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Air Quality Appraisal – Damage Cost Methodology

Interdepartmental Group on Costs and Benefits,

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Damage costs are one way of approximating the impacts of changes in air pollution. These values measure the marginal external costs caused by each additional tonne of pollutant emitted – or conversely the benefits of reducing a pollutant emitted by one tonne, and can be used to value the benefits of air quality impacts of certain policies or projects when the only information available is the amount (in tonnes) of pollutant that is reduced.
Given that the full air quality modelling process is quite resource and time intensive, and that sometimes it is not possible to carry out concentration modelling of air pollutants, damage costs have been developed as a simpler methodology that approximates the value of air quality changes by applying average values for the benefit of reducing a pollutant emitted by one tonne.
The use of damage costs is not, however, considered a replacement for detailed modelling and analysis. They are therefore only recommended for use with policies where cost-benefit analysis is considered over a period of less than 20 years and:

- as part of a filtering mechanism to narrow down a wide range of policy options into a smaller number that are then taken forward for more comprehensive assessment; or

- where air quality impacts are expected to be ancillary to the primary objectives or are relatively small.

There are a number of potential applications for the use of damage costs values across central government, such as project appraisals (project cost-benefit analysis) and Regulatory Impact Assessments (policy cost-benefit analysis). Further guidance on when to apply damage costs can be sought from Defra economists and contact details are provided at the end of this paper.
The methodology presented in this guidance on applying damage costs to air pollution impacts is outlined briefly below. It involves:

- Identifying and quantifying the reduction in emissions;

- Identifying the correct damage cost value to use;

- Converting damage costs to base year prices and applying uplift;

- Calculating benefits for each year;

- Discounting the benefits and calculating the present value; and

- Considering sensitivity analysis and qualitative assessments.

The main section of this paper provides a full description of damage costs and the methodology used. Annex 1 outlines the values needed for sensitivity analysis and Annex 2 provides quantified impacts (per tonne) for the relevant health impacts. A glossary is also provided at the end of this paper.

The methodology paper is intended to provide a consistent set of values for the analysis of air quality impacts and builds on the recent economic analysis report by the Interdepartmental Group on Costs and Benefits (IGCB), which accompanied and informed the Air Quality Strategy review consultation in 2006[1].

In addition to this methodology paper, the following resources are available and are also published on the IGCB website[2]:

- Step-by-step guidance, which details how to apply these damage costs.

- A Damage Cost Calculator, which provides a useful tool to help carry out the necessary calculations set out in the step-by-step guidance.

- A Q&A paper, providing further background and answers to frequently asked question

What the damage costs include

Air pollution has a number of important impacts on human health, as well as on the natural and built environments. The damage costs presented in this guidance paper include values for the impacts of exposure to air pollution on health – both chronic mortality effects (which consider the loss of life years due to air pollution)[3] and morbidity effects (which consider changes in the number of hospital admissions for respiratory or cardiovascular illness) – in addition to damage to buildings (through building soiling) and impacts on materials.

These are based on values for a range of health impacts and non-health impacts which were agreed following recommendations by the IGCB in 2005. A full methodology for damage costs was also agreed and published alongside the Third Report in 2006.[4]
Damage cost values are presented separately for three key pollutants:

- Particulate matter (PM_{10})

- Oxides of nitrogen (NO_X)

- Sulphur dioxide (SO_2)

- Ammonia (NH_3)

Table 1 below summarises the impacts included in the damage cost values for each of these three pollutants. A more detailed discussion of the additional effects not included in these values can be found in the caveats section later in the guidance. In addition, for those wishing to present quantified health impacts (e.g. the number of life years lost) alongside the monetised air quality benefit.

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[1] *http://ww2.defra.gov.uk/environment/quality/air/air-quality/economic/*
[2] *http://ww2.defra.gov.uk/environment/quality/air/air-quality/economic/*
[3] Although the annual pulse damage costs values (presented later in the document) represent a change in pollution, by one tonne, for one year, the chronic mortality impacts are followed up for 100 years to capture the more long term effect on health of the pollution change. The damage costs therefore include this 'follow-up' in the values provided.
[4] *http://ww2.defra.gov.uk/environment/quality/air/air-quality/economic/*

Annex 2 sets out figures for health impacts per tonne for each of the health impacts discussed in the table below.

Table 1 – Summary of impacts included in damage costs

	Chronic mortality effects	Morbidity effects (hospital admissions)	Building soiling	Impact on materials
PM_{10}	✓	✓	✓	
NO_X	✓	✓		
SO_2	✓	✓		✓
NH_3	✓	✓		

- For PM10, the damage cost includes the health impacts of particulate matter (both mortality impacts and morbidity impacts) in addition to the impact of building soiling by PM emissions. This does not include the impacts of secondary particulate matter.

- For NOX, the damage cost includes the health impacts of secondary particulate matter (as the emission of NOX causes the formation of nitrates, which are classed as particulate matter). The damage cost does not, however, include the health impacts of ozone formation as a result of the emission of NOX.

- For SO2, the damage cost includes the health impacts of secondary particulate matter (as the emission of SO2 causes the formation of sulphates, which are classed as particulate matter) but also includes the direct health impacts of SO2 as a gas. In addition the damage cost also includes the impact of SO2 on materials (e.g. through acid corrosion of stone and metals).

- For NH3 damage cost includes the health impacts of secondary particulate matter (as the emission of NH3 causes the formation of ammonia nitrate, which are classed as particulate matter).

PM10, NOX, SO2, and NH3 are four of the nine pollutants covered by the Air Quality Strategy. The remaining pollutants – such as carbon monoxide, lead and polycyclic aromatic hydrocarbons (PAHs) – have not been valued using the damage cost methodology and instead their impacts should be subject to a qualitative assessment.

Damage costs for PM10 are also provided for different sectors to reflect the larger differences in emissions between the different sectors in question. Values have been provided for the following sectors:

- Electricity supplies industries (ESI)

- Domestic

- Agriculture
- Industrial
- Waste
- Road transport (also split by National Transport Model area)

The external costs of air pollution vary according to a variety of environmental factors, including overall levels of pollution, geographic location of emission sources, height of emission source, local and regional population density, meteorology and so on. These numbers take these issues into account to a certain degree only and should therefore be considered when presenting valued air quality impacts. A fuller list of caveats and uncertainty surrounding damage costs is discussed later in this guidance paper.

Damage costs to include in appraisals
Damage costs are only suitable to use in certain circumstances. For other instances the full impact-pathway approach may be more appropriate to use.

At present damage costs are recommended for use in policy analysis where cost-benefit analysis is appraising the policy over a period of 20 years or less and either:

- the policy does not have air quality improvements as its main objectives; or
- scoping analysis is being carried out to help filter potential policy options at the initial stage of the process.

A decision tree[5] is available on the IGCB website to help guide you decide which is the appropriate approach to valuing air quality for your application. If the damage cost approach is not recommended for your policy please contact Environment Policy Economics division in Defra (contact details below) who can advise on how best to assess the air quality impacts generated by your policy.

Table 2 below sets out the damage cost values that should be used as estimates for the annual pulse approach.[6] These values are per tonne of pollutant (reduced) in 2005 prices, split out by pollutant type and by sector, for PM.

A template spreadsheet is also available and is intended to provide a user-friendly method of carrying out the necessary calculations link to damage cost calculator. There is also a separate step by step guidance available at link to damage cost guidance

The damage costs are dominated by chronic mortality health impacts and are based on a 6% per 10µg.m-3 PM2.5 change in hazard rate recommended by Department of Health's Committee on the Medical Effects of Air Pollutants

[5] *http://ww2.defra.gov.uk/environment/quality/air/air-quality/economic/*
[6] The annual pulse approach refers to the impact of a one year change in emissions.

(COMEAP) in its recent interim statement.[7] This percentage change in hazard rate describes the relationship between a change in a particular pollutant (e.g. PM2.5) and a change in the age-specific mortality rate, which, in turn, leads to changes in life expectancy.

The damage costs are also presented as a 'low' and 'high' value given uncertainty surrounding the potential time lag between a change in air quality (PM10) and impact on health. The range presented in Table 2 below assumes a 40-year lag (low value) and a 0-year lag (high value).[8] Although the evidence is limited, the recent expert judgement from COMEAP tends towards a greater proportion of the effect occurring in the years soon after a pollution reduction rather than later. This suggests that more weight should be given to the high end (0-year lag) of the damage costs range shown below.

Table 2 – Damage cost values (by pollutant and sector)

Values in £ per tonne (2008 prices)	Annual Pulse Damage Costs		
	Low	High	Central
PM (Transport)[9]	34,753	50,439	44,430
• Central London	158,820	230,508	203,048
• Inner London	163,338	237,065	208,824
• Outer London	106,691	154,849	136,402
• Inner conurbation	84,449	122,568	107,967
• Outer conurbation	52,478	76,163	67,090
• Urban big	62,555	91,791	79,975
• Urban large	50,391	73,137	64,424
• Urban medium	39,618	57,501	50,651
• Urban small	25,022	38,316	31,990
• Rural	10,733	15,636	13,773
PM (ESI)	1,738	2,522	2,222
PM (Domestic)	20,157	29,255	25,770
PM (Agriculture)	6,951	10,088	8,886
PM (Waste)	14,944	21,689	19,105
PM (Industrial)	19,071	26,228	23,103
NOx	681	993	875
SO_2	1,208	1,698	1,496
NH_3	1,407	2,050	1,884
SPC	22	29	24

[7] Interim Statement on the Quantification of the Effects of Air Pollutants on Health in the UK', *Committee on the Medical Effects of Air Pollutants*, Department of Health (2006). Available at http://www.advisorybodies.doh.gov.uk/comeap/pdfs/interimlongtermeffects2006.pdf

[8] As discussed previously chronic mortality impacts are followed up for 100 years to capture the more long term effect on health of the pollution change.

[9] Damage costs for PM (transport) are at a UK-wide level, with disaggregated damage costs presented below split by current National Transport Model area. For further information on the breakdown of National Transport Model and populations covered by each sub-area, to help determine which area is most appropriate to use, please visit http://www.dft.gov.uk/stellent/groups/dft_econappr/documents/divisionhomepage/030708.hcsp.

The Damage Cost Guidance[10] provides a worked example showing the step-by-step methodology on how to apply these values correctly. This takes into account the need to:

- Recalculate damage costs in the baseline year prices of the appraisal period (by converting values using an assumed inflation rate of 2.5%)

- For each subsequent year, uplift the damage cost values by 2% per annum. This reflects the assumption that willingness to pay will rise in line with economic growth

- Discount future values at a rate of 3.5% per year (declining after the first 30 years) as set out in the Treasury's Green Book.

All three calculations are based on assumptions consistent with IGCB analysis about the uplift, inflation and discount rate, and are explained in detail in the worked example in the Air Quality Damage Cost Guidance[11].

The accompanying Q&A paper[12] also sets out answers to key questions on how to use damage costs correctly and indicates what information you need to undertake a valuation. The caveats and uncertainties in applying damage costs also need to considered and are presented in the section below.

Caveats

In applying damage costs to value air quality impacts it is important to consider that external costs of air pollution vary according to a variety of environmental factors, including overall levels of pollution, geographic location of emission sources, and meteorology. These numbers take these issues into account to a certain degree only.

Furthermore, the damage costs presented in this paper exclude several key effects as quantification and valuation is not possible or is highly uncertain. These are listed below and should be highlighted when presenting valuation results where appropriate.

The key effects that have not been included are:

- Effects on ecosystems (through acidification, eutrophication, etc);

- Impacts of trans-boundary pollution;

- Effects on cultural or historic buildings from air pollution;

- Potential additional morbidity from acute exposure to PM;

- Potential mortality effects in children from acute exposure to PM;

- Potential morbidity effects from chronic (long-term) exposure to PM or other pollutants;

[10] *http://ww2.defra.gov.uk/environment/quality/air/air-quality/economic/*
[11] *http://ww2.defra.gov.uk/environment/quality/air/air-quality/economic/*
[12] *http://ww2.defra.gov.uk/environment/quality/air/air-quality/economic/*

- Effects of exposure to ozone, including both health impacts and effects on materials;

- Change in visibility (visual range);

- Macroeconomic effects of reduced crop yield and damage to building materials; and

- Non-ozone effects on agriculture.

Damage costs are based on the methodology set out in the updated Third Report of IGCB in 2007 although this guidance provides updated damage cost values to those presented in Annex 3 of the report.[13] These damage costs are updated periodically following the new advice from COMEAP.

Where to obtain further guidance and advice
For further advice or help in applying these values to a policy appraisal please contact the Interdepartmental Group on Costs and Benefits, Air Quality subgroup:

Email: *igcb@defra.gsi.gov.uk*

[13] See Annex 3 of 'An economic analysis to inform the Air Quality Strategy review consultation', Defra (2006). Available at *http://www.defra.gov.uk/environment/airquality/publications/stratreview-analysis/index.htm*

ANNEX 1 – Sensitivity analysis

In light of the uncertainties surrounding the damage costs derived for air pollution impact valuation, policy/project appraisals should include a sensitivity analysis as recommended by the Treasury Green Book.[14] This will help show how vulnerable results are to key uncertainties in the damage cost values used.

The table below sets out the values that should be used to carry out sensitivity analysis in policy appraisal. These should be applied using the same method set out in Steps 3 – 6 of the worked example in Annex 1. The Excel template will automatically calculate your sensitivity results when calculating the central estimate (as outlined in Annex 1). These can be found in the cell directly below where the main results are shown.

You should present the results of your sensitivity analysis alongside the main results of the damage cost analysis, in particular noting if the 'low' or 'high' sensitivity result causes your overall analysis to 'switch' (e.g. – using the low sensitivity value as the value of air quality impacts in your cost-benefit analysis causes your analysis to no longer be cost-beneficial).

Values in £ per tonne (2008 prices)	Annual Pulse sensitivities	
	Low	High
PM (Transport)[15]	9,054	114,479
• Central London	41,378	523,168
• Inner London	42,555	538,050
• Outer London	27,796	351,450
• Inner conurbation	22,002	278,183
• Outer conurbation	13,672	172,863
• Urban big	16,298	206,062
• Urban large	13,129	165,994
• Urban medium	10,322	130,506
• Urban small	6,519	82,425
• Rural	2,807	35,488
PM (ESI)	453	5,724
PM (Domestic)	2,775	72,393
PM (Agriculture)	957	24,963
PM (Waste)	2,057	53,671
PM (Industrial)	2,488	64,904
NOx	287	4,545
SO_2	706	6,939

The sensitivities considered in this analysis are dominated by sensitivities around the chronic mortality effects of particles: the size of the mortality

[14] 'The Green Book: Appraisal and Evaluation in Central Government', HM Treasury (2003). Available at http://greenbook.hm-treasury.gov.uk

[15] Damage costs for PM (transport) are at a UK-wide level, with disaggregated damage costs presented below split by current National Transport Model area. For further information on the breakdown of National Transport Model and populations covered by each sub-area, to help determine which area is most appropriate to use, please visit http://www.dft.gov.uk/stellent/groups/dft_econappr/documents/divisionhomepage/030708.hcsp.

effects (based on the COMEAP recommendation[16] of 2% - 11% hazard rate reduction as an appropriate sensitivity range around the 6% reduction used for the main results) and the value used in monetising them. Other sensitivities are also considered, such as the values used in monetising morbidity impacts (hospital admissions for respiratory or cardiovascular disease), but only have a small impact on the overall values.

It is important to note that these are only sensitivities for the damage cost values – further sensitivities may need to be carried out depending on the nature of your policy (e.g. for modelling of emissions).

Sensitivity values are presented as “low” and “high” results incorporating the sensitivities outlined above. These low/high values should not be confused with those presented in the main section of the paper, which only aim to capture the uncertainty surrounding when the health effect of air pollution will occur

[16] ‘Interim Statement on the Quantification of the Effects of Air Pollutants on Health in the UK’, *Committee on the Medical Effects of Air Pollutants*, Department of Health (2006). Available at http://www.advisorybodies.doh.gov.uk/comeap/pdfs/interimlongtermeffects2006.pdf

ANNEX 2 – Health impacts

The effects on health of air pollution changes can also be presented as quantified health impacts instead of the monetised impacts discussed in the main part of this paper. These show:

- Chronic mortality effects – by quantifying the numbers of life years lost (over 100 years) per tonne of pollutant reduced

- Morbidity effects – by quantifying the number of hospital admissions saved per year (for both respiratory and cardiovascular illnesses) per tonne of pollutant reduced.

The table below sets out the health benefits per tonne consistent with the annual pulse approach. As no valuation is necessary the calculation to determine the air quality related health benefits of your policy is simply

Total health impact = Sum of number of tonnes of pollutant reduced (across appraisal period) x Health benefits per tonne

	Years of life lost over 100 years		Respiratory hospital admissions (per annum)	Cardiovascular hospital admissions (per annum)
	No lag	40 year lag		
PM (Transport)[17]	2.059	2.238	0.017	0.017
• Central London	10.226	9.409	0.079	0.080
• Inner London	10.517	9.677	0.082	0.082
• Outer London	6.870	6.321	0.053	0.053
• Inner conurbation	5.438	5.003	0.042	0.042
• Outer conurbation	3.379	3.109	0.026	0.026
• Urban big	4.028	3.706	0.031	0.031
• Urban large	3.245	2.985	0.025	0.025
• Urban medium	2.551	2.347	0.020	0.020
• Urban small	1.611	1.482	0.013	0.013
• Rural	0.694	0.638	0.005	0.005
PM (ESI)	0.112	0.103	0.001	0.001
PM (Domestic)	1.298	1.194	0.010	0.010
PM (Agriculture)	0.448	0.412	0.003	0.003
PM (Waste)	0.962	0.885	0.007	0.007
PM (Industrial)	1.164	1.071	0.009	0.009
NOX	0.082	0.089	0.001	0.001
SO_2[18]	0.121	0.132	0.001	0.001

[17] Damage costs for PM (transport) are at a UK-wide level, with disaggregated damage costs presented below split by current National Transport Model area. For further information on the breakdown of National Transport Model and populations covered by each sub-area, to help determine which area is most appropriate to use, please visit http://www.dft.gov.uk/stellent/groups/dft_econappr/documents/divisionhomepage/030708.hcsp.

[18] SO2 also generates additional health benefits as a gas of 0.002 death brought forward per annum (per tonne) and 0.002 respiratory hospital admissions per annum (per tonne).

Glossary

μg.m-3	micrograms per cubic metre
COMEAP	UK Department of Health's Committee on the Medical Effects of Air Pollutants
Hazard rate	A hazard rate describes the relationship between a particular pollutant (e.g. PM2.5) and a specific health outcome (e.g. life expectancy)
NOX	Oxides of nitrogen
Particulate matter (PM)	Particulate matter consists of airborne solid particles and liquid droplets that can adversely affect human health and damage materials. These particles are classified as "coarse" if they are smaller than 10 microns, or "fine" if they are smaller than 2.5 microns. PM also includes pollutants such as nitrates and sulphates (formed as a result of NOX and SO2 emissions), which are referred to a “secondary” particulate matter and form the basis of the NOX and SO2 damage cost values in this paper.
PM10	Particulate matter less than 10μm aerodynamic diameter
PM2.5	Particulate matter less than 2.5μm aerodynamic diameter
SO2	Sulphur dioxide
Uplift factor	A factor applied to the damage cost values reflecting the assumption that willingness to pay for health improvements will rise in line with economic growth.