially important effect of air pollution that is pertinent to stroke is the risk of atrial arrhythmias, which could predispose to thromboembolic events. It is plausible that the association between short term exposure to air pollution and cerebrovascular events is a result of these important mechanistic pathways.

Air pollution and stroke by income of nation

Most of the studies used to derive our pooled estimates originated from high income countries. The smaller number of studies from low and middle income countries is probably a result of less cohesive policies on air quality, inadequate environmental monitoring, and less robust disease surveillance. This is particularly concerning as it is these countries that bear a disproportionate burden of the global morbidity and mortality from stroke. More concerning are the trends for cerebrovascular disease, where the incidence is falling by...
12% in high income countries and increasing by 12% in low and middle income countries. Urban cities in low and middle income countries not only experience high levels of ambient air pollution but also have larger daily fluctuations in levels. Our pooled estimates stratified by region showed larger associations in low and middle income countries than in high income countries. Our estimates from low and middle income countries, however, predominantly come from East Asia, mainly mainland China followed by Latin America, South East Asia, and South Africa. There still remains a paucity of data from other highly populated regions including the Indian subcontinent and north and central Africa.

Limitations
Several limitations of our study should be considered. Firstly, unlike other cardiac conditions such as myocardial infarction, case definition for stroke, especially when administrative data are used, might be less reliable. Secondly, many studies measured concentrations of air pollution at remote monitoring sites, and it is therefore likely there will be some degree of misclassification of exposure. While there might be good correlations in measurements between pollutant concentrations at patient specific locations compared with those measured at remote stations, it is likely that highly urbanised city centres will not only experience higher concentrations but also greater fluctuations in concentrations. Therefore such ecological studies might underestimate the overall associations reported for stroke and air pollution. Thirdly, we did not have access to primary data and were not able to determine whether patients were included across multiple studies if there was partial temporal overlap between studies from the same geographical location. We did, however, exclude studies with complete geographical and temporal overlap during meta-analysis. Finally, we noticed significant heterogeneity (except for PM10) across all pollutants. This could be because of systemic differences in the baseline characteristics of the underlying population in addition to misclassification of both the measurement of pollutant and outcome. Our sensitivity analysis after exclusion of studies with a high risk of bias, however, showed similar results to the overall effect estimates.

Conclusion
Stroke remains the second most common cause of death and third most important cause of disability worldwide. Over the past 20 years many environmental studies have evaluated the association between outdoor air pollution and stroke, with varying conclusions. Our pooled estimates now show a marked and close association between exposure to pollutants and adverse stroke outcomes. Only a few studies originated from low or middle income countries and yet these countries experience the highest levels of air pollution and bear a disproportionate burden of global stroke mortality and morbidity. Public and environmental health policies that aim to reduce air pollution levels might reduce the burden of stroke.

Contributors: ASVS and KKL contributed equally. ASVS conceived and designed the study. ASVS, KKL, and AH acquired the data. ASVS, KKL, DM, DEN, and NLM analysed and interpreted the data. ASVS, DEN, DM, and NLM drafted the initial manuscript. All authors made critical revisions of the manuscript for important intellectual content and approved the final version of the report. ASVS is guarantor.

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Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Ethical approval: Not required.

Data sharing: No additional data available.

Transparency: The lead author, (the manuscript’s guarantor), affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained. This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

42 Wang Y, Eliot MN, Wellenius GA. Short-term changes in ambient
Pope CA, Burnett RT, Krewski D, et al. Cardiovascular mortality and
Miller KA, Siscovick DS, Sheppard L, et al. Long-term exposure to air
Qian Z, Lin HM, Stewart WF, et al. Seasonal pattern of the acute mortality
Qian Z, He Q, Lin HM, et al. Short-term effects of gaseous pollutants
Pönkä A, Virtanen M. Low-level air pollution and hospital admissions
Moolgavkar SH. Air pollution and daily mortality in three U.S. counties.


**Appendix 1: Detailed search strategy**

**Appendix 2: Flow chart of included studies**

**Appendix 3: Contextual details of included studies: summary of study demographics and pollutants measured**

**Appendix 4: Contextual details of included studies: adjustment and assessment of bias**

**Appendix 5: Funnel plots**

**Appendix 6: Individual forest plots for each pollutant**

**Appendix 7: Overall and stratified risk estimates for incident stroke and stroke mortality**

**Appendix 8: Sensitivity analysis summarising associations between air pollution and stroke before and after removal of studies with increased risk of bias**
Carbon Dioxide

Applicant’s Carbon Assessment

1.1 The base case is of the plant operating at maximum paper production. At this level of production the facility produces 460,000 tonnes of paper per annum and imports 399,500 MWh of electricity per annum and 520,500 MWh of natural gas per annum.

- According to 5.2 NTS: “Currently, Palm Paper Ltd. produces approximately 500,000 to 600,000 tons of newsprint paper per year by 200 employees”

- According to 4.2 Planning Statement: 1.2.4 The Lynn PM7 paper mill operates using entirely recycled paper to produce between 500,000 and 600,000 tonnes of newsprint paper per year, using a paper machine which is one of the most advanced in Europe. The paper mill employs around 200 people.

- 7.2.4 Currently the plant imports 399,500 MWh electricity per annum from the grid.

If Palm Paper currently produces approx 500,000 - 600,000 tonnes then maximum production is not 460,000, and if they currently import 399,500 MWh of electricity, then that is not the requirement for production of 460,000 tpa

3.2.1 Boiler Emissions
At a maximum production of 460,000 tonnes/annum of paper, the boilers release 95,630 tonnes of CO2 per annum directly to atmosphere.

3.4 Transport
The CCGT case requires 997,260 MWh per annum of natural gas to be imported to the facility. The base case requires 520,500 MWh per annum of natural gas import. Although there is a large increase in the amount of natural gas imported when operating the CCGT on site, this has not been taken into account as the facility is located near a large natural gas pipeline. Therefore it has been assumed that no further infrastructure for the transport of natural gas will be required.

- According to the pollution report from the EA’s website, where the latest year provided is 2012, CO2 emission was 80,595 tonnes. Given there is no breakdown for which plant, it simply says ‘combustion,’ one can assume this is Boiler Emissions, giving Palm Paper the best case scenario.

- There does not appear to be any calculations showing the conversion of methane, quantified as equivalent amounts of carbon dioxide, added to the figures.

- The figures provided only consider the emissions caused directly at the point of electricity generation. To provide a more complete picture of the emissions caused by generation technologies, all stages of their life cycles must be considered. These include their construction and maintenance; the extraction, processing and transport of their fuels (if applicable); and their ultimate decommissioning and disposal.

- The applicant has not allowed for any of these figures given that they are constructing a new facility, which would include all the associated transportation costs of labour and materials (from Germany), along with figures from the construction of the new gas pipeline. This will be a significant contributor to the carbon footprint and will have an impact on the overall carbon benefit, as such it must be included to provide a more accurate assessment conclusion to that provided.

The conclusion from the applicant’s carbon assessment without using figures showing the full implication gives a carbon benefit of 67,264 tonnes CO2/annum over the base case.

However, taking a closer and more simplified look at the effect on this site:

Centrica A Power Station (325 MW) is roughly twice as big as that proposed by Palm Paper (162 MW), EDF at Sutton Bridge (819 MW) roughly 5 times as large.

The Carbon Dioxide figures provided to the Environment Agency for 2010, when Centrica was operating (mothballed April 2012):

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<td>Centrica A 2010</td>
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</tbody>
</table>
The average of 1/5 of the Sutton Bridge CO2 (206,033) and ½ of the Centrica A CO2 (279,987) = 243,010 tonnes CO2/annum

Palm Paper’s proposal would increase their own current CO2 emission at this site by c 162,415 tpa.

Even using the applicants own figures, current boiler emissions 95,630 vs CCGT proposal 187,609, this still effectively doubles the CO2 production on this site.

(Would the applicant please provide their latest emissions figures, since a 15,000 tonne increase in 2 years does seem very excessive, particularly when they consider little more than 4 times that increase is ‘a significant reduction in carbon emissions.’)

All this proposal would effectively do is move the production of CO2 from somewhere else in the UK to this location, at the same time as increasing NOx and particulates, to an area where the effects of pollution and GHG would be magnified due the temperature inversion.

Policy CS08 considers Sustainable Development and establishes the need for good design. It also directly promotes the reduction of site emissions through the generation of cleaner energy

Since this proposal is only serving Palm Paper it does not constitute strategic utility infrastructure and it seems absurd for the applicant to claim:

The operation of the proposed CCGT plant will displace the two existing, and considerably less efficient, gas fuelled package boilers, and it will reduce overall CO2 emissions per unit electricity or steam generated (carbon intensity), which would be beneficial to the UK meeting its greenhouse gas emission reduction commitments.

Palm built 2 dirty boilers and added to the UK’s pollution and now claim to be assisting in reducing it by building something supposedly better designed!

The need for this proposal has not been addressed sufficiently enough to justify it, it is not being done for the UK benefit or our GHG emissions since these were raised without thought when Palm came to KL (they could have planned to include solar panels to their roof), it is only about Palm Paper’s profits.

It runs counter to aspects of national planning policy, the most significant of which, is this is not meeting the need for a low-carbon renewable energy development, it is 100% non-renewable.

The Climate Change Act 2008 established a legally binding target on the UK to reduce greenhouse gas emissions by 2050 to 80% below 1990 base levels, to achieve a 50% reduction in emissions over the 2023-27 period and to source 15% of energy from renewable sources by 2020. Clearly the UK needs to be less reliant on fossil fuels and reduce greenhouse gas emissions but once again it is signing up to agreements and picking and choosing what it adheres to and what it flouts, since the source here would be 100% non-renewable, and the proposal does not constitute strategic utility infrastructure.

Summary

The benefits this proposed development would generate, in an area where temperature inversion creates such high emission levels, are limited to little more than to the applicant themselves, and do not begin to outweigh the far-reaching and potentially significant adverse impacts on the surrounding fragile, internationally important environment, neither is it in accord with international obligations or the recent ruling by the Supreme Court. The benefits are also outweighed by the significant adverse impacts to human health, the nationally high number of the existing population who are already suffering or susceptible to respiratory disease and asthma, and the additional financial burden this would place on already stretched local doctors, hospital and NHS. Accordingly, consent should be refused.
Comments on 4.2 Planning Statement

8
EN-2 - Government Policy Criteria
8.1
Context
8.1.4
EN-2 then requires fossil fuel generating infrastructure to be resilient to climate change and states that applicants
should address three specific areas.
• Coastal changes and increased risk from storm surge:
• Effects of higher temperatures, including higher temperatures of cooling water:
• Increased risk of drought leading to a lack of available cooling water: EA shortage of water – goes into
very great detail in Palm Paper's original application.

9.2
Planning Policy Compliance
9.2.1
As demonstrated above, and in accordance with EN-1 and EN-2, both the highly efficient process which would be
used within the CCGT and the use of inbuilt mitigation measures to further address emissions will ensure
that air quality impacts will be negligible at both construction and operational stages.
9.2.2
This also ensures compliance with local Policy CS11, which addresses the potential
impacts on air quality arising from vehicle movements, together with emerging Policy POAW1 which sets
out the need to protect wider amenity, including air quality. Who is actually monitoring the HGV impacts to
air quality?

10.2.2
The application site does not lie within or overlap any designated statutory or non-statutory nature conservation
sites. The nearest designated site is the County Wildlife Site, which is an area of reed bed 400m to the north of the
proposed development. Mudflats along the Great Ouse River, to the west of the site, are listed as a priority
habitat in the UK Biodiversity Action Plan. There are no records of protected species within the application site
boundary and none observed during the Phase 1 Habitat Survey. There are no records of Great Crested Newts
within 1km of the application site and surveys of the site and the immediate surrounding area found no evidence
of Great Crested Newts, with low numbers of adult Smooth Newts noted. The County Wildlife Site supports a modest
range of relatively common species of birds, with the habitats within the application site considered to provide a
poor habitat for birds. There are protected species in the River Ouse, why have these been ignored? Why
have the discharges to water and sewers been glossed over when Mudflats along the Great Ouse River, to
the west of the site, are listed as a priority habitat in the UK Biodiversity Action Plan?
I have enclosed a map from the minutes of one of NCC’s meetings referring to the conservation of the
Wash, which shows the area also comes up the River Ouse to around the A47 bridge, just as the WBAP
does.

10.3.2
When assessed independently and cumulatively the emissions arising from the proposed CCGT would, using
either a 70m or 80m stack, be insignificant at all ecologically sensitive sites except the River Nar SSSI. At the
River Nar the impact of emissions would only be greater than 1% of the critical load in a small 0.2ha part of
the site, which contains scrub, bracken and neutral grassland and which is therefore not considered to
have any particular sensitivity to emissions. Why is the ecologist viewing effects in isolation when
ecologically, interdependence occurs, remove one another deteriorates?

10.3.3
There are not considered to be any potentially significant impacts arising on those ecological receptors
present at a more local level from air quality or dust, noise or visual disturbance and lighting. Light has a
very disturbing effect on Eels, seals and H porpoise if travelling up river after fish – if disturbed by light
they will turn round. Vibration of cars over bridge enough to disturb them, so may go upstream at night
when less traffic – lights on all night – why did no ecologist advise BC on this? Even the NCC ecologist
has not given his comments, if, as the BC told me at the hearing, they do not have their own ecologist and
rely on NCC, why when they were all involved in the Wash Biodiversity Action Plan, Marine, is no one
bothering to do the job they are supposed to be doing? It’s not as if the Harbour Porpoise, Eels, Otters and
Seals are able to speak up for themselves!
10.4 Planning Policy Compliance

10.4.1 Ecological impacts are minimised by the fact that the CCGT would be located within an existing industrial site on land containing no ecological receptors of value and due to the efficient nature of the CCGT process and the low levels of emissions created. This comment is offensive. The power station was a stand alone individual blot, Palm Paper were provided with a smooth path by the BC onto that site for their visually hideous and badly sited carbuncle, due to NCC needing a customer for a waste incinerator, which Palm duly obliged. They are well aware they will be assured of the same smooth path when it comes to them wanting to build the mirror image building next door.

10.4.2 In accordance with EN-1 the development therefore avoids significant harm to biodiversity. Even when appropriate weight is assigned to designated sites and protected species, there is a lack of any harm on these receptors of any significance arising from the proposal. In this respect the scheme also accords entirely with the protection and enhancement of biodiversity afforded at the local level by Policy CS12. Enhancement! How can a polluting blot on the landscape enhance biodiversity, this needs to be expanded on or discounted.

12.1.5 The current Environment Agency policy is to defend King’s Lynn and it is anticipated that this stance will remain over the lifetime of the development, which would ensure that existing flood defences are improved as necessary to address climate change. Not at all, this area will be sacrificed to the sea, it is not considered important and the EA made it quite clear in their response to Palm’s previous application. The Nat Grid pylon application also makes the EA’s stance clear that the condition of the flood defences to that area are poor and fair with no plans to upgrade. It is also a Rapid Inundation Zone, the frightening speed at which water would travel is much faster than anyone could think let alone move. As for getting flood warnings from the EA, best of luck there, I have been signed up for years and never once received an alert by text or email, neither has anyone else I know – that site is also out of range for warnings (again on Nat Grid’s application).

14.1.5 Plume visibility is also assessed. However any plume created by the proposed stack is only expected to be visible for less than 5% of daylight hours within any particular year and is therefore expected to have an insignificant impact on the appearance of the area. Is that figure massaged by making it annual or are the dirty emissions held back until night, can it be backed up by actual historical evidence from the existing plume or is this statement just referring to this proposal?

16.1.3 Overall the development would have a positive impact on the local economy, albeit one which is small in scale given the temporary nature of construction jobs. No it wouldn’t!!! The previous construction was testament to how little the UK benefited let alone the local people and economy, with virtually everything coming in from Germany, wasn’t there even accommodation provided on site for workers. Two Somalian’s were on a train coming here from London, they were engineers and had been brought over to work on the Palm site – are we to assume there was no one else in the entire UK who was suitable to employ or was that just down to cost?

16.2 Planning Policy Compliance

16.2.1 Whilst the socio-economic impacts of the proposal would be minor but positive, the proposed CCGT does represent investment by Palm Paper into its King’s Lynn facility, which remains one of the most prominent local employers in the town. In that respect the proposal complies with Policy CS01, which encourages economic growth and inward investment. As above. Little is from the UK and next to nothing comes into the town apart from pollution.

15.4 Planning Policy Compliance

15.4.1 Emerging Policy POAW4 states that development should protect or enhance the amenity of the wider environment, including noise. Appropriate mitigation measures, in the form of controls over noise at both the construction and operational phases, combined with current noise environment already present, will ensure that full compliance with this policy is achieved. Development neither protects or enhances the amenity of the wider environment – If decreases to CO2, NOx and particulates elsewhere, it simply adds to the exceedances already experienced in this area. When Palm want to avoid and remove conditions imposed on this application, who is the application made to, the Planning Inspectorate or the amenable local BC?
In accordance with those aspects of EN-1 and EN-2 which dealt specifically with noise and vibration in that the proposal would not create any significant adverse impacts on health or quality of life as a result of operational or construction noise. No consideration given to marine species in R. Ouse or to the residents in West Lynn, South Lynn and Clenchwarton who had to endure the constant thumping and ground vibration – why didn’t the applicant screw pile?

19
Alternatives to the proposed CCGT

19.1.1
The proposed CCGT is a technique used successfully by Palm Paper in two of their German paper mills, where it has allowed them to reduce overall CO2 emissions as well as their reliance on imported energy.

19.1.2
There are no oil or biomass fuelled processes currently available which have the capacity to serve the energy needs of the Palm Paper mill in a manner which is as environmentally benign as the proposed CCGT. Furthermore a ‘Do Nothing’ approach would in this case result in the continued use of the on-site gas boilers together with imported gas and electricity and would not result in the significant reductions in the overall CO2 emissions generated by the paper mill which the use of the CCGT is able to achieve. Planning permission exists for a sludge combustor on the site, which would be capable of generating some energy for use within the paper mill but would not be able to fulfil the entire requirements of the mill and which would therefore again not lead to the same benefits which can be created by the CCGT. This proposal is nothing to do with assisting in the reduction of CO2 emissions it is simply to made more money for the applicant. Why were Palm allowed to build here and create these emissions and reliance on UK power in the first place when it was to save them costs, cheaper here in UK than in EU? What percentage of HGVs entering/leaving the plant leave the UK or are EU plated HGVs used as hauliers because they too are cheaper? Palm’s carbon footprint to the UK is massive, there is no paper from Norfolk going to this plant to be recycled it isn’t good enough quality apparently, ours goes across to Wales while Palm have contracts with counties on the SW coast – all arriving by road.

19.1.3
In terms of the proposed development itself, the scale and design of the building is largely defined by its function and operational capacity, with aspects such as the finishing materials selected to complement the existing mill buildings. The size of the stack is a variable which has been considered in respect of air quality impacts; an issue discussed in the Environmental Statement, and following discussions with statutory consultees and the local community is considered to represent an appropriate balance between air quality and visual impacts. The positioning of the proposed CCGT within the site has been defined by the existing paper recycling process and the need for the steam and electricity created by the CCGT to feed into the paper machine at an appropriate point. Would it not be more transparent to say it was designed in such a way for the mirror image extension to go the other side, so with this in the middle, connections can be made to both? Again, any emissions from that will be added to the impact at this site and the visual impact will be horrific.
This Air Quality Assessment Addendum has been produced to address the following requests from the local authority:

(5) NO2 Tube 74 is at the closest residential receptor (the Travellers Park), has this been considered in the assessment of cumulative impacts?

1.5 Cumulative at NO2 Tube 74 - Travellers Park
Diffusion tube 74 (Travellers Park) is classified as a roadside site and as such was not used when calculating the background nitrogen dioxide levels. For completeness the cumulative impact of emissions is presented in the following table. The background concentration has been assumed to be the maximum monitored over the period 2008 – 2012 to align with the Air Quality Assessment and the analysis within the AQMA above.

The rational used here does not make sense as it is very important that the existing background levels would include these figures? How many of the other diffusion tubes on the roadside in King’s Lynn are classified as a roadside site and have therefore been ruled out for the Air Quality Assessment for this proposal, or is it just this awkward one?

Despite the reluctance to produce the figures for Tube 74 the conclusion provided:
As shown the cumulative impact of emissions does not cause an exceedence of the AQO, with either a 70m or 80m stack at the closest diffusion tube, Travellers Park (74). Increasing the stack height from 70m to 80m significantly reduces the impact at this monitoring site but even with the 70m stack the cumulative impact is considered acceptable.

How can this be anything but misleading?

(2) Diffusion tube data has been used for the years 2008-2011, more recent years data are available. What effect will this have had on the results of the AQA?

(4) We are concerned that the cumulative impact of the proposal and other adjacent sources is considered on all relevant sensitive receptors. Chapter 13 of the AQA sets out modelled cumulative impact however the impact on the King’s Lynn AQMA is not reported. We would expect to see modelling to include impacts on the King’s Lynn AQMA.

1.4 Cumulative impact on the AQMA
The Environment Agency guidance document H1 Annex F states that the long term process contribution 1% threshold is based on the judgement that:
“It is unlikely that an emission at this level will make a significant contribution to air quality since process contribution will be small in comparison to background levels, even if a standard is exceeded.”

Despite this, the following tables present the breakdown of the contribution from each process to the cumulative process contribution at the Kings Lynn AQMA receptor for a 70m stack. Why a 70m stack when their ‘modelling’ showed this to be unacceptable?

1.2 Additional diffusion tube data
The baseline review was undertaken using all the data available at the time of writing. Since writing the report, more recent data has become available. The background concentration used in the Air Quality Assessment was the maximum monitored concentration from any background monitoring site within 6km of the site for the period 2008 to 2011. As a result of any additional data the impact of emissions will not change but the significance of the effect may. A review has been undertaken of the background monitoring data presented in the King’s Lynn and West Norfolk Borough Council LAQM Progress Report 2013. This is presented in the following table. As shown the
maximum background nitrogen dioxide concentration does not increase when the more recent data is included. Therefore the significance of effect presented in the Air Quality Assessment remains valid. Report written April 2014, data would have been available for 2013 yet reliance was on data from a report by the BC written in 2013, why was the 2013 data not used? It is May 2015, data should be available from the BC for 2014.

Annual mean NO2 is used, a much clearer indication of the impact to the AQMAs, would be on the daily/hourly data, which would show how very high the emissions are. Annual averages are as meaningless as daily averages, 5 hours of peak time high emissions are lost when averaged with 10+ hours of much quieter evening/night activity. Four years ago I was proudly told by a member of the Borough Council how they massaged the figures using annual levels to make them look better than they were.

Air pollution prompts UK health warning
19 March 2015
Smog over parts of England, Wales and Northern Ireland has prompted a warning from Public Health England. The Department for Environment said there was moderate to high levels of the pollution, which is caused by traffic fumes and other sources. Air pollution has also blown in from Europe and Public Health England said the conditions could affect people with lung or heart problems or asthma.

Defra said levels were due to fall to moderate or low levels by Friday. Smog is formed when pollutants, dust, pollen and other particles that would normally be dispersed by winds are prevented from escaping from the layer of cool air that is trapped at the Earth’s surface.

Sotiris Vardoulakis, head of Public Health England’s air pollution and climate change group, said: "While most people will not be affected by short term peaks in air pollution - some individuals, particularly vulnerable groups such as those with existing heart or lung conditions, may experience increased symptoms."

This doesn’t reach the news when we get TI in this area

“Women who resided 50 to 200m from a major road were more likely to have higher anxiety symptoms than those living more than 200m away. But those living within 50m of a major road did not experience this association”

and people’s health
http://www.bmj.com/content/bmj/350/bmj.h1295.full.pdf

Short term exposure to air pollution and stroke: systematic review and meta-analysis
Abstract
Objective
To review the evidence for the short term association between air pollution and stroke
Conclusion
Gaseous and particulate air pollutants have a marked and close temporal association with admissions to hospital for stroke or mortality from stroke. Public and environmental health policies to reduce air pollution could reduce the burden of stroke.

“What is already known on this topic
Stroke is a major cause of disability worldwide with an increasing incidence, particularly in low and middle income countries.
While exposure to outdoor air pollution is strongly associated with acute cardiac events, the relation between air pollution and stroke is less clear.”

Two of the lowest areas of deprivation in Norfolk are within 1km of AQMAs
According to the study, low- to middle-income countries experienced the strongest associations, compared to high-income countries. They also believe that for vulnerable people, such as elderly or people with pre-existing heart issues, heavy air pollution may cause chronic inflammation and trigger a stroke or heart attack.

While PP are financially benefiting from this planning application, the knock on effects to the local population of this increase in air pollution affects their well-being, quality of life and puts an increasing financial strain on our local doctors and hospital. Why should the health of the people of KL&WN, particularly the deprived and vulnerable be further compromised …..?
Air pollution 'link to stroke risk'

25 March 2015

Air pollution is linked to an increased risk of stroke, a large global study in the British Medical Journal suggests. Scientists say even short-term spikes in pollution were mirrored by a rise in strokes - particularly in low and middle-income countries.

The work builds on earlier studies linking pollution to cardiovascular risk. UK experts say although pollution is lower in the developed world, it may still pose a significant risk.

Pollution peaks

Parts of the UK are breaching pollution limits set by the European Union in 2010. And the UK government says some major cities may well continue to do so until at least 2025.

The European Environment Agency warns that air pollution can lead to major illness and contribute to premature deaths.

The latest study looked specifically at the risk of stroke. Scientists from Edinburgh University scoured the results of 94 studies covering 28 countries across the world.

They say the trends were consistent - a short-term rise in pollution was associated with a rise in the number of people admitted to hospital for strokes and in stroke deaths.

The link was the strongest in low and middle-income countries and on the day people were exposed to high pollution.

The review looked at a range of possible pollutants - from gases such as sulphur dioxide, nitrogen dioxide and carbon monoxide to fine soot particles known as PM 2.5.

Dr Anoop Shah, lead author of the study, said: "This study now demonstrates that even short-term exposure to air pollution can trigger disabling strokes or death from stroke.

"One of the key differences between risk of stroke due to air pollution and other risk factors such as smoking or high blood pressure is that the whole general population is exposed.

"As such, this increased risk of stroke is in the general population and not just those previously thought to be at high risk."

But Dr Shamim Quadir at the Stroke Association said more work was needed to establish how strong this link is and whether or not air pollution could be considered as a risk factor for stroke.

Level check

The British Heart Foundation, which funded the study, says there is an urgent need for the UK government to meet pollution targets. It says failure to do so could be putting hundreds of thousands of people at risk - though further research is needed to confirm this estimate.

The charity suggests people with heart conditions or lung disease should monitor air pollution where they live and work.

Air pollution 'causing deadly public health crisis'

Dec 2014

New schools, care homes and hospitals should be built far away from major roads because of the dangers of air pollution, a report by MPs says.

The Environmental Audit Committee argues air pollution is a "public health crisis" causing nearly as many deaths as smoking.

It also suggested a scrappage scheme for diesel cars to cut emissions. The government said it was "investing heavily" in clean air, but campaigners said it was ignoring the issue.

There are an estimated 29,000 deaths annually in the UK from air pollution. Nitrogen dioxide is known to cause inflammation of the airways, reduce lung function and exacerbate asthma. Particulate matter - tiny invisible specks of mineral dust, carbon and other chemicals - are linked to heart and lung diseases as well as cancer.

Some particulate matter lodges in the lungs, while the finest particles can enter the bloodstream, risking damage elsewhere in the body.

Dr Ian Mudway, a lecturer in respiratory toxicology at King's College London, told the BBC: "The evidence is there. The 29,000 figure is very solid, so really it is a case of acting."
"But it is a strange one, because it's their third [report] in five years and it is an attempt to get the government to do anything."

The British Lung Foundation said the recommendations "may seem drastic", but air pollution was so bad they were necessary "to protect the nation's health."

"Our dirty air will simply not clean itself, and this issue is one that will, without the government's intervention, continue to impact on current and future generations," said Dr Penny Woods, the charity's chief executive.

Asthma UK said air pollution increased the risk of a life-threatening attack and "urgent and concerted action" was needed to bring pollution levels down.

Chief executive Kay Boycott said: "In the short term some of the measures recommended in this report, such as the publicising of high air pollution forecasts, could help people with asthma know in advance if they should seek advice from their GP or asthma nurse."

Simon Gillespie, the chief executive of the British Heart Foundation, said: "The government cannot continue to ignore this issue. "Enough is enough. The government must act on these recommendations quickly if we are to improve the quality of the air we breathe and protect the nation's heart health."

A government spokesperson said there would be a full response to the report in the future, but added: "Clean air is vital for people's health and, while air quality has improved significantly in recent decades, we are investing heavily in measures across government to continue this, committing £2bn since 2011 in green transport initiatives."

(NaturalNews) That toxic, smoggy air can harm physical health is nothing new or surprising. It has repeatedly been linked to chronic inflammation and an increased risk of cardiovascular diseases and cancer. New studies, however, suggest that air pollution negatively impacts not only our physical health but mental well-being as well.

Two new studies published on March 24 in The BMJ (British Medical Journal) shine a new light on how pollution may negatively affect our health and happiness.

In the first study,(1) Researchers at the University of Edinburgh analyzed 103 observational studies, conducted in 28 different countries around the globe, looking for a link between air pollution and cardiovascular health.

Stroke is the second leading cause of death worldwide, killing around 5 million people each year. According to the scientists at the Edinburgh University, common risk factors of a stroke include obesity, smoking and high blood pressure, but clear evidence of environmental factors such as air pollution is nonexistent at the moment.

After analyzing the 103 studies in depth, they had to conclude that there was a "clear association" between air pollution and people's short-term risk of having or dying from a stroke or heart attack.

In another study,(2) researchers from the Johns Hopkins Bloomberg School of Public Health and Harvard University tried to find the answer to the question of whether air pollution may be related to anxiety, which affects around 16% of our population at some point in their life.

They investigated more than 70,000 women, aged 57 to 85 years, enrolled in the US Nurses' Health Study. The study concluded that around 15% showed high symptoms of anxiety, which could be linked to exposure to fine particle pollution coming from cars and industrial sources.

They believe that air pollution may worsen or trigger anxiety attacks through free radical damage and inflammation or deteriorate an existing health condition which can make people more anxious or depressed.

A press release(3) regarding the two studies released by The BMJ states:

In an accompanying editorial, Michael Brauer from the University of British Columbia, Canada,
writes that these studies "confirm the urgent need to manage air pollution globally as a cause of ill health" and that reducing "air pollution could be a cost effective way to reduce the large burden of disease from both stroke and poor mental health."

Although the answers found in these studies clearly associates air pollution to stroke and anxiety symptoms, both studies were observational and don't prove that air pollution is the direct link.

Melinda Power, a researcher at Johns Hopkins University, in Baltimore, who led the anxiety study, and her team included many other factors that could contribute to anxiety in their study. But she says that we have to be careful with the conclusion we draw from this, because there could be tons of other explanations.

"I think some of the most likely alternative explanations would be other forms of pollution," she noted. CBS News reported that she mentioned chronic noise from traffic as one possibility.

"It's too soon to declare that better air quality could help ease anxiety symptoms," Power stressed, "But it's an interesting finding," she said. "And studies need to look further into the association between air pollution and mental health."

So while most anxiety symptoms are covered up by mind-damaging psych drugs, the answer may simply be a reduction in air pollution.

16.6.10 The closest vibration-sensitive residential properties to the proposed development are considered to be the Saddlebow Caravan Park and houses in South Lynn at a distance of 700m and 770m respectively. On the basis of these distances it has been assessed as being highly unlikely that vibration from construction operations would be perceptible and mitigation measures are considered unnecessary. How can they possibly come to this conclusion!!

Current Chemical - Quality River Ouse

Grid reference: X: 559,612.88; Y: 326,162

GREAT OUSE

Water Body Name: GREAT OUSE
Water Body ID: GB530503300300
River Basin District: Anglian
Typology: Mixed, macro, extensive intertidal
Hydromorphological Status: Heavily Modified
Current Ecological Quality: Moderate Potential
Current Chemical Quality: Fail
2015 Predicted Ecological Quality: Moderate Potential
2015 Predicted Chemical Quality: Fail
Overall Risk: At Risk
Protected Area: Yes
Number of Measures Listed (waterbody level only): 7

Current Chemical Quality

Site details
Water Body Name: GREAT OUSE
Water Body ID: GB530503300300
River Basin District: Anglian
Current Chemical Quality: Fail

Priority Substances:

OVERALL PRIORITY SUBSTANCES Does Not Require Assessment

Priority Hazardous Substances:

OVERALL PRIORITY HAZARDOUS SUBSTANCES Fail
Mercury (and its compounds)
2015 Predicted Chemical Quality

Site details
Water Body Name          GREAT OUSE
Water Body ID             GB530503300300
River Basin District      Anglian
2015 Predicted Chemical Quality Fail

2015 Predicted Chemical Quality:

Predicted Chemical Quality by 2015 Fail
Overall Objective         Good Potential by 2027
Reason for not good by 2015 Disproportionately expensive, Technically infeasible
Ecology

River Nar

The ecology consultant said the SSSI status was due to the aquatic vegetation and came across as rather
disseismic of the water voles, otters (and other wildlife) despite their heavy protection under the Habitats
Directive. (Not to harm or disturb them)

Recently, Coca Cola teamed up with the World Wildlife Fund (WWF) (1) to protect and restore two of the
unique English chalk streams, one of which is the River Nar, one of only 200 chalk steams in the world.

According to Coca Cola’s website:
“Water is the main ingredient in all of our products, and it’s also an important part of our production process. That’s
why we want to make sure we use it in a way that’s responsible and sustainable. We also want to show other
businesses how they can reduce their impact on freshwater environments.
As part of our global commitment to sustainability, our goal is that by 2020 we will be safely returning to nature the
same amount of water that we are using.

The River Nar: a case study
This river is directly linked to us because it flows through an area where we get 80 per cent of the British sugar beet
we use in our drinks. It's a site of scientific interest because its healthiest stretches are pure, clear homes for otters,
water voles, trout and kingfishers.
The WWF UK is helping us to get this river closer to good ecological status, a requirement under the EU Water
Framework Directive.”

According to the World Wildlife Fund website:
“The Nar is a site of special scientific interest. In its healthiest stretches the river's water is pure and clear and
teeming with wildlife. It's home to otters, water voles, trout and kingfishers.
But not all of the Nar is thriving. Some of it is suffering because too much water has been taken from the river to
support domestic water supplies and agriculture. And it's impacted by pollution – mainly pesticides and fertiliser
from local farms. In many stretches of the river, this has resulted in the disappearance of the species traditionally
found along chalk streams.
The Nar flows through an area where around 80% of the sugar beets used in the drinks Coca-Cola manufactures in
the UK is grown. Through our partnership, and our work to help reduce the negative impact of farming on the river,
Coke is showing a pioneering commitment to improve the sustainability of the supply chain for its drinks in the UK.
We're also working with the Norfolk Rivers Trust to develop a plan for the Nar and its catchment area that outlines
how to manage the river so it’ll have the best chance of flourishing. And the project is demonstrating what good
river management can look like – so across the country others can follow suit.
Much more needs to be done in the coming years to help bring English rivers back from the brink.
But after our first year we’ve made some great strides towards our goal, and we’re already seeing positive impacts
on the ground.”

Whilst the current pollution impact to the River Nar is mainly due to pesticides and fertiliser run off from
farms further afield from Palm Paper, the air quality in the vicinity of this proposal already has an
exceedance of background levels of 130%, and any addition to that unacceptably high figure at this
location, no matter how small it has been mitigated down to, has to be viewed in a much bigger, longer
term picture. The process contribution of 3.6% (after mitigation attempts) to a SSSI is significant, to
simply hide this contribution behind an existing exceedance is totally unacceptable, and has been going
on too long, hence the 130% figure. The continued addition of incremental increases of air pollution in
this location is simply continuing to the further detriment of the environment and is just not
environmentally sustainable, particularly when it is not essential infrastructure, rather something that only
benefits the company wishing to construct it.

For an ecologist to say the Nar otter and water vole are not directly sensitive to the AQO of 30
micrograms/cubic metre, while completely ignoring the existing background exceedance, is disrespectful
to the otter and water vole, and more importantly, their fragile environment.

Statement of Common Ground
2.3
The River Nar SSSI

2.3.1

The parties agree the methodology and conclusions reached regarding the potential impact of the proposed development on the River Nar SSSI. The conclusions of Section 3.5.2 of the ES [Document 5.1] are agreed, which state that the emissions from the CCGT are only greater than 1% of the critical load in approximately 0.2ha of the designated site, which comprises an area which is not considered to have particular sensitivity to emissions.

Fails to consider the interdependence of habitats

(1) http://www.coca-cola.co.uk/packages/sustainability/replenishing-our-rivers/
http://www.wwf.org.uk/wwf_articles.cfm?unewsid=6535
(2) http://www.boston.gov.uk/CHttpHandler.ashx?id=5944&p=0

**Roydon Common and Dersingham Bog**

Either environmental laws are adhered to or the decision made to scrap them all together then sit back and allow our environment to be desecrated. This continual creep, creep, creep under the radar of acceptability is immoral.

The world is well aware that water is becoming a scarce resource, Palm Paper abstracts a horrific quantity for their existing paper mill, freshwater from the Flood Relief Channel under an existing abstraction licence, for 22,000m³ per day

The UK signs up to ..... and then fails to adhere to their
Had Defra, the EA, NE and PHE been carrying out their roles in the manner in which the UK public and the EU expect, then the

Supreme Court ruling proved Defra have been wilfully

Far too much lobbying takes place

**Biodiversity 2020**

In October 2010 in Nagoya, Japan, over 190 countries around the world reached an historic global agreement to take urgent action to halt the loss of biodiversity. This agreement recognised just how important our wildlife and ecosystems are for sustaining a healthy planet and for delivering essential benefits for people. Biodiversity is key to the survival of life on Earth. Its loss deprives future generations of irreplaceable genetic information and compromises sustainability.

The ambition was to halt overall loss of England’s biodiversity by 2020 and in the longer term to move progressively from a position of net biodiversity loss to net gain, but with half that decade gone, no change has taken place. conservation charities, supported by millions of members of the public and volunteers, already make a vital contribution in protecting biodiversity, but are constantly thwarted by the statutory bodies whose word is final.
As with so many agreements that the UK enter into, there is a failure to follow through with the actions necessary to deliver the commitments made, due to corporate lobbying.

Direct case in point is response to WWPC

6. Need
Can the applicant justify the need for the development as it is not low carbon renewable but uses natural gas, a fossil fuel, and runs counter to aspects of national planning policy?

Chapter 7 of the Planning Statement (Document 1.4) describes the Need and Sustainability of the new plant.

Section 4.6 of EN-1 addresses Combined Heat and Power and notes that the Government has committed to promoting good quality CHP, given the ability of CHP to use less fuel to generate the same amount of heat and power, thereby reducing the level of emissions.

It cannot be overlooked that consultants for an application are paid to make a case for the applicant, and to provide figures that will, on paper, show the application will not cause harm. Equally, through a slightly different interpretation of ‘modelling,’ figures can be produced to show it will cause harm, such is the fragility of ‘modelling. However, the lack of genuine protection by the very statutory bodies who are there to protect people and their environment, allow ‘tweaking’ to take place. We saw during the PI how the best-case scenarios are presented while the evidence ignored. The tentative use of words like should, could or expected, does not show embodiment of the Precautionary Principle

5.1 ES P.72

Internal Drainage Board (IDB) system. The IDB must therefore be consulted...

**Water Abstraction and Effluent Discharge**

Table 17 (summary of environmental study) ..... concludes that the development proposal will have no significant impact under normal circumstances and that no water resource or water quality assessment is required and that no mitigation measures are necessary. However, we recommend that the Environmental Statement give further consideration to operation under abnormal circumstances such as during a drought. The applicant should provide further detail regarding what safeguards will be put in place in the event of a drought when licence conditions may have to be implemented restricting the amount of water available for the operation of the CCGT and dilution of the site effluent discharge.

The existing water abstraction licence, 6/33/56/*S/0300, currently allows abstraction for the purpose of Industrial Use (Paper Production). This licence is likely to require variation to add a new purpose to reflect the change of use of some of the water.

EA response from 28/3/2013:

The information included in the application states used for the package boilers would be substitute turbines. The quantity of water used in this specific unchanged and therefore will not require the current licence. The purpose of the current licence is; Industrial Use. The purpose is still accurate if the package boilers change.
Economic cost of the health impact of air pollution in Europe

Clean air, health and wealth
Abstract

This paper extends the analyses of the most recent WHO, European Union and Organisation for Economic Co-operation and Development research on the cost of ambient and household air pollution to cover all 53 Member States of the WHO European Region. It describes and discusses the topic of air pollution from a Health in All Policies perspective, reflecting the best available evidence from a health, economics and policy angle and identifies future research areas and policy options.

Keywords
AIR POLLUTION
COST OF ILLNESS
ENVIRONMENTAL HEALTH
HEALTH IMPACT ASSESSMENT
HEALTH POLICY
PARTICULATE MATTER
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<td>ambient air pollution</td>
</tr>
<tr>
<td>AOP</td>
<td>ambient ozone pollution</td>
</tr>
<tr>
<td>APMP</td>
<td>ambient particulate matter pollution</td>
</tr>
<tr>
<td>AQG</td>
<td>air quality guidelines</td>
</tr>
<tr>
<td>B/C</td>
<td>benefit–cost (ratio)</td>
</tr>
<tr>
<td>BOD</td>
<td>burden of disease</td>
</tr>
<tr>
<td>CAAA</td>
<td>Clean Air Act Amendments</td>
</tr>
<tr>
<td>CAFE</td>
<td>Clean Air for Europe</td>
</tr>
<tr>
<td>CAPP</td>
<td>Clean Air Policy Package</td>
</tr>
<tr>
<td>CBA</td>
<td>cost–benefit analysis</td>
</tr>
<tr>
<td>CLE</td>
<td>current legislation (scenario)</td>
</tr>
<tr>
<td>DALY</td>
<td>disability-adjusted life-years</td>
</tr>
<tr>
<td>DRG</td>
<td>diagnosis-related group</td>
</tr>
<tr>
<td>EEA</td>
<td>European Environment Agency</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>GBD</td>
<td>global burden of disease</td>
</tr>
<tr>
<td>GDP</td>
<td>gross domestic product</td>
</tr>
<tr>
<td>HAP</td>
<td>household air pollution</td>
</tr>
<tr>
<td>IARC</td>
<td>International Agency for Research on Cancer</td>
</tr>
<tr>
<td>IHME</td>
<td>Institute for Health Metrics and Evaluation</td>
</tr>
<tr>
<td>LYL</td>
<td>life-years lost</td>
</tr>
<tr>
<td>MIT</td>
<td>Massachusetts Institute of Technology</td>
</tr>
<tr>
<td>MTFR</td>
<td>maximum technically feasible reduction</td>
</tr>
<tr>
<td>NO&lt;sub&gt;x&lt;/sub&gt;</td>
<td>nitrogen oxides</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
</tr>
<tr>
<td>PM</td>
<td>particulate matter</td>
</tr>
<tr>
<td>PPP</td>
<td>purchasing power parity</td>
</tr>
<tr>
<td>QALY</td>
<td>quality-adjusted life-years</td>
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<tr>
<td>US$</td>
<td>United States dollar</td>
</tr>
<tr>
<td>EPA</td>
<td>(United States) Environmental Protection Agency</td>
</tr>
<tr>
<td>VOLY</td>
<td>value of a life-year</td>
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<tr>
<td>VSL</td>
<td>value of a statistical life</td>
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<tr>
<td>VSLY</td>
<td>value of a statistical life-year</td>
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<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>WTP</td>
<td>willingness to pay</td>
</tr>
<tr>
<td>YLD</td>
<td>years of life lost to disability</td>
</tr>
<tr>
<td>YLL</td>
<td>years of life lost</td>
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</table>
This report was first prepared for the WHO Regional Office for Europe by Dr Rana Roy, with research assistance from David Weiss and Stuart Baird.

Dr Roy’s initial report was reviewed and discussed at an expert WHO meeting held in Bonn, Germany, on 27–28 November 2014. Following the meeting, Dr Roy developed this final version of the report, in collaboration with Marco Martuzzi and Frank George (WHO European Centre for Environment and Health), and Nils Axel Braathen (Organisation for Economic Co-operation and Development).

Contributions and comments from Mike Holland, Eliza Lanzi and all participants at the November 2014 WHO meeting are gratefully acknowledged. Srdan Matic, Elizabet Paunovic, Marie-Eve Heroux, Francesca Racioppi, Dorota Jarosinska and Bianca Bortot (WHO Regional Office for Europe) also contributed to the project and to completing this report.
This study reports on the economic cost of the public health impacts of ambient and household air pollution, with particular reference to the countries of the WHO European Region.

Current estimates of the joint effects of ambient and household air pollution include an estimated 7 million premature deaths globally each year, representing one in eight of the total deaths worldwide.

In the WHO European Region as a whole, the estimated mortality in 2010 was approximately 600,000 premature deaths, which represents a marked decrease from 2005 for the Region overall. Only half-a-dozen countries out of the 53 WHO European Region Member States registered a slight increase in deaths. The evidence from epidemiology underpinning these estimates is well established, while the evidence from economics shows that ambient and household air pollution also imposes an economic cost to society of several trillion dollars per year, globally.

Present-day economics uses a standard method for assessing the cost of mortality at the level of society: the “value of statistical life” (VSL), as derived from aggregating individuals’ willingness to pay to secure a marginal reduction in the risk of premature death. This permits researchers and policy-makers to assess the comparative magnitude of the value that societies attach to a given health impact, and of proposals to mitigate it, using money as a common metric. The economic cost of a mortality impact is given by the VSL value, multiplied by the number of premature deaths. The economic benefit of a mitigating action becomes the same VSL value, multiplied by the number of prevented premature deaths.

Owing to a multi-year research effort spearheaded by the Organisation for Economic Co-operation and Development (OECD), a set of values for average adult VSL in 2005 is now available, along with a method to compute country-specific VSL values for countries both within and outside the OECD and for years beyond 2005.

In contrast, a standard and commonly agreed method by which to measure the cost of morbidity is not yet available. Research is currently being progressed toward establishing an agreed method and agreed values but at present this research can only proceed with indicative estimates. Recent practice and available evidence provide a rationale for using an additional 10% of the overall cost of mortality as a best estimate for the additional cost of morbidity.

On the basis of this method, and these approaches and assumptions, it is possible to estimate the economic cost of air pollution health impact in the countries of the WHO European Region. As of 2010:

- the annual economic cost of premature deaths from air pollution across the countries of the WHO European Region stood at US$ 1.431 trillion; and
- the overall annual economic cost of health impacts and mortality from air pollution, including estimates for morbidity costs, stood at US$ 1.575 trillion.

These results are relatively robust, in that the most common variations on this method and these assumptions do not alter the overarching conclusion: the health impact of air pollution is substantial, and given that good health
and a long life are obviously highly valued by society, economic analyses show that the economic cost of air pollution – and hence the benefits of cleaner air – are very large.

In comparing these huge estimated societal costs to country-specific gross domestic product figures, the significance and magnitude of these costs become even more evident: in 44 WHO European Member States the societal costs are equivalent to more than 1\% of the respective gross domestic product and in only four of the 48 Member States considered in the analysis do these societal costs amount to less than 1\%.

Available evidence on air pollution emission sources suggests that, across the WHO European Region as a whole, several sectors should be targeted for abatement policies. Motorized road transport, household fuel combustion together with agriculture and industrial coal burning sources are of special concern, in terms of their contribution to the health impact of ambient and household air pollution, and the consequent societal costs.

A relatively successful, if imperfect, regulatory regime on air quality in Europe has resulted in substantial progress, especially in European Union Member States, in terms of health impacts and costs, even in the absence of a pricing system capable of taking full account of externalities.

However, in view of the persistence of the problem of air pollution in Europe, filling existing knowledge gaps and correcting distortions in taxes and subsidies – for example, the preference of diesel over petrol – remains highly desirable.

To pursue this goal, operating in the anticipated period of time until a full correction of prices can be achieved, there is a case for conceiving the chronological framework of correction following the approach: regulation + investment + pricing, based on:

- strengthening existing regulation and compliance;
- using available evidence on external costs in relevant investment decisions; and
- closing the information gaps required to prepare a model of fully corrected prices.

The framework presented above – and discussed in further detail in the present report – can be used to provide practical guidance on where and how to strengthen the policy response to the problem of air pollution’s health impacts.
Introduction

This document addresses the economic cost of the public health impacts of air pollution, with particular reference to the countries of the WHO European Region.

It presents a summary of the relevant epidemiological evidence on air pollution’s health impacts, including in particular recent relevant work released by WHO (WHO, 2014a; WHO, 2014b) and the preceding Global Burden of Disease (GBD) Study, GBD-2010 (Lim et al., 2012; IHME, 2013b; IHME, 2014). It describes a methodology for calculating the economic cost of these health impacts, developed and applied in recent work by the Organisation for Economic Co-operation and Development (OECD) (OECD, 2012, 2014), and presents a new estimate of the economic costs for each of the countries of the WHO European Region. Finally, taking into account available information and information gaps relating to the various sectoral sources of air pollution, the report discusses some of the key implications for policy.

The deleterious impact of air pollution on public health has long been assessed; mortality and morbidity outcomes have been extensively described. While the issue includes the complete set of health impacts, this study deliberately focuses exclusively on the economic cost of the health impacts of air pollution, considering health outcomes that allow economic assessment.

Health impacts of air pollution carry many significant financial and economic implications, not only in terms of the societal cost of mortality and morbidity, which is the key issue of interest for this report, but also household, hospital and public budgets and, therefore, decision-making within and outside of the health sector. These impacts also carry implications for social equity both within and between countries.

Moreover, the deleterious impact of air pollution is not confined to human health. There are many other impacts that are worthy of consideration: those on the built environment, on animal and plant health (with further consequential impacts on the productivity of agricultural and forestry resources), and on larger ecological systems. In this perspective, addressing air pollution can have significant co-benefits for other policy objectives and air quality may simultaneously benefit from interventions that pursue other priorities, such as climate change. Nonetheless, the subject of this study – the economic cost (only) of the public health impacts (only) of air pollution (only) – merits attention in its own right.

The past few years have witnessed substantial accumulation of new evidence on the health effects of air pollution, on the economic cost of these impacts, and thus on the costs and benefits of policy initiatives designed to combat air pollution. As a result, it is now possible to state – and important to communicate – that, relative to many other known environmental health risk factors, the health impacts of air pollution are larger than previously assumed. Moreover, this physical toll imposes a greater economic cost than previously assumed and, consequently, the net economic benefit to be gained by reducing this cost is far greater than previously assumed.

Reducing air pollution and the toll it imposes is not primarily a matter for health policy or for the health sector alone. Rather, it is a policy matter for all the many sectors in which air pollution is generated, and, thereby, a matter requiring a whole-of-government policy
approach, as underlined by WHO’s Health 2020 policy (WHO Regional Office for Europe, 2015). It is therefore desirable to address this problem in terms that can engage decision-makers across the whole of government, and the use of economic evidence provides a well-established common ground, to this end.
1. The evidence from epidemiology

1.1 GBD owing to air pollution

Air pollution is the largest contributor to the burden of disease (BOD) from the environment. WHO estimated that air pollution in 2012 was responsible for 7 million premature deaths, including almost 600,000 in the WHO European Region. This is equivalent to one in eight of the total number of deaths worldwide. This finding more than doubles previous estimates (WHO, 2014a).

Air pollution is a risk factor for several causes of death, but cardiovascular and cerebrovascular causes of death account for the greater share of attributable mortality: 80% in the case of ambient air pollution (AAP) and 60% in the case of household air pollution (HAP) (WHO, 2014b).

AAP is a broader term used to describe air pollution in outdoor environments. The pollutants that are most harmful to health – closely associated with excessive premature mortality – are fine particulate matter (PM) PM$_{2.5}$ particles that penetrate deep into lung passageways. PM is a mixture, with both physical and chemical characteristics, varying by location and time of year, with seasonal trends. The relative contribution of local, national and transboundary air pollution emissions to the air pollution mixture where people live also varies according to the geography of the area and the presence of other sources of pollution. PM$_{2.5}$ is often used as a general indicator of the air pollution mixture. Other pollutants, such as ground-level ozone, also contribute to the BOD from air pollution. However, by far the biggest quantifiable share of the BOD from air pollution comes from exposure to PM, and its long-term health effects in particular. For this reason, this report focuses on PM.

Premature deaths translate into substantial years of life lost (YLL). In addition, air pollution is responsible for a range of diseases, contributing to the BOD, but the years of life lost to disability (YLD) are difficult to quantify and as such can only represent a relatively small fraction of the estimated total BOD, expressed in disability-adjusted life-years (DALYs).

A publication by WHO in 2014 gives a global estimate for 2012 of 3.7 million premature deaths from AAP and 4.3 million premature deaths from HAP, cumulating in 7 million premature deaths from the joint effects of AAP and HAP (WHO, 2014b). The whole is less than the sum of its parts because the effects of AAP and HAP are not fully independent of each other. This subtraction procedure is not applied in many cases, however – for example, in high-income countries where HAP effects are assumed to be minimal – but it can be difficult to estimate where it is relevant. Hence, WHO advises that the estimate for joint effects should be interpreted with caution (WHO, 2014b).

The GBD-2010 Study, which formed the evidence base for the recent OECD study entitled The cost of air pollution: health impacts of road transport (OECD, 2014), estimates the 2010 death toll from each of the three types of air pollution – (1) ambient particulate matter pollution (APMP), (2) ambient ozone pollution (AOP) and (3) HAP from solid fuels – to be...
breakthroughs in exposure assessment and epidemiological method – and is not indicative of large increases in the actual death toll from year to year. On the contrary, the implementation of clean air regulations and other mitigation measures has succeeded in limiting the actual change in the global premature death toll from air pollution to a relatively modest increase. Moreover, as is detailed below, there has been a modest decrease rather than an increase in mortality from air pollution within the WHO European Region. Therefore a two-fold message needs to be communicated: improved knowledge has led to larger estimates of the BOD from air pollution; however, improved practices have helped in reducing emissions of air pollutants and reduce overall population exposure, especially in Europe.

1.2 The evolving evidence

As is reported in WHO (2014b), the estimate of the global mortality from HAP (for the year 2012) is more than twice as much as its previous reported estimate (for 2004): a leap from 2 million to 4.3 million. In the case of AAP, the latest estimate is almost three times as much previously reported (for 2008): a leap from 1.3 million to 3.7 million (in 2010). The increase in the latter (AAP) is the most dramatic and it is illuminating to track this increase over successive studies. Table 1.1 reports the estimates in four successive studies.

Table 1.1. The reported change in estimates of premature deaths from AAP in successive studies, 2000–2012 (selected years)

<table>
<thead>
<tr>
<th>Study</th>
<th>Year 2000</th>
<th>Year 2008</th>
<th>Year 2010</th>
<th>Year 2012</th>
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<tbody>
<tr>
<td>WHO-GBD 2000(a)(b)</td>
<td>(\approx) 0.8 million</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHO-BOD (2008)(c)</td>
<td>(\approx) 1.3 million</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GBD-2010 Study(d)(e)</td>
<td>(\approx) 3.4 million</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>WHO-BOD 2012(f)</td>
<td>(\approx) 3.7 million</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: data reported in or extracted from:
\(a\) Cohen et al., 2004 (p.1414);
\(b\) Cohen et al. 2005 (p.1302);
\(c\) WHO, 2011;
\(d\) Lim et al., 2012 (p.2238);
\(e\) IHME, 2013a;
\(f\) WHO, 2014b (p.1).
The GBD-2010 Study was based on evidence incorporating the results of several critical breakthroughs in the technology and methods of epidemiology, as well as continuing advances in toxicology and the clinical knowledge of diseases. Of these, the following developments deserve particular mention.

- Advanced monitoring methods have been employed, including remote-sensing satellite technology, to estimate emissions and ambient concentrations of pollutants (see, inter alia, Brauer et al., 2012; Evans et al., 2013, and Amann, Klimont & Wagner, 2013).
- There is a much-improved understanding of the relation between emissions/concentrations of pollutants and the exposure of populations to such chemicals, and of the relation between population exposure and the health impacts of it – resulting in the use of new integrated exposure-response functions (currently undergoing continuing refinement) (WHO Regional Office for Europe, 2013a; 2013b).
- A new understanding has arisen of the link between air pollution and lung cancer (see Beelen et al., 2008; Silverman et al., 2012; Fajersztajn et al., 2013; Raaschau-Nielsen et al., 2013), paving the way for the classification by the International Agency for Research on Cancer (IARC) of outdoor air pollution as a human carcinogen (IARC, 2012, 2013; Benbrahim-Tallaa et al., 2012).
- A fuller understanding has emerged of the cardiovascular, cerebrovascular and respiratory health impacts of air pollution (see, inter alia, Shah et al., 2013; Wellenius et al., 2012; and Laumbach & Kipen, 2012).
- A more comprehensive and more consistent methodology is being used to assemble and analyse the epidemiological evidence base, in order to establish the relative risk of each relevant risk factor in terms of mortality and morbidity, for each relevant disease (see Lim et al., 2012), resulting in each risk factor being more accurately assigned to its relative share in the given number of premature deaths and DALYs in any given year (see Lim et al., 2012 and IHME, 2013b).

There are at least three areas in which future studies are likely to generate new results. The first is through the use of better and more complete data for existing risk–outcome pairings, especially in low- and middle-income countries (see WHO Regional Office for Europe, 2014). This need not necessarily entail any change to established exposure-response functions and may involve a more complete gathering of hospital records. The second is through the selection of the air pollutants to be used for estimating health impacts. Whereas the effects of AAP are now measured through the effect of PM$_{2.5}$, it is increasingly accepted that other pollutants are of relevance (see EEA, 2013a; EC, 2013). In particular, there is now an increasing focus on the independent impact of exposure to nitrogen dioxide (NO$_2$) (see WHO Regional Office for Europe, 2013a; Holland, 2014). The third area in which new results are likely to be generated is through the expansion of the list of diseases against which the relevant risk is paired. For now, including in GBD-2010 Study, the calculation of the BOD of air pollution has been restricted to four main disease groupings: cancers, and cardiovascular, cerebrovascular and respiratory diseases. However, there is evidence to suggest that air pollution may also play a part in a range of other diseases, including neonatal and neuropsychological impairments (see, for example, Guxens & Sunyer, 2012).

Therefore, it cannot be ruled out that continuing improvements in knowledge will result in more evidence on the deleterious health impacts of air pollution being uncovered and presented, further increasing the magnitude of the estimated BOD.
1.3 The improved practice

In contrast to the dramatic revision of the numbers reported before and after the GBD-2010 Study – from 1.3 million premature deaths reported for 2008, to 3.7 million reported for 2012 – the actual change in estimated premature deaths over time is relatively modest.

As shown in Table 1.2, in the period from 2005 to 2010 the estimated global mortality from AAP – defined here as the sum of APMP and AOP – increased by an absolute figure of approximately 135 000; that is, by about 4%.

Inclusion of AOP values, which is necessary given the available data, limits comparability with other estimates based on PM alone. However, since AOP makes up less than 5% of the 3.376 million reported premature deaths, it can be concluded that there has been a modest increase only with reference to global mortality from AAP since 2005.

As reported by the OECD (OECD, 2014) and as shown in Table 1.2, mortality decreased in the 34 countries of the OECD by about 20 000 premature deaths (≈ 4%), although this was offset by an increase in premature deaths in China, India and the rest of the world. In the same period, the 53 Member States of the WHO European Region, taken together, also recorded a reduction in premature deaths of about 68 000 (≈ 12%) – that is to say, a greater reduction and rate of reduction than that recorded for the 34 OECD countries, taken together.

Table 1.2. Change in estimated premature deaths from AAP, 2005–2010

<table>
<thead>
<tr>
<th>Deaths from ambient PM + AOP</th>
<th>2005</th>
<th>2010</th>
<th>Change from 2005 to 2010 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global total</td>
<td>3 240 129</td>
<td>3 375 977</td>
<td>+4.2</td>
</tr>
<tr>
<td>OECD-34</td>
<td>497 958</td>
<td>478 104</td>
<td>−4.0</td>
</tr>
<tr>
<td>WHO European Region</td>
<td>577 221</td>
<td>509 100</td>
<td>−11.8</td>
</tr>
</tbody>
</table>


These data are consistent with the evidence presented by the OECD (OECD, 2014), which shows that most of the OECD’s European member countries achieved a reduction in premature deaths over this period – to a greater or lesser extent – while most of its non-European member countries did not: the United States of America achieved a reduction, but the remaining non-European countries – Canada, Mexico and Chile in the Americas, Japan and the Republic of Korea in Asia, as well as Australia and New Zealand – suffered an increase in premature deaths from 2005 to 2010 (see OECD, 2014). The evidence presented here shows that the results from the non-OECD part of the WHO European Region do not alter the basic pattern found for OECD member countries in Europe.

It is important to note that the improvement observed in the WHO European Region follows in the wake of regulatory intervention across the relevant sectors within the European Union (EU), which also influences the rest of the Region. For the EU, the European Environment...
Agency (EEA) recorded an overall improvement in the trend of pollutant emissions for the period from 2002 to 2011 (EEA, 2013a), with reductions in emissions of primary PM (14% for PM$_{10}$ and 16% for PM$_{2.5}$) and in emissions of its main precursors, including by 27% for nitrogen oxides (NO$_x$). NO$_x$ emissions are also a precursor for ozone and the 27% reduction in NO$_x$ emissions was matched by similar reductions in other ozone precursor gas emissions. Moreover, and mainly owing to progressively tighter emission limits for Euro 4 vehicles in 2005 and Euro 5 vehicles in 2009, the reduction in emissions achieved in the critical transport sector – by 24% for PM$_{10}$, by 27% for PM$_{2.5}$, and by 31% for NO$_x$ – exceeded the reduction in emissions overall for the period in question.

Notwithstanding the improvements, the problem that the above-mentioned EU regulatory intervention was designed to address remains very serious. In particular, owing to the improvements in monitoring and modelling technology, it is now clear that the relatively rapid decline in pollutant emissions at source has been followed by a slower decline in ambient concentrations of pollutants and human exposure (see, for example, EEA, 2013a and OECD, 2014). The EEA (2013b) reported that in 2011, 33% of the urban population was exposed to PM$_{10}$ levels above the EU limit, and 88% to PM$_{10}$ levels above the tighter WHO air quality guidelines (AQG) limit. The OECD also argued (OECD, 2014) that the problem has been compounded by increasing market penetration of diesel (see also Carslaw et al., 2011; EEA, 2012; Moore & Newey, 2012; Carslaw & Rhys-Tyler, 2013). In contrast to petrol vehicles, diesel vehicles are reported to have not shown significant reduction in NO$_x$ emissions since the mid-1990s (Carslaw & Rhys-Tyler, 2013). However, partly as a consequence of policy and tax regulations designed to combat climate change, the recent past has witnessed a continuing shift from petrol to diesel vehicles (EEA, 2012).

At any rate, the yearly premature death toll from AAP of more than half a million people in the WHO European Region is a remarkably high number, setting the context in which any improving trend should be evaluated.

### 1.4 APMP and HAP in the WHO European Region

The evidence presented in Table 1.2 is relevant to the global and regional levels for ambient PM. The evidence presented in Table 1.3 is by country and reports mortality due to ambient PM and HAP from solid fuels, comparing the years 2005 and 2010.

Data for PM by country are available for all Member States of the European Region (with the exception only of Monaco and San Marino). Data by country for HAP from solid fuels are not available for 24 high-income countries. Where such data are available, predominantly in the low- and middle-incomes countries of the Region, they reveal a sufficiently serious problem to merit discussion in this report.

Table 1.3 shows the sum of mortality data for ambient PM and HAP from solid fuels, for the years 2005 and 2010. This is a simple sum, rather than an estimate of joint effects; it should therefore be interpreted with caution.

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2 These European emission standards define the acceptable limits for exhaust emissions of new vehicles sold in EU Member States. They are defined in a series of EU directives staging the progressive introduction of increasingly stringent standards (Euro 4 was introduced in January 2005, followed in September 2009 by Euro 5) and concentrated on cleaning up emissions from petrol and diesel cars, especially reducing PM and oxides of nitrogen (NO$_x$).

3 As noted above, a roughly similar pattern is observable in the United States: see, inter alia, the evidence presented in Amann, Klimont & Wagner (2013), American Lung Association (2013), and United States EPA (EPA, 2013).
<table>
<thead>
<tr>
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Table 1.3. (continued)

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<td><strong>565 271</strong></td>
<td><strong>498 538</strong></td>
<td><strong>220 575</strong></td>
<td><strong>164 231</strong></td>
<td><strong>785 846</strong></td>
<td><strong>662 769</strong></td>
</tr>
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Note. Monaco and San Marino are excluded owing to lack of data. Source: data extracted from IHME (2014).

As already noted, the WHO European Region, taken as a whole, achieved about a 12% reduction in premature deaths from ambient PM from 2005 to 2010. The 29 countries for which data on HAP from solid fuels are available achieved an overall reduction of about 25%. Nonetheless, the premature death toll (sum) as recorded in 2010 remains remarkably high (at about 663 000 in a single year).

In relative terms, HAP from solid fuels constitutes both a lesser and a declining share of the overall mortality from air pollution in the WHO European Region. In 2010, this share was about 25%, while globally, that share exceeded 50% (WHO, 2014b).

In addition to the number of premature deaths, the impact of air pollution on health can be captured by several other
indicators, of which the most commonly used are:

- years of life lost (YLLs), sometimes called life-years lost (LYLs) – namely, the number of years by which a life is shortened by a premature death;
- YLDs – a measure of the relative impact of different diseases on the population;

- DALYs lost – the sum of YLLs and YLDs, often referred to as BOD.

Table 1.4 presents country-specific estimates of DALYs lost as a result of air pollution in 2005 and 2010.

Table 1.4. DALYs lost as a result of air pollution (APMP, HAP, and APMP + HAP) per country in the WHO European Region, 2005 and 2010

<table>
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<td>41 438</td>
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<td>92 684</td>
<td>86 147</td>
<td>134 122</td>
<td>122 392</td>
</tr>
<tr>
<td>Bulgaria</td>
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<td>164 432</td>
<td>193 302</td>
<td>156 958</td>
<td>398 850</td>
<td>321 390</td>
</tr>
<tr>
<td>Croatia</td>
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<td>49 122</td>
<td>34 670</td>
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</tr>
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<td>-</td>
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<tr>
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<td>23 631</td>
<td>10 045</td>
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<td>122 508</td>
</tr>
<tr>
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<td>27 876</td>
<td>-</td>
<td>-</td>
<td>28 483</td>
<td>27 876</td>
</tr>
<tr>
<td>Estonia</td>
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<td>5 492</td>
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<td>8 909</td>
<td>17 897</td>
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</tr>
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<td>-</td>
<td>-</td>
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<td>-</td>
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<td>156 878</td>
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<td>-</td>
<td>-</td>
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<td>632 545</td>
</tr>
<tr>
<td>Greece</td>
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<td>117 569</td>
<td>-</td>
<td>-</td>
<td>130 321</td>
<td>117 569</td>
</tr>
<tr>
<td>Hungary</td>
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<td>159 555</td>
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<td>154 739</td>
<td>403 410</td>
<td>314 294</td>
</tr>
<tr>
<td>Iceland</td>
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<td>-</td>
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<td>Ireland</td>
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<td>-</td>
<td>-</td>
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<td>11 451</td>
</tr>
<tr>
<td>Israel</td>
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<td>39 563</td>
<td>-</td>
<td>-</td>
<td>42 109</td>
<td>39 563</td>
</tr>
<tr>
<td>Italy</td>
<td>482 927</td>
<td>436 848</td>
<td>-</td>
<td>-</td>
<td>482 927</td>
<td>436 848</td>
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<tr>
<td>Kazakhstan</td>
<td>281 429</td>
<td>244 457</td>
<td>256 429</td>
<td>159 122</td>
<td>537 858</td>
<td>403 579</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>87 449</td>
<td>74 414</td>
<td>162 712</td>
<td>146 609</td>
<td>250 161</td>
<td>221 023</td>
</tr>
<tr>
<td>Latvia</td>
<td>7 398</td>
<td>19 339</td>
<td>21 910</td>
<td>11 579</td>
<td>29 308</td>
<td>30 918</td>
</tr>
<tr>
<td>Lithuania</td>
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<td>29 974</td>
<td>31 403</td>
<td>18 716</td>
<td>56 796</td>
<td>48 689</td>
</tr>
<tr>
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<td>2 389</td>
<td>-</td>
<td>-</td>
<td>3 058</td>
<td>2 389</td>
</tr>
<tr>
<td>Malta</td>
<td>3 817</td>
<td>3 606</td>
<td>-</td>
<td>-</td>
<td>3 817</td>
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</table>
A comparison of Table 1.3 and Table 1.4 shows that the trend in DALYs from air pollution in the WHO European Region over time closely mirrors the trend in number of premature deaths. This is not surprising, because mortality is by far the larger contributor to the BOD; YLDs are but a small fraction of DALYs, as shown in Table 1.5.

However, YLDs also matter. Table 1.5 presents results by country for YLDs as a percentage of DALYs, for ambient PM only (since data are available for 51 rather than 29 countries) and for 2010 only (since the relative share, rather than the change over time, is the focus here). YLDs expressed as a percentage of DALYs reflect not only the prevalence of illness in a given country, but also that country’s ability to respond to illness by treating individuals and prolonging their lives. It is therefore unsurprising that high-income countries with the highest standards of health care provision show the highest values in Table 1.5. See, for example, the results for countries such as Israel, as well as various European countries (Austria, Belgium, France, Iceland, Italy, the Netherlands and Switzerland). It follows that, other things being equal, this value could be expected to increase with the general progress of society.
Table 1.5. YLDs from APMP in relation to DALYs from APMP per country in the WHO European Region, 2010

<table>
<thead>
<tr>
<th></th>
<th>YLDs from APMP</th>
<th>DALYs from APMP</th>
<th>YLDs from APMP as a % of DALYs</th>
</tr>
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<tr>
<td>Albania</td>
<td>1 182</td>
<td>29 858</td>
<td>3.96</td>
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<td>Andorra</td>
<td>39</td>
<td>469</td>
<td>8.42</td>
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<td>Armenia</td>
<td>2 067</td>
<td>49 141</td>
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<tr>
<td>Austria</td>
<td>4 720</td>
<td>45 883</td>
<td>10.29</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>4 897</td>
<td>130 019</td>
<td>3.77</td>
</tr>
<tr>
<td>Belarus</td>
<td>4 161</td>
<td>157 970</td>
<td>2.63</td>
</tr>
<tr>
<td>Belgium</td>
<td>10 157</td>
<td>89 698</td>
<td>11.32</td>
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<td>Bosnia and Herzegovina</td>
<td>1 498</td>
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<td>4.13</td>
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<td>5 311</td>
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<td>2 333</td>
<td>49 122</td>
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</tr>
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<td>422</td>
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<td>7.66</td>
</tr>
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<td>112 463</td>
<td>5.06</td>
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<td>11.81</td>
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</tr>
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<td>55 743</td>
<td>632 545</td>
<td>8.81</td>
</tr>
<tr>
<td>Greece</td>
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<td>117 569</td>
<td>5.92</td>
</tr>
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<td>436 848</td>
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<td>244 457</td>
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</tr>
<tr>
<td>Kyrgyzstan</td>
<td>2 029</td>
<td>74 414</td>
<td>2.73</td>
</tr>
<tr>
<td>Latvia</td>
<td>781</td>
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<td>4.04</td>
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<td>Lithuania</td>
<td>1 382</td>
<td>29 974</td>
<td>4.61</td>
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<tr>
<td>Luxembourg</td>
<td>232</td>
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<td>9.70</td>
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<td>Malta</td>
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<td>3 606</td>
<td>8.55</td>
</tr>
<tr>
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<td>7 632</td>
<td>5.11</td>
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<tr>
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<td>108 603</td>
<td>10.96</td>
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<tr>
<td>Norway</td>
<td>251</td>
<td>2 769</td>
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<td>Poland</td>
<td>19 878</td>
<td>439 664</td>
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<td>Portugal</td>
<td>3 823</td>
<td>54 689</td>
<td>6.99</td>
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<tr>
<td>Republic of Moldova</td>
<td>1 861</td>
<td>62 037</td>
<td>3.00</td>
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<td>Romania</td>
<td>13 056</td>
<td>386 302</td>
<td>3.38</td>
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<td>51 309</td>
<td>1 935 290</td>
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<td>Serbia</td>
<td>5 209</td>
<td>120 811</td>
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<tr>
<td>Slovakia</td>
<td>2 690</td>
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</tr>
<tr>
<td>Country</td>
<td>YLDs from APMP</td>
<td>DALYs from APMP</td>
<td>YLDs from APMP as a % of DALYs</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>----------------</td>
<td>-----------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Spain</td>
<td>19,895</td>
<td>211,686</td>
<td>9.40</td>
</tr>
<tr>
<td>Sweden</td>
<td>1,123</td>
<td>14,048</td>
<td>7.99</td>
</tr>
<tr>
<td>Switzerland</td>
<td>4,681</td>
<td>36,242</td>
<td>12.92</td>
</tr>
<tr>
<td>Tajikistan</td>
<td>2,071</td>
<td>79,435</td>
<td>2.61</td>
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<tr>
<td>The former Yugoslav Republic of Macedonia</td>
<td>1,031</td>
<td>30,493</td>
<td>3.38</td>
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<tr>
<td>Turkey</td>
<td>24,298</td>
<td>722,346</td>
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<tr>
<td>Turkmenistan</td>
<td>3,955</td>
<td>133,870</td>
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<tr>
<td>Ukraine</td>
<td>25,154</td>
<td>947,069</td>
<td>2.66</td>
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<td>United Kingdom</td>
<td>29,412</td>
<td>360,700</td>
<td>8.15</td>
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<td>Uzbekistan</td>
<td>12,904</td>
<td>507,522</td>
<td>2.54</td>
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<tr>
<td><strong>Minimum value</strong></td>
<td></td>
<td></td>
<td><strong>2.28</strong></td>
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<tr>
<td><strong>Maximum value</strong></td>
<td></td>
<td></td>
<td><strong>13.90</strong></td>
</tr>
</tbody>
</table>

**Value across the WHO European Region**  
4.85

*Note*. Monaco and San Marino are excluded owing to lack of data.  
*Source*: data extracted from IHME (2014).

An additional reason for the low share of YLDs is that the data record for premature deaths is more complete than for morbidity, and critical data gaps still remain (WHO Regional Office for Europe, 2014). Since the problem of incomplete morbidity data is more pronounced in low-income countries, the share of YLDs is expected to increase over time, as this information gap is filled. These points do not undermine the finding that YLDs make up only a low share of DALYs, but they do suggest that this share will increase over time and bring with it an increasing focus on the issue of morbidity from air pollution.
2. The evidence from economics

2.1 The valuation of life and health

The epidemiological evidence shows that air pollution is responsible for several million premature deaths per year – a global total of 7 million premature deaths in 2012, as reported in WHO (2014b). The evidence from economics shows that such pollution also imposes, by virtue of being responsible for those deaths, a so-called economic cost to society of several trillion dollars per year. As reported by the OECD (OECD, 2014), in the case of AAP for the 34 OECD countries plus China and India, this cost can be estimated at a combined total of 3.5 trillion United States dollars (US$) for the year 2010.

Economists face a difficulty here, as they often need to address conflicting estimates, produced by those who are not specialists in the field and do not understand its first principles. Also, they are often obliged to address those who might challenge the field from debatable philosophical starting points, misleading decision-makers with proposals based on estimates of costs (including health costs), which, explicitly or implicitly, place a default value of zero on the loss of life itself. It therefore appears necessary to restate, briefly, the first principles of economics as they apply to the problem at hand.

From Aristotle to William Petty, and including the many contributions from thinkers in China, India and elsewhere, there has long been a tradition of studying the management of income and wealth – that of households, of sovereigns and even of nations. But the modern science of economics that emerged from, and was a defining part of, the Franco-Scottish Enlightenment of the 18th century – pre-eminently, in the works of Francois Quesnay and Adam Smith – represents a definite break with this preceding tradition.

The new tradition begins with an explicit rejection of the view that wealth consists in gold or some other form of money – what Smith called the chrysohedonistic illusion – and takes as its object of study the so-called real economic phenomena that lie behind the monetary veil. Money becomes not the thing being measured but, at best, the instrument with which to measure it; an imperfect instrument with which to measure non-monetary phenomena.

In the language of present-day economics, which has developed far beyond but nonetheless remains descended from the tradition of Quesnay and Smith, value is a measure of the things that individuals in their millions value in the ordinary sense of the word, and cost is a measure of their loss, whether absolutely or as a means of securing other valuable things. For the purpose of the present discussion, these things include those listed below.

- Consumption. Along with consumption comes the sacrifice of some items of consumption in order to secure others, including the sacrifice of current consumption in the act of investment in order to secure greater future consumption.

- Leisure. This also entails the sacrifice of some leisure in the act of labour in order to secure consumption.

- Health. This also involves the sacrifice of some part of consumption in order to secure health.

\(^4\) In the relevant literature, this economic cost to society is also referred to as social cost, welfare cost, welfare loss or loss in social welfare. These terms indicate the same thing, which in this report is referred to as economic cost, for simplicity.
• Life. This includes the sacrifice of some part of consumption in order to preserve life.

Individuals are obliged to conduct trade-offs, or substitutions, between different valued things on a daily basis – and therefore to value them relative to each other. The task of the economist then becomes one of aggregating at a social level these millions of individual valuations at their marginal rates of substitution. What is being aggregated here, however, is precisely the valuations by individuals of the value to individuals.

As shown in the sections that follow, economics today possesses a standard method by which to execute this task, at least in the case of the cost of mortality, which is by far the largest component of the cost of air pollution. Before proceeding to the analysis, it is important to describe the contributions from other disciplines and why they need to be considered separately from the contribution of economics, and not conflated with it.

It is obvious that in actual cases of illness, and up to the point of death, the various responsible agents – individuals, households, hospitals, governments – must manage their respective budgets. In recent years, there have been important innovations in the allocation of these financial costs (in particular hospital costs) to particular diseases and risk factors; for example, by means of the method known as diagnosis-related groups (DRGs), and – principally in the United States, but also in Europe – through the work of WHO and other organizations (see, for example, Busse et al., 2011).

This work of accounting is obviously important, but is not to be confused with economics. The financial cost to a household, for example, of the premature death of a family member might be no more than the previously saved-up funeral expense; it might be near-zero for the hospital concerned; it might be a negative cost to government and/or a net saving in pension payments. In terms of economics, the cost being estimated is the loss of the thing to which individuals normally attach great value: life itself. By whatever means it is aggregated, the value to the individual – based on the individual's own valuation – is unlikely to be near-zero, let alone negative, and more likely to be positive and significant.

Even before the point of death, even in cases of illness, where it appears as though accountants and economists are considering the same costs, they are not counting the same thing, but rather addressing two features of the same reality. Consider, for example, a night's hospital stay on the part of a given patient. The financial cost may be found in, inter alia, the attributable part of the wages paid to the relevant medical staff, the attributable part of the bills paid to the relevant suppliers of equipment, energy, materials, and so on. In contrast, the economic cost is the sacrifice of value by the individual patient and, if relevant, the patient's household. This entails the sacrifice of consumption as a result of the wages foregone, the sacrifice of leisure as a result of the free time foregone, and so on. There are different calculations at work: they are not interchangeable, nor can their results be added up.

Similar considerations apply to the impact on the national accounts of air pollution or any other health risk factor. The premature deaths of working-age people will have an impact on the national accounts through the loss of labour inputs to production and the outputs of it. Those responsible for measuring, analysing and forecasting changes in gross domestic product (GDP) will have an interest in measuring this impact. Clearly, however, a calculation that stops counting at retirement age and implicitly places a zero value on the death of a person of 65 years or over will yield a very different estimate from the economist's estimate of the value to the individual. Even before the point of death, there are different calculations at work addressing different features of the same reality: counting the lost output as a result of the patient's absence from work is not the same as counting the patient's own loss.

None of this is to deny the validity,
importance or policy relevance of accounting, including national accounting. But the information yielded needs to be considered separately from the information on economic costs. Thus, there is a case for bringing to the attention of decision-makers simultaneously, side-by-side, both the economic cost estimates of air pollution and the estimates of its direct impact on GDP.\footnote{See, for example, related works by the United States Environmental Protection Agency (EPA)\footnote{EPA, 2011a; 2011b}, along with current OECD research exploring the subject (OECD, 2014). Unpublished works on local air pollution matters are also informing related decision-making (for example, a report prepared by Elisa Lanzi (OECD Secretariat) for the 2nd ad-hoc technical workshop of the CIRCLE project on costs of inaction and resources scarcity and the consequences for long-term economic growth, held on 2–3 October 2014 at the OECD headquarters in Paris). There is an interesting parallel here with the issue of GDP impacts from public investment projects. In recent years, and for certain high-profile projects, the United Kingdom Department for Transport has reported results in terms of both economic evaluation and national accounts – that is, both cost–benefit results and GDP impacts – in the same document. That said, these calculations have been carefully presented separately, and the reasons for it explained (see, for example, United Kingdom Department for Transport, 2005).}

Section 2.10 of this chapter presents some important recent results from the United States on both sets of estimates: the economic cost and the GDP impact.

### 2.2 The standard method for calculating the cost of mortalities: value of a statistical life (VSL)

This section focuses on the standard method for estimating economic costs and presents new results that have arisen from applying this method to the WHO European Region. It also shows that common variations on the standard method – within the discipline of economics – do not alter these results significantly: the economic cost is similarly large as long as this is indeed the cost being measured.

Present-day economics possesses a standard method by which to measure the cost of mortality at the level of society as a whole: VSL, as derived from aggregating individuals’ willingness to pay (WTP) to secure a marginal reduction in the risk of premature death. Despite its unfortunate name, suggesting a monetary judgement on the worth of an individual life, this method is safely grounded in economic first principles, seeking to aggregate the valuations by individuals of the value to individuals.\footnote{For recent expositions on the subject, including the inevitable complexities and caveats, see (inter alia) Blausque (2012), Braathen (2012), Hunt & Ferguson (2010), Hunt (2011), and OECD (2012; 2014). The exposition in the present study borrows heavily from current OECD research (OECD, 2014).}

The algebraic reasoning informing this method is elegant in its simplicity. Suppose that each individual has an expected utility function, $EU$, relating the utility of consumption over a given period, $U(y)$, and the risk of dying in that period, $r$, of the form:

$$EU(y, r) = (1 - r) U(y).$$

The individual's WTP, to maintain the same expected utility in the event of a reduction in the level of risk from $r$ to $r'$ is the solution to the equation:

$$EU(y - \text{WTP}, r') = EU(y, r).$$

VSL is thus the marginal rate of substitution between these two valued items, consumption and the reduction in the risk of dying, such that:

$$VSL = \frac{\delta \text{WTP}}{\delta r}.$$

The simplest way to discover the relevant individuals' WTP is – of course – to ask them. A WTP survey is in fact the starting point of the calculation. The OECD describes the basic process of deriving a VSL value from such a survey (OECD, 2012:14):

*The survey finds an average WTP of US$30 for a reduction in the annual risk of dying from air pollution from 3 in 100 000 to 2 in 100 000. This means that each...*
individual is willing to pay US$ 30 to have this 1 in 100 000 reduction in risk. In this example, for every 100 000 people, one death would be prevented with this risk reduction. Summing the individual WTP values of US$ 30 over 100 000 people gives the VSL value – US$ 3 million in this case. It is important to emphasise that the VSL is not the value of an identified person’s life, but rather an aggregation of individual values for small changes in risk of death.

This approach yields a simple result for researchers and policy-makers, which contributes to assessing the magnitude of a given problem, in terms of monetized societal value. The economic cost of the impact being studied – in the present case, the cost of mortality from air pollution – is the VSL value multiplied by the number of premature deaths. The economic benefit of a mitigating action becomes the same VSL value multiplied by the number of prevented deaths.

Owing to the multi-year research effort, embodied in a report by the OECD (OECD, 2012) – including its meta-analysis of VSLs starting with 1095 values from 92 published studies – both researchers and policy-makers can now use a set of OECD-recommended values for the average adult VSL. In units of (2005) US$, the recommended range for OECD countries is US$ 1.5 million to US$ 4.5 million, with a recommended base value of US$ 3 million.

This in turn enables the computation of country-specific VSL values for both OECD and non-OECD countries from 2005 onwards. The sections of this chapter that follow present this computation for the countries of the WHO European Region for 2005 and 2010, together with an exploration of some of the equity issues arising in the derivation and use of such country-specific VSLs.

Some words of reflection on these methods by the originator of the WTP approach, Jacques Drèze, throw into sharp relief their underlying motivation; namely, the failure of accounting to recognize the loss of value to the individual. The original case concerned the cost of mortality from road injury, but the point can easily apply to mortality from air pollution or any other environmental factor. Drèze recalls (Dehes, Drèze & Licandro, 2005:8–9):

In 1960, two French engineers were wondering how much should be spent on investments enhancing road safety. So they tried to define the economic value of a life saved. They suggested measuring that economic value by the future income of a potential victim … and stumbled on the question: should the value of future consumption be subtracted, in order to appraise society’s net loss? I realised at once that this very question pointed to the basic flaw of the approach: people want to survive and consume, not starve! Going back to the root of the problem, I introduced what is known today as the “willingness to pay” approach to valuing lives in safety analysis. How much would an individual be willing to pay in order to reduce his probability of accidental death? That is for the individual to decide, given his resources … [and] the subjective importance he attaches to survival… Road safety being a public good, individual willingness to pay should then be aggregated as in the Lindahl-Samuelson theory of public goods.

The standard method has undergone many developments and refinements over the subsequent half-century but it remains true to its original point of departure: its fidelity to individual valuations of the value to the individual.

2.3 Country-specific VSLs and intra- and international equity

The meta-analysis of VSL studies and VSL values by the OECD (OECD, 2012) yielded a recommended base value for average adult VSL in OECD countries of US$ 3 million for the year 2005 and using (2005) US$. The derivation of
country-specific values, and analysis of years other than 2005, involves two main adjustments:

• an adjustment for differences in per-capita income (per-capita GDP) and with the best-estimated income elasticity, in order to derive the value for any given country for the year 2005;

• an adjustment for post-2005 income growth ($\Delta Y$) and price inflation ($\Delta P$) in order to derive values for that given country for years following 2005.

Details of the methodology are described elsewhere (OECD, 2012; Braathen, 2012; OECD, 2014), but it is important to recall five elements in particular.

1. The OECD base value of US$ 3 million is the starting point for the calculation, both for OECD countries and for several other (non-OECD) countries, such as China and India (OECD, 2014).

2. The calculation is performed in purchasing power parity (PPP)-adjusted US$ estimates, and not through national currencies, reconverted into PPP-adjusted US$ estimates.

3. These PPP-adjusted US$ estimates reflect those published in the OECD’s statistical database for OECD countries and in the World Bank database for non-OECD countries.

4. The income elasticity beta applied is 0.8, being the mid-point of the best estimate of 0.7–0.9 (as established by the OECD) (OECD, 2012), without use of further sensitivity tests with alternative estimates.

5. The income elasticity adjustment is applied not only to the 2005 level but also to its growth in the post-2005 period.

The result for any given country, $C$, for any given year (here 2010), is thus:

$$VSL_{C,2010} = VSL_{OECD,2005} \times (\frac{Y_{C,2005}}{Y_{OECD,2005}})^\beta \times (1 + %\Delta P + %\Delta Y)^\beta.$$  

As already discussed, a VSL value is an aggregation of individual valuations; that is, WTP figures, as elicited from surveys, to secure a marginal reduction in the risk of premature death. It is a fact of life that, in the present day as much as in the past, individuals are differentially endowed with the means with which to make such a trade-off. At one end of the scale, some are obliged to work for their living for a dollar a day; at the other, some hold an inherited fortune, yielding an income of 1 billion dollars per year. All societies have therefore sought to socialize these risks to a greater or lesser extent in the form of public goods; to share the burden of these risks at least partially through the collective treasury, rather than impose it exclusively on the individual’s purse at the point of need, in addition to measures designed to redistribute incomes to a greater or lesser extent. It so happens that the level at which this socialization of risks is executed today is, principally, the level of the nation-state. Thus it is most often appropriate to aggregate at the level of country-specific VSLs, rather than at a lower level, such as a neighbourhood or (more realistically) a city or province, or at a higher level, such as the world as whole or (more realistically) a continent-wide union.

The point here is not that the problem of air pollution is, in the nature of things, national: it is not. Rather, the point is that the burden of addressing the problem and bearing the costs of any solution – that is, effecting the sacrifice of some value in consumption in order to secure the greater value of lives saved – is, in the present day, principally the responsibility of national governments.

National-level VSL is an aggregate value, reflecting the level at which the socialization of risks is executed. One consequence is that, as far as the use of VSLs is concerned, the problem of intranational variability in the ability to make the relevant trade-offs is suppressed. To the extent that income inequality occurs within countries, within-country variability in WTP also exists; however, national VSLs average out such variability and reflect the monetary valuations made by people in different countries about any good, including risk.
Differences in country-specific VSL values will thus tend to mirror the differences in country-specific per-capita income levels in any given year, as shown in Table 2.1. Because differences in income are very pronounced across the region, so are VSLs, with the highest value around 22 times the lowest.

This result is not a normative judgement on the part of the economists; it is simply recognition of the present-day reality: the citizens of low-income countries execute their relevant trade-offs largely without reference to the resources of high-income ones. The economist’s calculation would change if in fact the socialization of risks were devolved to a lower level, or elevated to a higher level.

The latter possibility is not far-fetched, given the role played by EU institutions and legislation in EU countries. Therefore, aside from the calculation of country-specific VSLs based on the OECD data formula for the countries of the WHO European Region (OECD, 2014) and the calculation of the economic costs of air pollution on the basis of these country-specific values, this chapter also presents an alternative calculation of the economic costs of air pollution for EU countries, on the basis of a common EU-wide VSL value.

Finally, it is important to note that the phenomenon of differential rates of growth in per-capita income in fact acts to change the differences in country-specific VSLs. Normally, this entails a movement toward the convergence of VSL values, as the lower income countries catch up with the higher income ones, as becomes apparent by comparison of the many countries in Table 2.1 (for example, the ratio of Germany’s VSL to Poland’s VSL falls from about 2:1 in 2005 to about 1.5:1 in 2010). However, issues of international equity do exist; they lie in different means and abilities to prevent and respond to environmental threats, including trans-boundary ones, such as air pollution and, even more so, climate change. The variability of VSLs by country reflects the different levels of resources available to deal with environmental risks – an issue that can only be addressed in international discussion of burden-sharing arrangements or the lack thereof.

Table 2.1. Computed country-specific VSL values per country in the WHO European Region, 2005 and 2010

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US$ (millions)</td>
<td>US$ (millions)¹</td>
<td>US$ (millions)²</td>
</tr>
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<td>Albania</td>
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<td>1.11</td>
</tr>
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<td>Armenia</td>
<td>3.00</td>
<td>0.62</td>
<td>0.83</td>
</tr>
<tr>
<td>Austria</td>
<td>3.00</td>
<td>3.28</td>
<td>3.67</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>3.00</td>
<td>0.66</td>
<td>1.45</td>
</tr>
<tr>
<td>Belarus</td>
<td>3.00</td>
<td>1.11</td>
<td>2.01</td>
</tr>
<tr>
<td>Belgium</td>
<td>3.00</td>
<td>3.17</td>
<td>3.50</td>
</tr>
<tr>
<td>Bosnia and Herzegovina</td>
<td>3.00</td>
<td>0.85</td>
<td>1.06</td>
</tr>
<tr>
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<td>3.00</td>
<td>1.23</td>
<td>1.77</td>
</tr>
<tr>
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<td>3.00</td>
<td>1.75</td>
<td>2.07</td>
</tr>
<tr>
<td>Cyprus</td>
<td>3.00</td>
<td>2.54</td>
<td>2.87</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>3.00</td>
<td>2.28</td>
<td>2.75</td>
</tr>
<tr>
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<td>3.00</td>
<td>3.25</td>
<td>3.46</td>
</tr>
<tr>
<td>Estonia</td>
<td>3.00</td>
<td>1.86</td>
<td>2.27</td>
</tr>
<tr>
<td>Finland</td>
<td>3.00</td>
<td>3.05</td>
<td>3.32</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------------------------------------------</td>
<td>---------------------------------------------------------</td>
<td>---------------------------------------------------------</td>
</tr>
<tr>
<td>France</td>
<td>3.00</td>
<td>2.96</td>
<td>3.16</td>
</tr>
<tr>
<td>Georgia</td>
<td>3.00</td>
<td>0.55</td>
<td>0.84</td>
</tr>
<tr>
<td>Germany</td>
<td>3.00</td>
<td>3.09</td>
<td>3.48</td>
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<tr>
<td>Greece</td>
<td>3.00</td>
<td>2.54</td>
<td>2.82</td>
</tr>
<tr>
<td>Hungary</td>
<td>3.00</td>
<td>1.90</td>
<td>2.32</td>
</tr>
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<td>3.39</td>
<td>4.46</td>
</tr>
<tr>
<td>Ireland</td>
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<td>3.68</td>
<td>3.75</td>
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<tr>
<td>Israel</td>
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<td>2.44</td>
<td>2.92</td>
</tr>
<tr>
<td>Italy</td>
<td>3.00</td>
<td>2.86</td>
<td>3.00</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>3.00</td>
<td>1.11</td>
<td>1.85</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>3.00</td>
<td>0.30</td>
<td>0.49</td>
</tr>
<tr>
<td>Latvia</td>
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<td>2.10</td>
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<td>1.65</td>
<td>2.15</td>
</tr>
<tr>
<td>Luxembourg</td>
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<td>5.78</td>
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<td>2.25</td>
<td>2.65</td>
</tr>
<tr>
<td>Montenegro</td>
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<td>1.08</td>
<td>1.45</td>
</tr>
<tr>
<td>Netherlands</td>
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<td>3.40</td>
<td>3.76</td>
</tr>
<tr>
<td>Norway</td>
<td>3.00</td>
<td>4.34</td>
<td>4.65</td>
</tr>
<tr>
<td>Poland</td>
<td>3.00</td>
<td>1.61</td>
<td>2.10</td>
</tr>
<tr>
<td>Portugal</td>
<td>3.00</td>
<td>2.28</td>
<td>2.50</td>
</tr>
<tr>
<td>Republic of Moldova</td>
<td>3.00</td>
<td>0.39</td>
<td>0.63</td>
</tr>
<tr>
<td>Romania</td>
<td>3.00</td>
<td>1.18</td>
<td>1.67</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>3.00</td>
<td>1.42</td>
<td>2.40</td>
</tr>
<tr>
<td>Serbia</td>
<td>3.00</td>
<td>1.09</td>
<td>1.75</td>
</tr>
<tr>
<td>Slovakia</td>
<td>3.00</td>
<td>1.83</td>
<td>2.42</td>
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<td>Slovenia</td>
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<td>2.46</td>
<td>2.90</td>
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<tr>
<td>Spain</td>
<td>3.00</td>
<td>2.79</td>
<td>3.06</td>
</tr>
<tr>
<td>Sweden</td>
<td>3.00</td>
<td>3.21</td>
<td>3.50</td>
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<tr>
<td>Switzerland</td>
<td>3.00</td>
<td>3.52</td>
<td>3.85</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3.00</td>
<td>0.26</td>
<td>0.44</td>
</tr>
<tr>
<td>The former Yugoslav Republic of Macedonia</td>
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<td>1.01</td>
<td>1.26</td>
</tr>
<tr>
<td>Turkey</td>
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<td>1.38</td>
<td>2.02</td>
</tr>
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<td>Turkmenistan</td>
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<td>0.69</td>
<td>0.97</td>
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<tr>
<td>Ukraine</td>
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<td>0.78</td>
<td>1.42</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>3.00</td>
<td>3.26</td>
<td>3.55</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>3.00</td>
<td>0.34</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Notes. Andorra, Monaco and San Marino are excluded owing to incomplete data. All presented numbers have been rounded up/down after the first two digits.

1 OECD base value of US$ 3 million in 2005, adjusted for differences in per-capita GDP at PPP, with an income elasticity to the power of 0.8.

2 OECD base value of US$ 3 million in 2005, adjusted for differences in per-capita GDP at PPP, with an income elasticity to the power of 0.8, and adjusted for post-2005 income growth and inflation.

Sources: data for OECD and non-OECD countries, respectively, were extracted from OECD (2013) and World Bank (2013).
2.4 Estimating the cost of morbidity

Economics possesses a standard method by which to measure the cost of mortality. However, as was argued at some length by the OECD (OECD, 2014), it does not yet possess a standard method by which to measure the cost of morbidity. Nor do researchers and policymakers possess anything like a set of OECD-recommended values for the several disease outcomes at issue here.

With regard to morbidity, there is not yet a clear consensus on exactly what outcomes need to be calculated or the values at which they are to be calculated. This is not entirely surprising. As discussed by the OECD (OECD, 2014), a defensible calculation of the costs of morbidity, grounded in economic first principles, is necessarily a more complex exercise than the calculation of the cost of mortality, as these costs are, in reality, plural in several respects.

- Morbidity includes a plurality of endpoints, varying greatly in extent of severity, and complicating enormously the task of eliciting and aggregating individual WTP values.
- Morbidity imposes costs on a plurality of agents: to begin with, the individual who is suffering ill health, but also the many who are involved in the organization and execution of formal and informal care of ill individuals.
- The individual who is suffering ill health suffers a plural loss: not only the pain and suffering imposed by the illness but also the loss of some part of consumption (and leisure) in expending income (and time) in averting and mitigating activities in response to current and prospective morbidities.

Therefore, and without departing from the distinction between economic calculation and other forms of calculation, such as national accounting, it is legitimate to calculate the costs of morbidity in a plural manner, as the sum of separate elements of cost, as listed by Hunt & Ferguson (2010).

- **Resource costs** are represented by the direct medical and non-medical costs associated with treatment for the adverse health impact of air pollution, plus avertive expenditures. That is, all the expenses the individual faces visiting a doctor, ambulance costs, purchasing medicines and other treatments, plus any related non-medical cost, such as the cost of childcare and housekeeping owing to fact that the affected person cannot carry out these tasks.
- **Opportunity costs** are associated with the indirect costs related to loss of productivity and/or leisure time owing to the health impact.
- **Disutility costs** refer to the pain, suffering, discomfort and anxiety linked to the illness.

As already mentioned, research is currently under way on establishing the methodology, and currently available estimates are indicative. As noted by Hunt & Ferguson (2010), Hunt (2011) and the OECD (2014), several issues remain to be resolved, including:

- the need to specify the distinct endpoints to be captured in the cost calculation;
- the necessity to include each of the aforementioned three separate elements of cost (resource costs, opportunity costs and disutility costs);
- the need for consistency between methods for estimating the different cost elements and in particular, the importance of avoiding double-counting;
- the necessity to conduct and complete this complex search in a manageable manner, in order to provide readily useable information.

Nonetheless, as argued by the OECD
most comprehensive recent studies available. Quantitatively, however, this is not necessarily a serious limitation when estimating the economic cost of the BOD of air pollution, because mortality dominates over morbidity. As shown in the previous chapter, in current estimates YLDs are a small fraction of DALYs from air pollution, at about 5% of the sum of DALYs across the WHO European Region. Also, as shown in section 2.5, the most recent estimates of the economic cost of morbidity are below 10% of the overall economic cost of air pollution’s health impacts.

For the present, it seems preferable to choose an indicative estimate for the additional cost of morbidity from the

2.5 An indicative estimate for the additional cost of morbidity

The chosen indicative estimate for the additional cost of morbidity in the present study is – as shown by the OECD (OECD, 2014) – about 10%. This implies that morbidity constitutes approximately 9%, or < 10%, of the estimated total cost of health impacts from air pollution, with mortality accounting for about 91%, or > 90%, of the total.

The rationale for this choice is set out in the paragraphs that follow, but it bears repeating that this is no more than an additional indicative estimate. The primary and definite estimates on which the calculations in this study rest are those conducted for the economic cost of premature deaths from air pollution.

The recent past has seen the publication of two comprehensive cost–benefit analysis (CBA) studies on air pollution, one on each side of the Atlantic. The first is the evaluation conducted by the United States EPA of the 1990 Clean Air Act Amendments (CAAA) (see EPA, 2011a; 2011b). The second is the set of studies supporting the EU’s Clean Air Policy Package (CAPP) (see in particular, Holland (2014), and also the earlier version of that report (Holland, 2012), as well as Amann (2014) and the European Commission (EC, 2013)). Neither the work conducted in the United States nor that from the EU are directly concerned with the problem of estimating the economic cost of morbidity for the WHO European Region. However, the evidence they provide on the share of morbidity costs helps to underpin the indicative estimate chosen here.

The United States EPA (EPA, 2011a) provides a series of estimates of the annual monetized benefits – that is, of the economic benefits from the reduction in mortality and morbidity, as well as the benefits from the reduction in environmental impacts other than health – by target years and also cumulatively. The specific estimates are not relevant here; what is of interest is the distribution of the benefits gained, or, more precisely, its counterpart; that is, the distribution of the economic costs saved. The information in Table 2.2 is extracted from the central estimate in the final analysis for the year 2020.
In the case of the EU, Holland provides a CBA of various mitigation scenarios, estimated with various methods (Holland, 2014). Again, specific estimates of these benefits are not relevant here. What is of interest is the distribution of the monetized equivalent of health impacts in the baseline scenario – the set of impacts expected to be obtained under the CLE – and its estimation with the standard method only; that is, with mortality calculated at mean VSL. The information in Table 2.3 is extracted from the CLE baseline for the year 2025:

<table>
<thead>
<tr>
<th>Category</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM mortality as a % of health effects</td>
<td>89.5</td>
</tr>
<tr>
<td>Ozone mortality as a % of health effects</td>
<td>2.9</td>
</tr>
<tr>
<td>Sum of PM mortality and ozone mortality as a % of health effects</td>
<td>92.4</td>
</tr>
<tr>
<td>Sum of health effects as a % of total effects</td>
<td>95.0</td>
</tr>
<tr>
<td>Sum of PM mortality and ozone mortality as a % of total effects</td>
<td>87.8</td>
</tr>
</tbody>
</table>

Source: extracted from results given in Table 3.3 (in €) by Holland (2014).

Here, too, it is evident that mortality has a dominant share (91.9%). It is permissible again here to deduce that if morbidity costs amount to about 8% of health impacts, then an addition of about 9% to the estimated mortality cost provides an indicative estimate of the overall economic cost of health impacts.7

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7 The OECD (OECD, 2014) used an earlier version of this evaluation defined by Holland (Holland, 2012), since Holland’s later work (Holland, 2014) was evidently not yet available. As a result, the estimate cited therein was approximately a 9% share for morbidity costs and the formula adopted for the indicative estimate was an addition of about 10% to mortality costs.
Nonetheless, it remains the case that the information extracted is best used here as a guide – it is too early to suggest that all potentially significant biases to the estimation have been corrected. Used thus, it does provide sufficient guidance in favour of adding 10% to the primary estimate of mortality costs in the calculations that follow.

### 2.6 The economic cost of health impacts of air pollution in the WHO European Region

Table 2.4 presents estimates of the economic cost of premature deaths from air pollution, per country, for 2005 and 2010. It does so on two counts: from APMP, for which data are available for all Member States of the WHO European Region other than Andorra, Monaco and San Marino; and from the sum of APMP and HAP, for which a default value of zero for HAP is applied to those 24 high-income countries where no deaths are recorded in the data.

<table>
<thead>
<tr>
<th>Table 2.4. Economic cost of premature deaths from air pollution (APMP and APMP + HAP) per country in the WHO European Region, 2005 and 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economic cost of premature deaths from APMP</strong></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Albania</td>
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<tr>
<td>Armenia</td>
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<td>Austria</td>
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<td>Azerbaijan</td>
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<td>Germany</td>
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<td>Greece</td>
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</table>
Table 2.4. (continued)

<table>
<thead>
<tr>
<th>Country</th>
<th>Economic cost of premature deaths from APMP US$ (millions)</th>
<th>Economic cost of premature deaths from APMP + HAP US$ (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005¹</td>
<td>2010²</td>
</tr>
<tr>
<td>Hungary</td>
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<td>21 281</td>
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<tr>
<td>Ireland</td>
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<td>Israel</td>
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<td>Italy</td>
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<tr>
<td>Kazakhstan</td>
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<td>Malta</td>
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<td>Montenegro</td>
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<td>567</td>
</tr>
<tr>
<td>Netherlands</td>
<td>26 594</td>
<td>24 644</td>
</tr>
<tr>
<td>Norway</td>
<td>1 533</td>
<td>864</td>
</tr>
<tr>
<td>Poland</td>
<td>47 121</td>
<td>51 870</td>
</tr>
<tr>
<td>Portugal</td>
<td>7 885</td>
<td>9 205</td>
</tr>
<tr>
<td>Republic of Moldova</td>
<td>1 688</td>
<td>2 028</td>
</tr>
<tr>
<td>Romania</td>
<td>30 931</td>
<td>36 109</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>139 423</td>
<td>225 975</td>
</tr>
<tr>
<td>Serbia</td>
<td>10 185</td>
<td>12 420</td>
</tr>
<tr>
<td>Slovakia</td>
<td>8 246</td>
<td>9 134</td>
</tr>
<tr>
<td>Slovenia</td>
<td>2 489</td>
<td>2 539</td>
</tr>
<tr>
<td>Spain</td>
<td>42 124</td>
<td>42 951</td>
</tr>
<tr>
<td>Sweden</td>
<td>3 219</td>
<td>3 641</td>
</tr>
<tr>
<td>Switzerland</td>
<td>10 471</td>
<td>10 225</td>
</tr>
<tr>
<td>Tajikistan</td>
<td>722</td>
<td>1 226</td>
</tr>
<tr>
<td>The former Yugoslav Republic of Macedonia</td>
<td>1 834</td>
<td>2 094</td>
</tr>
<tr>
<td>Turkey</td>
<td>37 524</td>
<td>56 932</td>
</tr>
<tr>
<td>Turkmenistan</td>
<td>3 379</td>
<td>4 791</td>
</tr>
<tr>
<td>Ukraine</td>
<td>59 655</td>
<td>74 935</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>89 741</td>
<td>83 069</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>6 400</td>
<td>8 299</td>
</tr>
<tr>
<td><strong>Total (of available data)</strong></td>
<td>1 007 223</td>
<td>1 156 118</td>
</tr>
</tbody>
</table>

Notes. Andorra, Monaco and San Marino are excluded owing to incomplete data.
1 OECD base value of US$ 3 million in 2005, adjusted for differences in per-capita GDP at PPP, with an income elasticity to the power of 0.8.
2 OECD base value of US$ 3 million in 2005, adjusted for differences in per-capita GDP at PPP, with an income elasticity to the power of 0.8, and adjusted for post-2005 income growth and inflation.
Sources: data on economic indicators for OECD and non-OECD countries, respectively, were extracted from OECD (2013) and World Bank (2013); data on deaths for all countries were extracted from the IHME (2014).
Table 2.5 adds the chosen indicative estimate of 10% to the economic cost of premature deaths, in order to present an indicative estimate of the economic cost of health impacts from air pollution across the WHO European Region (excluding Andorra, Monaco and San Marino) for 2005 and 2010, at an aggregate level.

Table 2.5. Indicative estimate of the economic cost of health impacts from air pollution (APMP and APMP + HAP) across the WHO European Region, 2005 and 2010

<table>
<thead>
<tr>
<th>Economic cost of health impacts from APMP if morbidity costs add ≈ 10% US$ (millions)</th>
<th>Economic cost of health impacts from APMP + HAP if morbidity costs add ≈ 10% US$ (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>2010</td>
</tr>
<tr>
<td>Indicative total across the WHO European Region</td>
<td>≈ 1 107 945</td>
</tr>
</tbody>
</table>

Note. Andorra, Monaco and San Marino are excluded owing to incomplete data.
Sources: data for OECD and non-OECD countries, respectively, were extracted from OECD (2013) and World Bank (2013); data on deaths for all countries were extracted from IHME (2014).

In absolute terms, the result is clear: air pollution imposes a large economic cost on the countries of the WHO European Region. As at 2010, the annual cost of premature deaths from air pollution across the countries of the Region stood at US$ 1.4 trillion, and the overall annual cost of health impacts from air pollution stood at US$ 1.6 trillion (see Box 2.1 at the end of this chapter).

This is to be expected for as long as air pollution remains a leading risk factor in premature deaths and as long as economists are willing to record the valuations that individuals report through their stated WTP to reduce the risk of premature death.

In terms of the change over time, the result is more complex. The cost of premature deaths from air pollution increased from 2005 to 2010 despite the decreasing number of deaths: the reduction of approximately 12% in premature deaths from APMP over this period has been attended by a 14.8% increase in estimated cost, and the reduction of 15% in premature deaths from APMP + HAP has been attended by a 13.7% increase in estimated cost. This divergence is the result of the increase in the VSL value for each death outpacing the reduction in the number of deaths. The pace of reduction in premature deaths has been too slow to counter an increase in cost, even if as many as 11 countries (around a quarter of the list) did achieve the desired outcome on both counts.

This is an important result: the increase in VSL values is no economic artefact, but rather the indication of a widespread trend. Increasing affluence brings in its wake a greater ability to secure a reduction in the risk of premature death by means of the requisite sacrifice in consumption. Society has signalled the requisite willingness, so it is for decision-makers to act on this signal.

Note that this refers to a greater ability to sacrifice consumption and not to a greater sacrifice. On the contrary, the calculation here assumes a lesser sacrifice: that is, the income elasticity is < 1. Thus, VSL values rise with increasing incomes but are assumed here to rise at a lesser rate. As it happens, although this assumption is based on an extensive body of evidence in high-income countries (see OECD, 2012), there is reason to suppose and evidence to suggest that the assumption is too conservative in the case of low-income countries transitioning to middle- and high-income status; it may be that, across this income range, income elasticity is > 1 and that VSL values increase at a greater rate than assumed here (see Hammitt & Robinson, 2011). If so, the rate of increase in the economic cost of premature deaths from air pollution in at least some of the non-OECD countries of the WHO European Region would be greater than that reported in Table 2.4, while starting from a lower base.
To put the figures in context, it may be useful to describe this cost not only in absolute terms (dollars) but also in relation to the metric by which many countries measure themselves nowadays: GDP. Table 2.6 reports the economic cost of premature deaths from air pollution as a percentage of GDP for each of the countries of the WHO European Region.

### Table 2.6. Economic cost of premature deaths from air pollution (APMP + HAP) as a percentage of GDP per country in the WHO European, 2005 and 2010

<table>
<thead>
<tr>
<th>Country</th>
<th>Economic cost of premature deaths from APMP + HAP US$ (millions)</th>
<th>Economic cost of premature deaths from APMP + HAP as a % of GDP (at PPP)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005</td>
<td>2010</td>
</tr>
<tr>
<td>Albania</td>
<td>3 622</td>
<td>4 572</td>
</tr>
<tr>
<td>Armenia</td>
<td>3 398</td>
<td>3 690</td>
</tr>
<tr>
<td>Austria</td>
<td>11 957</td>
<td>11 457</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>5 893</td>
<td>10 042</td>
</tr>
<tr>
<td>Belarus</td>
<td>12 900</td>
<td>19 865</td>
</tr>
<tr>
<td>Belgium</td>
<td>19 559</td>
<td>19 842</td>
</tr>
<tr>
<td>Bosnia and Herzegovina</td>
<td>5 920</td>
<td>7 228</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>26 182</td>
<td>32 091</td>
</tr>
<tr>
<td>Croatia</td>
<td>9 844</td>
<td>9 035</td>
</tr>
<tr>
<td>Cyprus</td>
<td>819</td>
<td>857</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>22 834</td>
<td>20 901</td>
</tr>
<tr>
<td>Denmark</td>
<td>5 955</td>
<td>6 283</td>
</tr>
<tr>
<td>Estonia</td>
<td>1 867</td>
<td>2 015</td>
</tr>
<tr>
<td>Finland</td>
<td>1 179</td>
<td>1 495</td>
</tr>
<tr>
<td>France</td>
<td>53 031</td>
<td>53 295</td>
</tr>
<tr>
<td>Georgia</td>
<td>5 562</td>
<td>9 127</td>
</tr>
<tr>
<td>Germany</td>
<td>154 382</td>
<td>144 715</td>
</tr>
<tr>
<td>Greece</td>
<td>22 300</td>
<td>22 785</td>
</tr>
<tr>
<td>Hungary</td>
<td>41 051</td>
<td>40 859</td>
</tr>
<tr>
<td>Iceland</td>
<td>62</td>
<td>96</td>
</tr>
<tr>
<td>Ireland</td>
<td>1 773</td>
<td>2 518</td>
</tr>
<tr>
<td>Israel</td>
<td>6 227</td>
<td>7 164</td>
</tr>
<tr>
<td>Italy</td>
<td>98 612</td>
<td>97 193</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>23 168</td>
<td>29 226</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>2 597</td>
<td>3 571</td>
</tr>
<tr>
<td>Latvia</td>
<td>2 401</td>
<td>3 779</td>
</tr>
<tr>
<td>Lithuania</td>
<td>5 043</td>
<td>6 041</td>
</tr>
</tbody>
</table>
reported in Table 2.6 is that, as at 2010, the economic cost of premature deaths from air pollution amounted to less than 1% of GDP in only 4 of the 48 countries of the WHO European Region (for which results are available): Finland, Iceland, Norway and Sweden.

In 22 of the 48 countries for which results are available – almost half the number of countries in the WHO European Region – the economic cost of premature deaths from air pollution is, in round numbers,
at or above 10% of GDP. Furthermore, in no less than 10 of the countries of the Region, the economic cost of premature deaths from air pollution is, in round numbers, at or above 20% of GDP.

### 2.8 Economic cost calculation with a common VSL for EU countries

The rationale of using country-specific VSLs is discussed in section 2.3. The VSL seeks to aggregate the willingness of individuals to sacrifice some part of their consumption to secure a reduction in the risk of premature death. In the world as it is today, this trade-off between consumption and risk reduction is, as a general rule, conducted within the boundaries of each country, with national governments bearing the principal responsibility for effecting this trade-off, by means of legislation, regulation, taxation and public expenditure.

However, as already noted, it would be perfectly possible for this trade-off to be conducted at the level of such supranational entities as the EU. Indeed, the European Commission already bears an important measure of responsibility in this regard, by virtue of its capacity to propose legislation and regulation for Member States to agree, adopt and apply on an EU-wide basis.

Therefore, recognizing the possibility of a future reconfiguration of responsibilities in order to permit the trade-off between consumption and risk reduction to be conducted fully on a EU-wide basis, Table 2.7 calculates the per-country economic cost of premature deaths from air pollution for 2005 and 2010 for the (then) Member States of the EU on the basis of a common VSL – starting with a 2005 base figure of US$ 3.6 million as determined in the research presented by the OECD (OECD, 2012). Table 2.8 adds the chosen indicative estimate of 10% for morbidity to the economic cost of premature deaths in order to present an indicative estimate of the economic cost of health impacts from air pollution across the EU for 2005 and 2010, conducted on the same basis.

As shown in the two tables, this alternative calculation does not alter the key conclusion that the economic cost of air pollution is large. Rather, the cost appears even larger: the overall economic cost of health impacts from the sum of APMP and HAP in 2010 becomes US$ 1.483 trillion for the EU alone, as opposed to the US$ 1.575 trillion reported in Table 2.5 for the WHO European Region as a whole.

#### Table 2.7. Economic cost (with a common VSL) of premature deaths from air pollution (APMP and APMP + HAP) per EU Member State, 2005 and 2010

<table>
<thead>
<tr>
<th>Country</th>
<th>Economic cost of premature deaths from APMP US$ (millions)</th>
<th>Economic cost of premature deaths from APMP + HAP US$ (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005¹</td>
<td>2010²</td>
</tr>
<tr>
<td>Austria</td>
<td>13 112</td>
<td>12 839</td>
</tr>
<tr>
<td>Belgium</td>
<td>22 209</td>
<td>23 292</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>40 568</td>
<td>39 041</td>
</tr>
<tr>
<td>Cyprus</td>
<td>1 161</td>
<td>1 229</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>31 430</td>
<td>28 906</td>
</tr>
</tbody>
</table>
Table 2.7. (continued)

<table>
<thead>
<tr>
<th>Economic cost of premature deaths from APMP US$ (millions)</th>
<th>Economic cost of premature deaths from APMP + HAP US$ (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005¹</td>
</tr>
<tr>
<td>Denmark</td>
<td>6 600</td>
</tr>
<tr>
<td>Estonia</td>
<td>680</td>
</tr>
<tr>
<td>Finland</td>
<td>1 390</td>
</tr>
<tr>
<td>France</td>
<td>64 497</td>
</tr>
<tr>
<td>Germany</td>
<td>180 183</td>
</tr>
<tr>
<td>Greece</td>
<td>31 669</td>
</tr>
<tr>
<td>Hungary</td>
<td>41 391</td>
</tr>
<tr>
<td>Ireland</td>
<td>1 736</td>
</tr>
<tr>
<td>Italy</td>
<td>124 240</td>
</tr>
<tr>
<td>Latvia</td>
<td>1 432</td>
</tr>
<tr>
<td>Lithuania</td>
<td>5 059</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>645</td>
</tr>
<tr>
<td>Malta</td>
<td>833</td>
</tr>
<tr>
<td>Netherlands</td>
<td>28 180</td>
</tr>
<tr>
<td>Poland</td>
<td>105 482</td>
</tr>
<tr>
<td>Portugal</td>
<td>12 430</td>
</tr>
<tr>
<td>Romania</td>
<td>94 370</td>
</tr>
<tr>
<td>Slovakia</td>
<td>16 243</td>
</tr>
<tr>
<td>Slovenia</td>
<td>3 640</td>
</tr>
<tr>
<td>Spain</td>
<td>54 443</td>
</tr>
<tr>
<td>Sweden</td>
<td>3 610</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>99 165</td>
</tr>
<tr>
<td><strong>Total (of available data)</strong></td>
<td>986 397</td>
</tr>
</tbody>
</table>

Notes. Only those countries that were Member States of the EU in 2005 and 2010 are included.
1 OECD base value of US$ 3 million in 2005, adjusted for differences in per-capita GDP at PPP, with an income elasticity to the power of 0.8
2 OECD base value of US$ 3 million in 2005, adjusted for differences in per-capita GDP at PPP, with an income elasticity to the power of 0.8, and adjusted for post-2005 income growth and inflation.
Sources: data on economic indicators were extracted from OECD (2013); data on deaths were extracted from IHME (2014).

Table 2.8. Indicative estimate of economic cost (with a common VSL) of health impacts from air pollution (APMP and APMP + HAP) per EU Member State, 2005 and 2010

<table>
<thead>
<tr>
<th>Economic cost of health impacts from APMP if morbidity costs add = 10% US$ (millions)</th>
<th>Economic cost of health impacts from APMP + HAP if morbidity costs add = 10% US$ (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>2010</td>
</tr>
<tr>
<td>Indicative total across the EU</td>
<td>= 1 085 037</td>
</tr>
</tbody>
</table>

Note. Only those countries that were Member States of the EU in 2005 and 2010 are included.
Sources: data on economic indicators were extracted from OECD (2013); data on deaths were extracted from IHME (2014).
2.4 reports an appreciable increase in the economic cost of premature deaths from APMP + HAP in Poland, reflecting the relatively rapid increase in per-capita incomes and VSL values. On this reading, with its rising incomes, Poland was more able and willing in 2010 to sacrifice consumption in order to secure a reduction in air pollution risk than it had been in 2005. In contrast, with a common VSL, and only a moderate change in its value owing to slow-growing incomes in high-income EU countries, Table 2.7 reports Poland’s cost burden as little changed. The signal of a greater ability to pay and a great WTP is therefore lost.

In view of this, the alternative calculation with a common VSL is perhaps best interpreted as a confirmation of the overarching conclusion that the economic cost burden imposed by air pollution is similarly large by any reasonable measure, rather than as a guide to policy outlining details of costs and responsibilities for each individual country.

Despite the relative stability of the overall cost estimates, the alteration in the detailed pattern of results for each country when using a common VSL is not insignificant. If it were to be adopted as a policy guide in a world in which nation-states bear the primary responsibility for effecting the trade-off between consumption and risk reduction, the change would not be inconsequential.

For example: whereas Table 2.4 reports for the year 2005 an economic cost of premature deaths from APMP + HAP of about US$ 90 billion in Poland, the equivalent figure in Table 2.7, using country-specific VSLs, is about US$ 200 billion. The data in Table 2.7 therefore show Poland’s cost burden to be larger than Germany’s, using a common VSLs for EU countries, rather than smaller, as is the case with the country-specific VSL, shown in Table 2.4 (APMP +HAP). Moreover, there is also a significant alteration in the pattern of per-country results with regard to the change over time. Comparing 2010 with 2005, Table 2.9 Economic cost calculation using values of life-years (VOLYs) lost in lieu of VSLs

The variation presented in section 2.8 is an alternative calculation of VSL, using a single common value rather than differentiated country-specific values. There is another variation to the standard method that merits attention here: the use of units of VOLY (sometimes called the value of a statistical life-year (VSLY)) as an alternative to using units of VSL. As discussed in this section, there are some important theoretical issues involved in the choice between VSLs and VOLYs. However, remarkably – and importantly – there is little practical difference in terms of the outcomes in relation to the matter at hand. The use of VOLYs also serves to confirm the overarching conclusion about the size of the cost burden of air pollution in Europe today and the related policy implications.

First, it needs to be emphasized that the two epidemiological metrics used in these alternative economic calculations – the metric of YLLs (also called LYLs) and that of lives lost, or excess premature deaths – are equally legitimate metrics for counting the cost of air pollution. However, the former may be regarded as a more accurate indication of the mortality impact, given its ability to discriminate how long a premature death is moved forward in time (see COMEAP, 2010).

In the view of this study (as argued in Chapter 1), each of the relevant epidemiological metrics – attributed premature deaths, YLLs/YLLs, YLDs, DALYs/quality-adjusted life-years (QALYs), inter alia – remains a valuable aid to arriving at a full understanding of the impacts of air pollution. However, economists cannot be entirely indifferent to the choice between VSLs and VOLYs: that is, the choice between these alternative translations of the
epidemiological metrics into economic metrics.

As a matter of historical record, the use of VSLs – having been originally developed with explicit reference to economic first principles and in particular the principle of individual valuations of the value to the individual – has been established as a standard method for measuring the cost of mortalities since the 1960s. The use of VLYs emerged much later and has developed somewhat unevenly since the 1990s. In the United States, the United States EPA Science Advisory Board advised in favour of the continued use of VSLs, arguing that “alternative measures, such as the value of a statistical life-year or the value of a QALY, are not consistent with the standard theory of individual WTP for mortality risk reduction” (EPA, 2001:26). More recently, both the United Kingdom Government and the European Commission have conducted calculations using VLYs (see COMPEAP, 2010, and EC, 2013), although without abandoning VSLs altogether (see Hunt & Ferguson, 2010; Hunt, 2011; Robinson & Hammitt, 2013).

Turning to the present day, it remains the case that most governments across the countries of the OECD and beyond continue to calculate in VSLs rather than VLYs. This may be explained by some open questions on the methodology underlying the use of VLYs (discussed by the OECD (OECD, 2014)), including in particular two key points.

1. VLYs are rarely derived from WTP surveys (Hunt, 2011) – even if it is in principle possible to do so – and they therefore reflect the valuations of external parties, such as health professionals, rather than valuations by representative individuals in the general population.

2. However derived, VLYs will produce results that differ from, and are inconsistent with, the results given by VSLs: the cost of the premature death of a group of people of a given age will automatically be counted as less than the premature death of a comparable group of younger people with otherwise identical characteristics, since the number of YLLs for the former group will be less than that for the latter. It follows that VLYs, by counting life-years rather than lives in this calculation, “explicitly places a lower value on reductions in mortality risk accruing to older populations” (Hubbel, 2002:22).

However, how do the different metrics compare? In the final CBA for the EU CAPP, Holland (2014) details the economic benefits – that is, the reduction in economic costs – achievable from reducing air pollution in the EU. The study considers the (monetary) costs and (economic) benefits of a range of progressively ambitious pollution-reducing scenarios relative to the CLE baseline. Table 2.9 shows the estimated outcomes for 2030 for two scenarios: the first involves moving from the baseline to the European Commission’s proposal (B7) and the second involves moving beyond the Commission’s proposal to the maximum technically feasible reduction (MTFR). Estimates are given for four different metrics: median VLY, mean VLY, median VSL and mean VSL.
The different metrics produce different results. In moving from the baseline to the European Commission’s proposal, the use of a median VSL produces an estimate of benefits that is roughly twice as large as the estimate produced by using a median VOLY, as does the use of a mean VOLY. The use of a mean VSL produces an estimate that is roughly twice as large as that produced by the use of a mean VOLY (and, therewith, roughly twice as large as that produced by the use of a median VSL).

However, each calculation produces large estimated net benefits from the pollution-reduction policies in the European Commission’s proposal, within the same order of magnitude, and at many multiples of the monetary costs of these policies. Each calculation delivers the same advice on the decision required with regard to the proposal: namely, an affirmative response.

When the level of ambition moves beyond the European Commission’s proposal to the MTFR, the use of alternative metrics results in a difference in the sign of the net benefits (that is, negative in some cases, positive in others), and thereby also a difference in the advice that the analysis offers to decision-makers.

In Holland’s research (Holland, 2014), using the most conservative metric (the one yielding the lowest estimate of benefits: median VOLY), the point at which marginal cost equals marginal benefit is at 76% of gap closure. Using the least conservative metric (the one yielding the highest estimate of benefits: mean VSL), marginal cost equals marginal benefit at 92% of gap closure. In other words, all four metrics yield the result that abatement is economically justified up to 76% of gap closure and not beyond 92%.

The area of disagreement is an important matter of debate between specialists, in terms of the precise choice of instrument. However, this should not obscure the wider area(s) of agreement: the cost of air pollution is large; the benefits available from reducing these costs are large; and ambitious pollution-reduction policies are economically justified, including the proposal from the European Commission currently under debate.

Table 2.9. Estimated net health benefits of alternative scenarios using alternative metrics in the EU CAPP CBA, 2030

<table>
<thead>
<tr>
<th>Net health benefits in 2030 (28 Member States of the EU)*</th>
<th>€ (millions)</th>
<th>CLE – B7</th>
<th>B7 – MTFR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>3 334</td>
<td>47 347</td>
<td></td>
</tr>
</tbody>
</table>

**Net benefits with alternative metrics**

<table>
<thead>
<tr>
<th></th>
<th>Total with median VOLY</th>
<th>Total with mean VOLY</th>
<th>Total with median VSL</th>
<th>Total with mean VSL</th>
<th>WHO European Region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35 140</td>
<td>74 437</td>
<td>70 012</td>
<td>135 371</td>
<td>509 100</td>
</tr>
<tr>
<td></td>
<td>–28 063</td>
<td>–8 606</td>
<td>–11 059</td>
<td>21 002</td>
<td>–11.8</td>
</tr>
</tbody>
</table>

*Countries belonging to the EU in 2014.
Source: extracted from Table 5.2 in Holland (2014).
2.10 A comparison of economic (welfare) and GDP impact assessments

As defined at the outset, the focus of this chapter is the economic cost to society of air pollution: a term that is interchangeable in standard economic theory with social cost, welfare cost, or welfare loss. It is acknowledged that other standpoints are relevant, including, inter alia, calculations of the financial costs of: defined health impacts, the GDP impacts of air pollution, and measures to mitigate air pollution.

Moreover, while it is argued that these contributions need to be considered separately and that their results should not be conflated, it is also acknowledged that there is a case for bringing to the attention of decision-makers simultaneously the economic cost estimates of air pollution and the estimates of its impact on GDP: separate presentations, but side-by-side. This section does this, using the case of the United States EPA’s 2011 evaluation of the US CAAA (EPA, 2011a; 2011b).

The focus of the evaluation is very much on the economic (welfare) analysis: its main purpose is to provide an analysis of the costs and benefits of the 1990 CAAA, “incremental to those costs and benefits achieved from implementing the original 1970 Clean Air Act and the 1977 amendments” (EPA, 2011a:Abstract). As with any such CBA, the economic benefits being estimated are the economic costs saved as a result of the intervention – the economic costs of the reduction in premature deaths, the reduction in morbidity, the reduction in other negative environmental impacts, and so on. The costs to which these benefits are compared are the costs of implementation; namely, the resources sacrificed as a result of complying with the provisions of the intervention.

The assessment presents results in several categories: costs, benefits, net benefits, benefit–cost (B/C) ratios and costs per premature death avoided, with a central estimate as well as high and low estimates, by given target years as well as cumulatively. Table 2.10 presents only the central estimate for the year 2020.

The estimated benefits of US$ 2 trillion comprise the estimated economic costs associated with the loss of lives and health (and other valued things) that air pollution would have imposed in the United States in 2020, but that will now be saved as a result of its mitigation by

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Monetized direct costs</td>
<td>65 000</td>
</tr>
<tr>
<td>Monetized direct benefits</td>
<td>2 000 000</td>
</tr>
<tr>
<td>Net benefits</td>
<td>1 900 000</td>
</tr>
<tr>
<td>Benefits divided by cost (B/C ratio)</td>
<td>31:1</td>
</tr>
<tr>
<td>Costs per premature death avoided</td>
<td>280 000</td>
</tr>
</tbody>
</table>

Source: extracted from results given in Table 7-5 (in US$) by the United States EPA (EPA, 2011a).
means of the 1990 CAAA. It can therefore be compared to the US$ 1.575 trillion estimated in this study as the economic cost of the combined health impacts of air pollution in the WHO European Region in 2010 (see Table 2.5). Bearing in mind that the United States EPA study is relevant to the United States and the year 2020, with its considerably higher VSL values, and the fact that it includes a range of environmental impacts in addition to the impact on human health, the result is indeed comparable, notwithstanding the difference in population.

Given the argument and evidence presented to date, the significant benefits and high B/C ratios are not surprising. The costs of large-scale interventions to reduce air pollution, although they may appear sizeable at first glance, are small relative to the economic benefits gained, whenever these benefits are calculated in a manner consistent with economic first principles. In particular, the costs per premature death avoided, as given in the final row of Table 2.10, are small relative to VSLs.

The United States EPA (EPA, 2011a) also provides, by means of computable general equilibrium modelling, an estimation of the final impacts of the 1990 CAAA on GDP (as well as on consumption and the consumption–leisure trade-off). Here, the costs in question are the compliance expenditures, rather than the direct costs of compliance. Thus, whereas the latter excludes taxes, since they are a transfer from one party to another, all such expenditures need to be included in order to track the final impacts on GDP. In contrast, the benefits are limited to those included in GDP accounting. Thus, the lives of people that are not part of the labour force, and who are saved from premature death, are not counted.

The results are presented by the United States EPA (EPA, 2011a:Table 8-7, Table 8-8) in two case studies. The first is a cost-only case, which estimates the final impact on GDP of the expenditures related to the CAAA. The second is a labour force-adjusted case, which seeks to include as many of the benefits that can reasonably be included within GDP accounting: changes in labour force from reduced mortality, changes in labour force from reduced morbidity, and savings in medical expenditures. These changes permit an expansion of output in the rest of the economy, alongside a contraction in output in the health care sector itself. The results for the two cases are shown in Table 2.11.

---

**Table 2.11. Estimated GDP impacts presented in the United States EPA’s CAAA CBA, 2020**

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost-only case</strong></td>
<td></td>
</tr>
<tr>
<td>GDP with CAAA</td>
<td>20 202</td>
</tr>
<tr>
<td>GDP without CAAA</td>
<td>20 312</td>
</tr>
<tr>
<td>Change in GDP</td>
<td>–110</td>
</tr>
<tr>
<td><strong>Labour force-adjusted case</strong></td>
<td></td>
</tr>
<tr>
<td>GDP with CAAA</td>
<td>20 202</td>
</tr>
<tr>
<td>GDP without CAAA</td>
<td>20 197</td>
</tr>
<tr>
<td>Change in GDP</td>
<td>5</td>
</tr>
</tbody>
</table>

*Source: extracted from results given in Table 8-7 and Table 8-8 (in US$) by the United States EPA (EPA, 2011a).*
Two conclusions follow from these results.

- Counting the GDP-relevant benefits of pollution reduction can yield a net positive impact on GDP for ambitious interventions designed to achieve significant reductions in air pollution: in the case of the 1990 CAAA, this is a net addition to the United States GDP of US$ 5 billion in the year 2020.
- The net positive impact on GDP is trivial when compared to the economic benefits of reduced pollution, as defined in standard economic theory and as embodied in the standard method for valuing the loss of life: in this case, this is a net economic benefit of US$ 1.9 trillion in the year 2020.

An objection could be raised that the relatively meagre GDP impacts constitute an argument for better accounting of these impacts and better accounting of GDP itself. Indeed, the United States EPA concludes with a discussion of these analytical limitations (EPA, 2011a). As noted earlier, research is currently being undertaken to overcome these limitations.

Nonetheless, it remains the case that the economic benefits from reduced pollution will dwarf the positive change in GDP, as long as:

- GDP continues to be designed as a measure of the output of society’s economic actors – a measure that society surely needs to possess for many and various reasons – and not a measure of the welfare of all the individuals who constitute that society;
- economic costs and benefits continue to be defined as they are in standard economic theory; namely, as the value lost and the value gained by individuals, established by their individual valuations.

### Box 2.1. Putting trillions into context

1 trillion = 1 million million = 1 000 000 000 000

Estimates in the trillions of dollars can be illustrated by making simple comparisons to other figures, as detailed below.

- Approximate 2013 GDP figures according to the World Bank (World Bank, 2015) are: Germany US$ 3.7 trillion, Russian Federation US$ 2.1 trillion, Spain US$ 1.4 trillion, and Israel US$ 0.3 trillion.
- The total global health spending in 2009 was US$ 5.1 trillion (Bloom et al., 2011).
- Globally, the cost of illness was estimated at US$ 2.5 trillion for mental illness and US$ 0.9 trillion for cardiovascular disease in 2010 (Bloom et al., 2011).
- The total amount of overseas development assistance delivered since the mid-1990s is less than US$ 2 trillion (Bloom et al., 2011).
Policy implications: towards an evidence-based approach

3.1 The need for action and the need for reflection

The statement of evidence on the problem of air pollution, presented earlier – globally, a premature death toll in the millions, with an economic cost in the trillions; and in the WHO European Region, a toll of about 663,000 premature deaths, approximately 13 million DALYs, and an estimated economic cost of about US$ 1.6 trillion – is, ipso facto, a compelling argument for action to mitigate the problem.

However, the case for action is not new. Governments and supranational authorities from across the world have received advice from their own agencies and from supranational agencies such as WHO, the OECD and the European Commission, and have acted on it to a greater or lesser extent. In the EU in particular, there is a vast body of evidence and recommended actions that have been documented in the course of the development of the EU’s CAPP and in the processes related to it.9

Consider, for example, the quantification of the case for action in Holland’s final CBA for CAPP (Holland, 2014), in moving from the CLE baseline scenario to the European Commission proposal (B7) for strengthened regulations on emission controls (Table 3.1).

Table 3.1. Estimated costs, benefits, net benefits and B/C ratios in the EU CAPP CBA, 2030

<table>
<thead>
<tr>
<th>Commission proposal (B7): estimate for 2030</th>
<th>€ (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits over baseline (at mean VSL)</td>
<td>138,705</td>
</tr>
<tr>
<td>Net benefits (at mean VSL)</td>
<td>135,371</td>
</tr>
<tr>
<td>Benefits over baseline divided by cost (B/C ratio)</td>
<td>42:1</td>
</tr>
</tbody>
</table>

Source: extracted from Table 5.2 and Table 5.4 in Holland (2014).

Note, moreover, that the benefits displayed here are health benefits only (see Holland, 2014). The CAPP itself addresses a wider range of air pollution impacts, including damage to: agriculture and forestry, in the form of reduced crop

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9 See, in particular, Amann (2014), Holland (2014), WHO Regional Office for Europe (2013a; 2013b), and the European Commission impact assessment (EC, 2013).
could reduce the number of those who are at higher risk from air pollution, and in turn reduce the health toll of air pollution, without addressing its root causes.

In addition, there are several measures attempting to reduce exposure to air pollutants, rather than acting to reduce emissions. Consider, for example, recent research from the United States on the optimal design of cycle paths in relation to roads, or the optimal design of bus and tram stops in order to enable waiting users to face away from road traffic rather than toward it (Grabow et al., 2012; Figliozzi & Monsere, 2013).

Although these measures play a role in reducing the effects of air pollution, the largest benefits are to be expected from measures that reduce emissions. Important examples of this come from the estimate for the United States of about US$ 2 trillion in benefits gained by 2020 as a result of the 1990 CAAA, of which 95% are health benefits (see Table 2.2 and EPA, 2011a), and the estimate for the EU of about €140 billion in health benefits that would be available by 2030 if the European Commission’s proposal on the CAPP were to be adopted (see Table 3.1, as well as Holland (2014) and the European Commission (EC, 2013)).

It follows that these large-scale, multi-sector, as-comprehensive-as-possible initiatives to reduce air pollution at source are indeed appropriate actions. It also follows that well-designed policy instruments possess per se important attributes that promote action, providing means to promote innovation, information exchange and monitoring. Moreover, and evidently, they also demonstrate that the world does indeed possess enough knowledge to attack air pollution at source and to reduce it and its toll on life and health: that is good news.

Mitigating the toll on life and health imposed by air pollution is a multifaceted task: indeed, it is arguably not a singular task at all, but rather the sum of a number of separate tasks. Potential health benefits in the form of enabling more people to lead longer lives and with better quality of life can be, and are, secured through several, separate and often unrelated channels. Moreover, some of these channels need not in fact involve any attempt to reduce air pollution itself. For example, health programmes that result in the early identification and treatment of patients suffering from heart disease yields and fish stocks; landscape; the built environment, and so on (see EC, 2013). It therefore yields a wider range of pollution-reduction benefits. These are, as noted in the Introduction, matters that lie outside the remit of this study, but they are very much a part of the challenge posed by air pollution.

In any case, it is now clear that the toll imposed by air pollution is much more serious than was previously understood. Indeed, the very fact that such a remarkably high B/C ratio as that shown in Table 3.1 remains (42:1), requiring further action, is itself proof of the insufficiency of the interventions conducted to date. On the other hand, as documented in Chapter 1, it is also a fact that Europe has succeeded in reducing air pollution and its toll – not by nearly enough, but by more than has been achieved elsewhere. Europe has accomplished this more with regulatory instruments that have defined air quality standards than with other instruments in the policy arsenal. There is therefore a need for better understanding of regulatory instruments and their place within the arsenal: a better understanding of how to maximize their effectiveness and when to complement them along with other instruments.

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10 Examples include the European Air Quality Directive (European Parliament & Council of the European Union, 2008), which addressed the emissions of air pollutants; the Convention on Long-Range Transboundary Air Pollution; and a set of EU directives addressing emissions from large combustion plants, waste incineration plants, road vehicles and ships.
3.2 Sector-specific technical evidence and its limits

As reported in the preceding chapters, important recent evidence exists from epidemiology and economics perspectives on the resulting toll on health and its value, in the form of millions of premature deaths and DALYs globally, and the trillions of dollars. In order to inform effective policy-making, detailed, documented evidence is needed on the sectoral sources of air pollution’s impacts and costs. In Europe, as elsewhere, much data are available on the sources of air pollution, including evidence on the sources of air pollutant emissions, and also, albeit less extensively, on their concentrations and on the exposure of populations thereto. In particular, the EEA continually monitors and regularly reports on trends for emissions from the main pollutants for each of the EU Member States and for the EU as a whole (see, for example, EEA, 2014).

The final report of the Clean Air for Europe (CAFE) Programme estimated the actual contribution of road transport to NO\textsubscript{x} emissions for the year 2000 baseline to be 45% – and also its potential reduction to be 30% by 2020, with a mitigation policy scenario (see Amann et al., 2005:Fig. 4.8, Fig. 4.9). Subsequently, the EEA recorded that road transport’s share of NO\textsubscript{x} emissions had fallen to 33% by 2010 (see EEA, 2012:Fig. 4.1), while adding the warning that this overall reduction had been vitiated in part by “the increased proportion of NO\textsubscript{x} emitted directly as NO\textsubscript{2} from the exhaust of more modern diesel vehicles” (see EEA, 2012:32). Rafaj, Amann & Siri (2014) later reported that road transport has disappointed expectations, owing to the higher than projected penetration of diesel.

Such research on the sectoral sources of pollutant emissions provides much useful evidence, but is not in itself an answer to the question of the sectoral sources of pollution’s impacts and costs: how many premature deaths, DALYs and dollars can be attributed to the various sectors is not yet known, and a full estimation of the sectoral shares of air pollution impacts and costs across the WHO European Region cannot be presented here, as the required evidence base is not available.

However, the evidence that does exist indicates that, across Europe, commercial, institutional and household fuel combustion, transport, industrial emissions, energy production, agriculture, and waste and solvent product use are known to be the largest contributing factors (EEA, 2013b). Establishing the relative magnitude of these sources, and analysing available remedial policy strategies and options are key ingredients for improving air quality in Europe. The rest of this report is dedicated to exploring this matter further.

3.3 Estimating the main sectoral sources of air pollution impacts and costs

As argued by the OECD, with regard to ambient PM, the available literature suggests that road transport’s share of the economic cost of premature deaths – when properly calculated – is likely to be about 50% across the EU, albeit not in each Member State (OECD, 2014).

An important turn-of-the-century study covering Austria, France and Switzerland estimated road traffic-generated air pollution to be responsible for 54% of the economic cost of air pollution’s health impacts, including the cost of both mortality and morbidity, in the three countries taken together (Sommer et al., 2000). The technical evidence on relevant developments since then – including (a) the reduction in transport-sector emissions as documented by the EEA
(EEA, 2013a) (noted in Chapter 1), (b) the partial reversal of this downward through dieselization, and (c) the general growth in the transport sector – supports the plausibility of an estimate of about 50% for the EU today.

As far as their contribution to air pollution is concerned, diesel vehicles are more harmful than petrol vehicles. In contrast to petrol vehicles, diesel vehicles have not shown significant reduction in NOx emissions since the 1990s. Exhaust emissions from such vehicles are lower for carbon monoxide, non-methane volatile organic compounds and PM, but may be substantially higher for NOx. The fraction of NOx emitted as NO2 by diesel vehicles is high – at around 25–30%, as opposed to a few percent for petrol vehicles – and has shown a variable rather than downward trend over the years (Carslaw & Rhys-Tyler, 2013; Carslaw et al., 2011). The decrease in NOx emissions (30% between 2003 and 2012) is greater than the fall in annual mean NO2 concentrations (approximately 18%). This is attributed primarily to the increase in NO2 emitted directly into the air from diesel vehicles, plus the increasing numbers of newer diesel vehicles. However, owing to tax incentives favouring diesel over petrol, the recent past has witnessed a continuing shift from petrol to diesel vehicles. Holland (2014) counts this missing consideration as one of the most important limitations of the CAPP CBA.

The most recent studies that offer estimates broken down by sector also support an estimate of about 50% responsibility (directly or indirectly) for the damage inflicted by the road transport sector in EU countries. A 2013 study from the Massachusetts Institute of Technology (MIT) (Caiazzo et al., 2013) calculates sector shares of premature deaths from air pollution across the United States (see also Chu (2013) and Dedoussi (2014) for the further development of this line of research). The breakdown is not the same as for Europe, but this is unsurprising, given the long-established higher share attributed to power generation in the United States relative to the EU, and the correspondingly lower share for road transport and other sectors.11 An earlier MIT study for the United Kingdom also supports the validity of the estimate of a share of about 50% responsibility for the road transport sector in EU countries. The study provides a range of estimates, both nominal and corrected, of premature deaths per year in the United Kingdom by fuel combustion sector, along with some estimates for London in particular (shown in Table 3.2) (Yim & Barrett, 2012).

In the discussion of these estimates, Yim and Barrett (2012) make two further caveats of relevance to this study. The first relates to modelling technology: note should be taken that that the road transport estimate in particular is likely to be an underestimate, as the peaks in roadside

### Table 3.2. Share of combustion sectors as a percentage of combustion emissions-related premature deaths in the United Kingdom and in London, 2005

<table>
<thead>
<tr>
<th>Sector</th>
<th>United Kingdom</th>
<th>London</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≈ share of premature deaths (%)</td>
<td>≈ share of premature deaths (%)</td>
</tr>
<tr>
<td>Road transport</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Other transport</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Power generation</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Other sectors</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>All sources</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Sources: extracted from Table 1 (and related discussion) presented by Yim & Barrett (2012).

11 Further discussion exists on the differences between the two sides of the Atlantic, presented by Caiazzo et al. (2013).
PM$_{2.5}$ may not be accurately represented owing to the model resolution. The second relates to toxicology: it should be taken into account that potentially significant unquantified uncertainty is the differential toxicity among PM species, and the outcome of this is that the health impact of road transport is likely to be further underestimated.

However, it is difficult to judge whether the share of approximately 50% attributed to road transport in EU Member States might also apply to the rest of WHO European Region. It is perhaps more likely that a full study encompassing the countries to the east of the EU would establish a contraction for the share contributed by road transport and a corresponding expansion of the share attributable to the sum of all others sectors identified in Table 3.2: namely, other transport, power generation and other sectors.

With regard to HAP, by definition, household fuel combustion can be assumed to account for 100% of the impact. As far as its share in the totality of premature deaths from APMP and HAP is concerned, three points are worth noting.

1. From the evidence presented in the GBD-2010 Study (IHME, 2014), as recorded in Chapter 1 (see in particular Table 1.3), HAP accounted for about 25% of the sum of the premature deaths from APMP and HAP in the WHO European Region as a whole in 2010 (164,231 out of 662,769). It accounted for around 50% of the sum, and sometimes more than 50%, in a number of WHO European Region Member States.

2. These figures likely underestimate the real share of premature deaths from APMP and HAP, partly because of less complete data collection in the areas in which HAP is predominant and partly because a default value of zero is assigned for 24 high-incomes countries for which no data on premature deaths from HAP were recorded.

3. There is some evidence to suggest that HAP has been increasing since the onset of the economic downturn in 2009 (also noted by the European Commission (EC, 2013)).

Proceeding with the available evidence-based estimate of a 25% share attributable to HAP in the sum of premature deaths from APMP and HAP in the WHO European Region and, therewith, a 25% share attributable to household fuel combustion as a sectoral source of this sum, the shares of premature deaths from air pollution attributable to the main responsible sectors (as recorded in Table 3.2: namely, other transport, power generation and other sectors).

Table 3.3. Indicative estimates of sector shares in premature deaths from air pollution in the WHO European Region, 2010

<table>
<thead>
<tr>
<th>Sector</th>
<th>(≈) Share of premature deaths from APMP (%)</th>
<th>(≈) Share of premature deaths from HAP (%)</th>
<th>(≈) Share of premature deaths from APMP + HAP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household fuel combustion</td>
<td>0</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Road transport</td>
<td>50</td>
<td>0</td>
<td>37.5</td>
</tr>
<tr>
<td>The remainder (other transport power generation, and other sectors)</td>
<td>20</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>All sources</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Sources: extracted from text and tables presented earlier in this report.
These findings suggest that in the WHO European Region road transport and household fuel combustion combined account for the majority of the impacts and costs. No other single source, such as industry, power generation, agriculture, transport (other than motorized road transport) contributes as much. It is therefore a matter for concern that there is evidence to suggest instances of recent and continuing regress rather than progress in precisely these two sectors; in one case due to increasing diesel penetration and other due to the effects of the economic downturn in relatively poorer regions (see EC, 2013). Serious reflection on the policy response to air pollution, and on how best to sharpen that response, should pay particular attention to these two sectors.

### Table 3.4. Indicative estimates of sector shares in the economic cost of premature deaths from air pollution in the WHO European Region, 2010

<table>
<thead>
<tr>
<th>Sector</th>
<th>(≈) Share of economic cost of premature deaths from APMP (%)</th>
<th>(≈) Share of economic cost of premature deaths from HAP (%)</th>
<th>(≈) Share of economic cost of premature deaths from APMP + HAP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household fuel combustion</td>
<td>0</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Road transport</td>
<td>50</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>The remainder (other transport power generation, and other sectors)</td>
<td>50</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>All sources</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Sources: extracted from text and tables presented earlier in this report.

3.4 The logical framework for correction: “pricing + investment + regulation”

A striking feature of the record of pollution abatement policies over the last several decades – whether in Europe, the United States, or elsewhere – has been its predominant reliance on regulatory interventions to impose new limits and standards across multiple sectors of the economy (see the European Commission (EC, 2013) and the United States EPA (EPA, 2011a) for summary reviews of this record).

Yet, as a general rule, economists tend to prioritize the policy of “getting prices right” in addressing the problem of externalities. In reflecting on past and future policy, this divergence merits attention. Economics holds that the general welfare is maximized when the price paid for consuming a product – each good or service, including each trip by road, rail, sea and air – is equal to the additional cost it imposes on all. However, as a result of various market imperfections, market prices can deviate sharply above or below this point; and when this happens, the gain to the winner – the producer in the former case, or the consumer in the latter – is less than the loss to the rest of society. The general welfare is thus reduced.¹²

For example, a consumer may gain by purchasing and driving a cheaper but more polluting car, but the loss to society can far outweigh that gain. Therefore, in the presence of externalities such as pollution, economists have generally

¹² The argument is spelt out and fully referenced in Roy (2008), from which this brief statement here borrows freely.
recommended a tax to raise the marginal price of the product for the user up to the marginal cost imposed by its use (or equivalent monetary incentives) and thereby “price out” welfare-reducing consumption that would otherwise be “priced in”. In moving thus from the original price to the corrected price, there is a net gain to society.

Within this framework, pricing and investment have vital, complementary roles to play. The question of pricing logically comes prior to the question of investment, as the wrong answer to the former will generate wrong answers to the latter, and quite possibly at a significant cost to the welfare of future generations. The schedule of demand that follows from the wrong set of prices is not the same as the schedule of demand that would follow from a corrected set of prices. A correction to prices is likely to alter the composition, location, scale and timing of the investment required to meet future demand.

Regulation, too, has a vital, and also complementary role to play. Economists generally recognize that there is a strong case for both initiating and maintaining regulations that pass a cost–benefit test; for example, higher mandatory standards for new vehicles. However, economists also recommend a correction of prices, for example via differentiated taxes on more polluting vehicles and fuels in order to shift consumption patterns to cleaner vehicles and fuels, until the point at which polluting cars and vehicles are retired entirely from use. At this limiting point, regulatory controls assume the role of a watching brief over a corrected market, for example to ensure that manufacturers do not reintroduce the production of polluting vehicles.

This framework, however, has important limitations, as exemplified by the CBA for the CAPP (described earlier), with a B/C ratio of 42:1. Such a disproportionate ratio is itself evidence that something has gone wrong with the system of price signals faced by consumers and producers, the schedule of demand and supply following from it, and the investment, production and sales decisions made in response to this schedule. It is only at the end of this sequence, and in consequence of it, that the outcomes can be bad enough to offer the possibility of good returns from further corrective action. Such a possibility should therefore direct the attention of policy-makers to the beginning of the sequence.

Thus described, the policy framework for correcting externalities recommended by economics can be summarized using the formula: pricing + investment + regulation. Today, however, the evidence gained from the story of air pollution and its mitigation suggests that there is a case for rethinking this framework – not so much its logical sequence as its chronology, and not in order to abandon it but to understand it anew and to apply it more effectively.

### 3.5 The evidence on the efficacy of pricing, investment and regulation

Much evidence exists to show that pricing works effectively as a policy instrument, when correctly devised and applied. Sector-specific relevant examples include the introduction of the congestion charging scheme in central London, which succeeded in sharply reducing the number of kilometres driven by vehicles and thereby reducing not only congestion but also fuel consumption and air pollution (Roy, 2014). Policies also include reductions in company-car subsidies in a few countries that have reduced the number of kilometres driven and thereby reduced the several and various attendant externalities (Le Vine & Jones, 2012).

At the same time, the evidence suggests that such examples of corrections to prices have been too limited and too localized to correct distorted prices in
fuel combustion ranks (along with road transport) as one of the two main sectoral sources of the health impact of air pollution. It is also clear, therefore, that the role of any price distortions acting to encourage the use of more polluting forms of household energy is an issue that is in need of additional focused research.

The evidence on investment is more encouraging. Fortunately, it is not the case that public and private investors have continued uninterruptedly to invest to meet the demand resulting from distorted prices. This is partly because governments – recognizing that current market prices have not been corrected – have sometimes explicitly used shadow prices in their ex ante evaluations, such as estimates for the costs of externalities that have not been corrected in the market price. This is partly because both public and private investors have sometimes assumed that the near future would bring a correction and have made their investment decisions in anticipation of it.

Finally, regulation has succeeded in reducing air pollution, especially in Europe. As evidenced in Chapter 1 (Table 1.2), the 53 Member States of the WHO European Region (taken together) did achieve a greater reduction in premature deaths from air pollution, and a greater rate of reduction, than that recorded for the 34 OECD countries (taken together) for the period under study. As noted earlier, and detailed by the European Commission (EC, 2013) and elsewhere, pollution abatement policies have relied principally on regulation.

This has not been flawless, however. The policy failure with regard to diesel has been a failure of regulation as well as a failure in terms of pricing, since the compliance regime has failed to prevent a significance divergence between the test cycle performance, which secures regulatory approval, and the actual on-road performance of the approved vehicles. As the European Commission describes it (EC, 2013:24):

[T]he problem is due in part to the poor

One of the adjustments to prices in this sector, intending to respond to the problem of climate change, was the tax differential in favour of diesel, which actually worsened the problem of air pollution (Upton, 2013; Harding, 2014), as it increased the diesel-vehicle share of the total vehicle market. The European Commission’s review of current policy also emphasizes this point, stating that “[T]he consequences of the less than hoped for effects of the vehicle standards relating to diesel passenger cars and light-duty vehicles have been exacerbated by national taxation policies favouring diesels” (EC, 2013:25).

Moreover, another misconceived response to the problem of climate change may have served to distort prices in such a way as to worsen the problem of air pollution. With regard to household fuel combustion, the European Commission’s review notes: “[T]he problem is not only continuing coal use, but also increase in biomass use, driven partly by renewables policy” (EC, 2013:32).

As is clear from Table 3.3 above, for the WHO European Region household
representativeness of the standardised test cycle used for type approval in the EU ... and the weakness of in-service conformity testing. Under the current regime an engine type has to meet the type-approval requirements when tested according to the test cycle, but under normal driving conditions the real emissions can be much higher.

The result is that “while the NOx emission limit values for diesel passenger cars have been tightened by approximately a factor of 4 from 1993 to 2009 (Euro 1 to Euro 5), the estimated average NOx emissions in real driving conditions have slightly increased” (EC, 2013:24). Clearly, this is mainly a matter of regulation and not of pricing; however, the tax differential in favour of diesel has added to the problem, leading consumers to shift from petrol to diesel vehicles.

In any case, the record of regulation in this field – including both its successes and failures – is positive. Thus, it seems reasonable to conclude that the instances of failure are arguments for refining and strengthening the scope for stringent regulation, rather than arguments for weakening it.

3.6 The chronological framework for correction: “regulation + investment + pricing”

The evidence on the actual record of pollution abatement policy and the various instruments used to date does not falsify the theoretical proposition that the general welfare is maximized when prices are equal to marginal costs, nor the recommendation that they should be equalized. Nor does this evidence undermine the priority accorded to pricing in the logical sequence described earlier: it remains true that both investments and regulations are necessarily obliged to act on a schedule of demand and supply that is itself shaped by the schedule of prices, whether it is right or wrong.

However, the chronological sequence is another matter. Suppose the evidence noted above to be not simply a case of human error but the result of intractable time lags in developing and implementing tax reform, and/or information gaps which also impose critical time lags, and further suppose that the problem does not apply in the same way or to the same degree in the case of regulation.

For example, mandatory vehicle standards have been in place for long enough to have become a fact of life: the relevant actors expect them to be maintained and tightened over time (even if some attempt elaborate ways of evading the effects of the tighter limits). However, national road pricing, for example, is not in place: it is not a matter of adjusting the actual prices in the light of new information, but of bringing the scheme into effect against the force of inertia.

Moreover, the information requirements are not the same: witness the incompleteness of the evidence base on the sector sources of air pollution. The information gaps here are not necessarily critical to the design of regulation (even if they impact on the precision of the CBAs). For example, setting and enforcing a more rigorous compliance regime and with tighter standards for new diesel vehicles does not need to wait for the determination of the precise contribution of diesel vehicles to marginal costs: it is sufficient to know that standards need to be tightened further. Setting and implementing a full schedule of corrected prices through purchase taxes, fuel taxes and road-user charges, however, does require a greater degree of precision in knowledge. In short, if Europe is to act on the problem immediately and continuously, rather than at a designated date in the future, it needs to begin at the place in which it finds itself today, rather than waiting for future information.

A relatively successful, albeit imperfect regulatory regime on air quality in Europe, and a relatively good knowledge of its own points of weakness have resulted
in substantial progress in terms of health impacts and costs, even in the absence of a price system capable of taking full account of externalities. In view of the persistence of the problem of air pollution in Europe, however, correcting distortions in taxes and subsidies remains highly desirable.

To pursue this goal, operating in the anticipated period of time until a full correction of prices can be achieved, there is a case for conceiving the chronological framework of correction following the approach: regulation + investment + pricing, as set out in the list below.

- First, maintain and strengthen existing and planned regulatory controls on air pollution and the associated compliance regimes, refining these as required.
- Next, develop and extend guidance on using shadow prices in relevant investment decisions – a procedure which does not require the same level of precision as the setting of actual prices.
- Then, over a period of years, close the information gaps required to prepare a model of fully corrected prices, and pursue full implementation.

Throughout this period, adjust the uncorrected prices as the requisite information becomes available – beginning immediately, with the undoing of those changes that are known to have acted in the wrong direction, such as any tax preferences given to diesel over petrol.

Recalling the evidence on the sectoral sources of air pollution's impacts and costs in the WHO European Region, the chronological framework suggested above can provide some practical guidance on where and how the policy response to the problem could be strengthened.

Assuming implementation of the measures proposed in the EU impact assessment policy, with the geographical scope covering the whole of the WHO European Region rather than the EU alone (but with the technical scope restricted to impacts on public health rather than the full range of environmental impacts), the implications for additional policy action that follow from the analysis are shown in Table 3.5.

### Table 3.5. Implications for additional policy action regarding the main sectoral sources of air pollution in the WHO European Region, 2010

<table>
<thead>
<tr>
<th>Sector</th>
<th>Additional policy action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household fuel combustion</td>
<td>CAPP +&lt;br&gt;  • focused research effort and, as necessary:&lt;br&gt;  • removal of subsidies for polluting fuels&lt;br&gt;  • appropriate guidance on investment in substitutes&lt;br&gt;  • a longer term correction to relevant prices</td>
</tr>
<tr>
<td>Road transport</td>
<td>CAPP +&lt;br&gt;  • a more rigorous compliance regime&lt;br&gt;  • removal of tax advantage for diesel&lt;br&gt;  • appropriate guidance on investment in substitutes&lt;br&gt;  • a longer term correction to relevant prices</td>
</tr>
<tr>
<td>The remainder (other transport power generation, and other sectors)</td>
<td>CAPP +&lt;br&gt;  • continued research and monitoring and, as necessary:&lt;br&gt;  • new regulatory/investment/pricing options</td>
</tr>
</tbody>
</table>

Sources: extracted from text and tables presented earlier in this report.
Nothing in the chronological framework proposed in this section relieves the urgency of the fact that prices need to be fully corrected in order to maximize the general welfare. The case for pricing reform, hitherto pursued with limited success, must continue to be pursued. Information gaps will need to be closed and new models will need to be developed. Interdisciplinary work and cross-sectoral action are needed to allow evidence and expertise to support the existing process of reform in terms of regulation and investment decision-making.


References


The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

Member States

Albania
Andorra
Armenia
Austria
Azerbaijan
Belarus
Belgium
Bosnia and Herzegovina
Bulgaria
Croatia
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Georgia
Germany
Greece
Hungary
Iceland
Ireland
Israel
Italy
Kazakhstan
Kyrgyzstan
Latvia
Lithuania
Luxembourg
Malta
Monaco
Montenegro
Netherlands
Norway
Poland
Portugal
Republic of Moldova
Romania
Russian Federation
San Marino
Serbia
Slovakia
Slovenia
Spain
Sweden
Switzerland
Tajikistan
The former Yugoslav Republic of Macedonia
Turkey
Turkmenistan
Ukraine
United Kingdom
Uzbekistan
The harbour porpoise is the smallest cetacean to occur in UK waters, never reaching more than 2m in length. It has a dark grey back and is paler below. It has a robust body and a small, round head with no beak. The dorsal fin is small, triangular and centrally placed on the back. Porpoises are usually sighted alone or in very small groups. They are undemonstrative, travel slowly and rarely approach boats.

1. CURRENT STATUS

National Status

- The harbour porpoise is predominantly a coastal species, favouring shallow waters over the continental shelf. It is limited to the cold temperate and subarctic waters of the Northern Hemisphere. In the eastern North Atlantic it ranges from Iceland south to the coasts of Senegal, including the North Sea, the Baltic Sea and the western Mediterranean.

- There is some evidence of a decline in the numbers of harbour porpoise in the UK since the 1940s. However, generally the conservation status around the UK is poorly known. The SCANS (Small Cetacean Abundance in the North Sea and adjacent waters) surveys, coordinated by the Sea Mammal Research Unit (SMRU) in July 1994, provided the first population estimates of harbour porpoises and other small cetaceans around the UK, including the North Sea. The surveys estimated a total harbour porpoise population in the North Sea, English Channel and Celtic Sea of approximately 340,000 (Hammond et al. 1995). An estimate of abundance in the eastern sector of the North Sea between the North Norfolk coast and the north-east coast of Scotland was 16,900 animals (Hammond et al. 2002). In the 1994 SCANS survey no porpoises were recorded in the North Sea south of the Wash. The SCANS surveys were repeated in July 2005 and preliminary results have shown an increase in the density of porpoises in the southern North Sea, including the Norfolk sector (Macleod et al 2006).

- The harbour porpoise is listed on Appendix II of the Bern Convention and Annexes II and IV of the EU Habitats Directive. It is on Appendix 2 of the Bonn Convention and is covered by the Agreement on the conservation of small cetaceans in the Baltic and North Seas (ASCOBANS), a regional agreement of the Bonn Convention. It is protected under schedule 5 of the Wildlife and Countryside Act 1981 (As amended by the Countryside and Rights of Way Act 2000). No SACs have currently been designated for this species.

Norfolk Status

- Found off the Norfolk coast. The local status is poorly known, but anecdotal sighting records and stranding data indicates that harbour porpoises were previously more common in Norfolk waters and that the population declined during the middle part of the twentieth century (Seago 1992, 1997). However, in the last decade, there has been an increase in sightings and strandings along the entire Norfolk coast, with a peak in records during the winter and early spring (Jan-April).
• Similar increases have been noted in neighbouring Dutch waters. Porpoises were virtually extinct in Dutch coastal waters in the early 1960s, but systematic annual land-based and at-sea surveys carried out since 1970 have shown significant increases in sightings and strandings since the mid-1980s, with a marked increase in records over the last 15 years (Camphuysen 2004).

2. CURRENT FACTORS IN NORFOLK CAUSING LOSS OR DECLINE

There are several factors affecting the status of this species:

• **Bycatch:** Accidental capture in fishing nets is considered to be a major threat to this species around the UK (UK BAP). Harbour porpoises are particularly vulnerable to bottom-set gillnets because they tend to feed at, or close-to, the seabed. During the early 1990s, it was estimated that 7,000 harbour porpoises were caught annually in the Danish North Sea gillnet fishery, and 1,000 in the UK gillnet fishery. The latter figures represent more than 2% of the total porpoise population in the central and southern North Sea. According to the International Whaling Commission and ASCOBANS, continued bycatch at this rate is likely to be unsustainable.

• **Environmental contaminants (toxic substances at sea, marine debris, disease and noise disturbance):** Contamination of the marine environment by anthropogenic input has increased dramatically over the last 50 years. Many of the contaminants which give the greatest cause for concern (e.g. PCBs) are relatively poorly metabolised or excreted by animals. As predators at the top of the food chain, harbour porpoises are very susceptible to the build-up of such contaminants.

• **Environmental change (effects of fishing and possibly climate change):** In UK waters, Evans (1990) has suggested that the decline in porpoise numbers during the latter part of the 20th century was due to the depletion of herring stocks. It has also been suggested that the decline in harbour porpoise strandings along the Dutch coast may have been caused by changes in the herring stocks through overfishing, particularly in the mid-1960s (Smeenk & Addink 1990). The increase in the North Sea herring stock in recent years may be one of the reasons for an increase in sightings of harbour porpoises in the south-eastern North Sea (Camphuysen 1994).

• **Disturbance:** Disturbance from boat traffic is thought to be increasing, as boat-based leisure activities become more popular. Porpoises are prone to disturbance of two principal types: 1) Physical disturbance: Vessels cause disturbance, and fast craft can potentially cause physical injury through collisions; 2) Noise disturbance: Noise travels far underwater, and noise from boat engines and echosounders may cause disturbance to porpoise activities or mask porpoise echolocation. In the long-term, areas of high boat traffic may be avoided by porpoises, potentially excluding them from important feeding or calving areas.

Offshore windfarms may potentially impact on populations of harbour porpoises and other cetaceans. The precise impact of offshore windfarms on harbour porpoises is currently not fully understood. Impact may be positive, creating artificial reefs around the moorings, which could increase fish abundance; or negative, with displacement of prey species or porpoises themselves due to disturbance. This disturbance may be acoustic if there is transmission of sound or vibrations from the rotating blades into the water.

3. CURRENT ACTION IN NORFOLK

• Post mortems and tissue studies are carried out by the Natural History Museum (London) on stranded specimens to establish the cause of death and condition of the animals at the time of death.
4. ACTION PLAN OBJECTIVES AND TARGETS

National
• Maintain the current geographical range of the harbour porpoise.
• Maintain the current abundance of the harbour porpoise.
• In the long-term, ensure that no anthropogenic factors inhibit a return to waters that it previously occupied.

Norfolk
• Ensure that the local populations of harbour porpoise are maintained and enhanced.
<table>
<thead>
<tr>
<th>NATIONAL ACTION</th>
<th>NORFOLK ACTION</th>
<th>ACTION BY:</th>
<th>PARTNERS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Policy and Legislation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1.1 Extend the ASCOBANS boundary to include the Western Approaches and the Irish Sea through a bilateral treaty with the Republic of Ireland and agreement of ASCOBANS Parties.</td>
<td>No action proposed.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1.2 Seek to improve coastal water quality by reducing the discharge of substances which are toxic, persistent and liable to bioaccumulate, giving priority to phasing out PCBs, and reducing discharges of organohalogens to safe levels.</td>
<td>Seek to improve coastal water quality where discharges of these substances are present in Norfolk.</td>
<td>EA</td>
<td></td>
</tr>
<tr>
<td>5.1.3 Continue the duty on sea fisheries regulators to take account of wider impacts on wildlife and habitats (in addition to target species) when deciding fishery management measures.</td>
<td>Assess the impact of fisheries management on harbour porpoise, in keeping with the duty to take account of wider impacts on wildlife and habitats.</td>
<td>ESFJC, DEFRA</td>
<td>NE, SMRU</td>
</tr>
<tr>
<td>5.1.4 Consider in the light of research at 3.2, the possible need to monitor and control gill nets and other set net fisheries.</td>
<td>Assess the need to monitor and control bottom-set gill nets and other set net fisheries.</td>
<td>ESFJC, DEFRA</td>
<td>SFCs, Cefas</td>
</tr>
<tr>
<td>5.1.5 Continue to introduce agreed codes of conduct to reduce disturbance from acoustic sources and physical pressures.</td>
<td>Assist with the introduction of codes of conduct as and when these become available.</td>
<td></td>
<td>LAs, Coastal BAP Group</td>
</tr>
<tr>
<td>NATIONAL ACTION</td>
<td>NORFOLK ACTION</td>
<td>ACTION BY:</td>
<td>PARTNERS:</td>
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</tr>
<tr>
<td>5.2</td>
<td>Site Safeguard and Management</td>
<td>No action proposed.</td>
<td></td>
</tr>
<tr>
<td>5.2.1</td>
<td>Review existing UK marine site protection to determine how it might be improved. If appropriate, introduce additional protection and emergency designation to benefit the species.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3</td>
<td>Species Management and Protection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3.1</td>
<td>Work with fishers with the aim of reducing and avoiding by-catches in active and passive gear, and to dispose of discarded gear safely.</td>
<td>Advise fisheries managers and fishermen on best practice.</td>
<td>ESFJC, DEFRA</td>
</tr>
<tr>
<td>5.3.2</td>
<td>Introduce codes of practice to reduce disturbance from whale-watching.</td>
<td>Encourage the development of codes of practice for ports, harbours and staithes that safeguard marine animals from sea-based recreational activities.</td>
<td>NE, LAs, Wash &amp; North Norfolk SAC, Harbour Authorities</td>
</tr>
<tr>
<td>5.4</td>
<td>Advisory</td>
<td>No action proposed.</td>
<td>No action proposed.</td>
</tr>
<tr>
<td>5.5</td>
<td>Future Research and Monitoring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.5.1</td>
<td>Expand research on the areas frequented by harbour porpoise to identify waters which may qualify for further protection as SACs or Marine Nature Reserves.</td>
<td>Carry out further surveys to assess distribution of porpoises.</td>
<td>ESFJC, Coastal BAP Group, NNNS</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Establish long-term research on population and conservation needs of all small cetaceans in UK waters, co-ordinated through ASCOBANS.</td>
<td>Produce and distribute a sightings card and set up a recording network to report all sightings. ESFJC to assist with distribution of sighting cards and collation of records from SFC staff.</td>
<td>Coastal BAP Group, ESFJC, NNNS</td>
</tr>
</tbody>
</table>
### 5.5.3 Subject to the results of the research at 3.2, consider monitoring of UK populations and reporting of by-catches of small cetaceans (including observers on vessels, where feasible).

**NORFOLK ACTION:** Produce and distribute a sightings card. Monitor local populations and set up procedures to report bycatches of small cetaceans. ESFJC to assist with distribution of sighting cards to Fishery Officers and collation of records from SFC staff.

**ACTION BY:** Coastal BAP Group, ESFJC, SFCs, DEFRA, JNCC, SMRU, Cefas

**PARTNERS:**

### 5.5.4 Seek to minimise the by-catch of small cetaceans by promoting research into fishing gear and other possible mechanisms.

**NORFOLK ACTION:** Disseminate information about improved fishing gear and other mechanisms for reducing bycatch.

**ACTION BY:** ESFJC, DEFRA

**PARTNERS:** Seafish, SFCs, Cefas

### 5.5.5 Promote research into the causes of death of the harbour porpoise within UK waters to determine the context and need for future conservation action.

**NORFOLK ACTION:** Disseminate information about causes of harbour porpoise deaths.

**ACTION BY:** ESFJC, DEFRA

**PARTNERS:** Cefas

### 5.5.6 Pass information gathered during survey and monitoring of this species to JNCC or BRC in order that it can be incorporated in a national database and contribute to the maintenance of an up-to-date Red List.

**NORFOLK ACTION:** Pass survey and monitoring data to NBRC and JNCC.

**ACTION BY:** ESFJC, Coastal BAP Group, NNNS

**PARTNERS:** Cefas

### 5.6 Communications and Publicity

#### 5.6.1 Subject to the results of research at 3.2, consider the need to encourage fishermen to report sightings and by-catches through an awareness programme.

**NORFOLK ACTION:** Launch an awareness programme in Norfolk to encourage reporting of sightings by fishermen, recreational sailors and the bird watching community.

**ACTION BY:** Coastal BAP Group, NNNS, DEFRA

**PARTNERS:** LAs, fishermen, recreational sailors, birdwatchers
## Harbour Porpoise - Norfolk Action Plan

<table>
<thead>
<tr>
<th>NATIONAL ACTION</th>
<th>NORFOLK ACTION</th>
<th>ACTION BY:</th>
<th>PARTNERS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.6.2</td>
<td>Encourage international exchange of information to assess and, if appropriate, reduce by-catches.</td>
<td>Encourage exchange of information and datasets between Norfolk and other North Sea research groups.</td>
<td>ESFJC, Coastal BAP Group</td>
</tr>
<tr>
<td>5.6.3</td>
<td>Continue to publicise reporting schemes for strandings and live sightings.</td>
<td>Publicise local reporting schemes for strandings and live sightings.</td>
<td>NE, NNNS, Coastal Topic Group</td>
</tr>
</tbody>
</table>

### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>Cefas</td>
<td>Centre for Environment, Fisheries and Aquaculture Science</td>
</tr>
<tr>
<td>DEFRA</td>
<td>Department of Environment, Food and Rural Affairs</td>
</tr>
<tr>
<td>EA</td>
<td>Environment Agency</td>
</tr>
<tr>
<td>ESFJC</td>
<td>Eastern Sea Fisheries Joint Committee</td>
</tr>
<tr>
<td>JNCC</td>
<td>Joint Nature Conservation Committee</td>
</tr>
<tr>
<td>LAs</td>
<td>Local Authorities</td>
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<tr>
<td>NBRC</td>
<td>Norfolk Biological Records Centre</td>
</tr>
<tr>
<td>NE</td>
<td>Natural England</td>
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<tr>
<td>NHM</td>
<td>Natural History Museum</td>
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<tr>
<td>NNNS</td>
<td>Norfolk and Norwich Naturalists' Society</td>
</tr>
<tr>
<td>SAC</td>
<td>Special Area of Conservation</td>
</tr>
<tr>
<td>Seafish</td>
<td>The Sea Fish Industry Authority</td>
</tr>
<tr>
<td>SFC</td>
<td>Sea Fisheries Committee</td>
</tr>
<tr>
<td>SMRU</td>
<td>Sea Mammal Research Unit</td>
</tr>
</tbody>
</table>
REFERENCES


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Sea Mammal Research Unit  
Gatty Marine Laboratory  
University of St Andrews  
ST ANDREWS  
Fife  
KY16 8LB

Telephone:  01334-462630  
Website:  http://smub.st-and.ac.uk/

Natural History Museum (UK Whale and Dolphin Stranding Scheme)  
Cromwell Road  
LONDON  
SW7 5BD

Telephone:  020-79425000  
Website:  http://www.nhm.ac.uk/nature-online/life/mammals/science-whalestrandings/

Centre for Environment, Fisheries and Aquaculture Science (Cefas)  
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Telephone:  01502-562244  
Website:  http://www.cefas.co.uk/
Setting out with real porpoise

Lynn ferry operators Steve and Gail Kingston have shared this picture of what is believed to be a porpoise swimming in the Great Ouse. The couple received the picture from a friend, who took it from the boardwalk at West Lynn over the last few weeks.