Uncertainty, Variability and Gaps

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Sources of uncertainty:

(some overlap between categories)

i) uncertainty of **data** and **parameters** of models

e.g. slope of a dose-response function, cost of a day of restricted activity, and deposition velocity of a pollutant;

ii) uncertainty about **choice of models**

e.g. assumptions about causal links between a pollutant and a health impact, assumptions about form of a dose-response function (e.g. with or without threshold)

iii) uncertainty about **policy** and **ethical choices**

e.g. discount rate for intergenerational costs, and value of statistical life;

iv) uncertainty about the **future**

e.g. the progress of medicine in the treatment of cancers;

v) idiosyncrasies of **the analyst**

e.g. interpretation of ambiguous or incomplete information, and human error.

Uncertainty ≠ variability

Don’t confuse uncertainty and variability of impacts!

Both can cause estimates to change,

but in very different ways and for totally different reasons:

Uncertainty: insufficient knowledge at the present time,

future estimates may be different when we know more.

Variability: damage cost can vary with the type of source

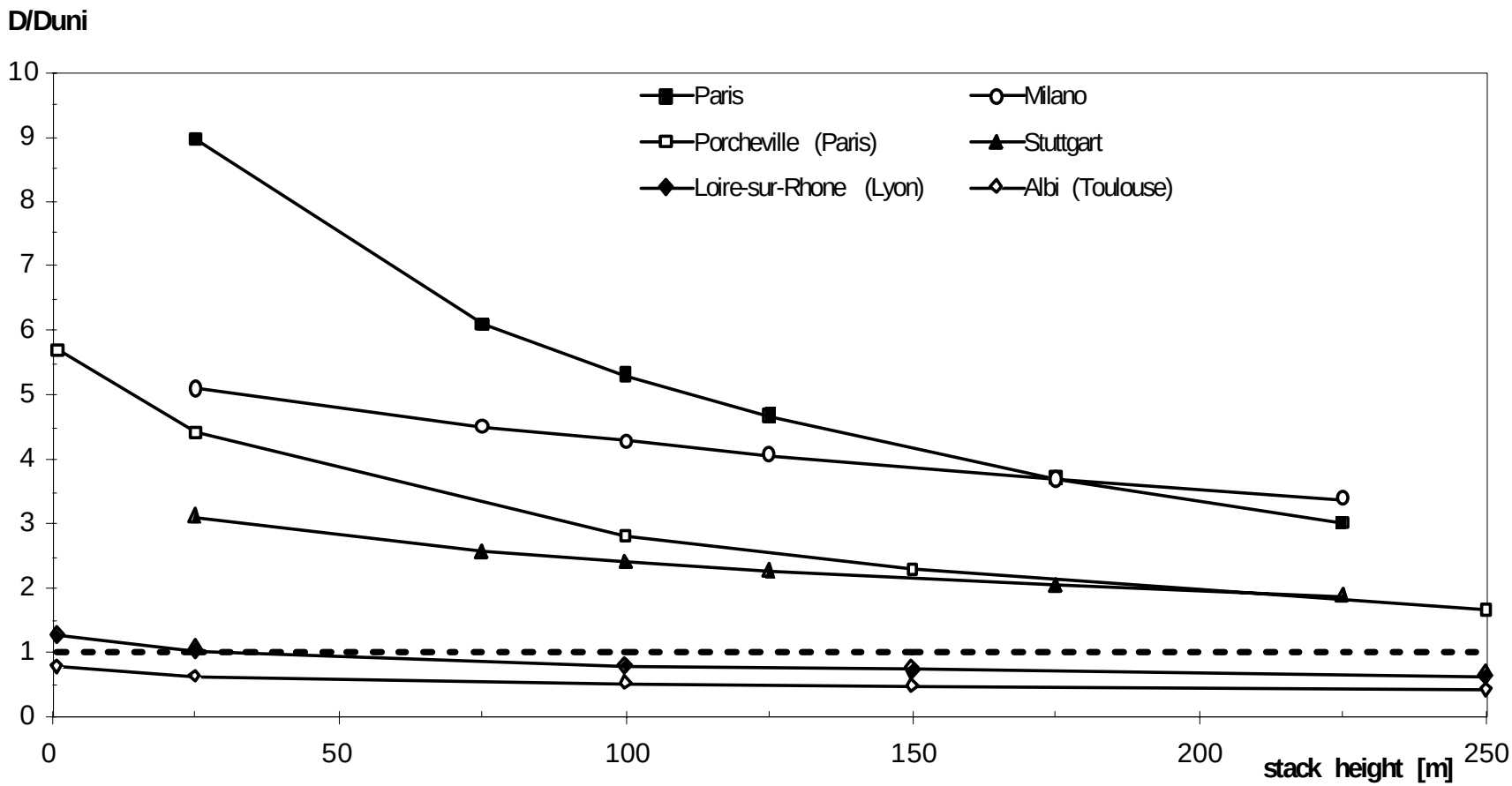
(where, ground level or tall stacks, …).

Damage cost per kWh are proportional to the emissions and vary with the technologies used.

These variations are independent of the uncertainties.

Variability with Site and Stack Height

A few examples.
Duni = typical value for central Europe (from “uniform world model”).



Difficulties

Quantifying the sources of uncertainty in this field is problematic because of a **general lack of information**.

Usually one has to fall back on **subjective judgment**, preferably by the experts of the respective disciplines.

The uncertainties due to **strategic choices of the analyst**, e.g. which dose-response functions to include, are difficult to take into account in a formal uncertainty analysis.

$\Rightarrow$ the **comprehensive uncertainties** can be much larger than the ones that have been quantified (uncertainties due to data and parameters).

Systematic analysis of uncertainties of environmental impacts has rarely been done: usually people indicate simple "high" and "low" estimates, taking only high and low estimate for a particular parameter.

Methods for Estimating the Uncertainty

i) For uncertainty of data and parameters of models:

Statistical analysis

ii) uncertainty about choice of models:

Expert judgment and Statistical analysis

iii) uncertainty about policy and ethical choices:

Sensitivity analysis

iv) uncertainty about the future:

Sensitivity analysis

v) idiosyncrasies of the analyst:

Be careful! And require peer review!

Statistical analysis for all sources if one can characterize the sensitivity scenarios by probability distributions

Uncertainty due to Lack of Information on Toxicity of the Constituents of PM

Most CRFs (Concentration-Response functions) for air pollution are based on **PM_{10} or $PM_{2.5}$ in ambient air** (including natural soil particles, apparently not very toxic),

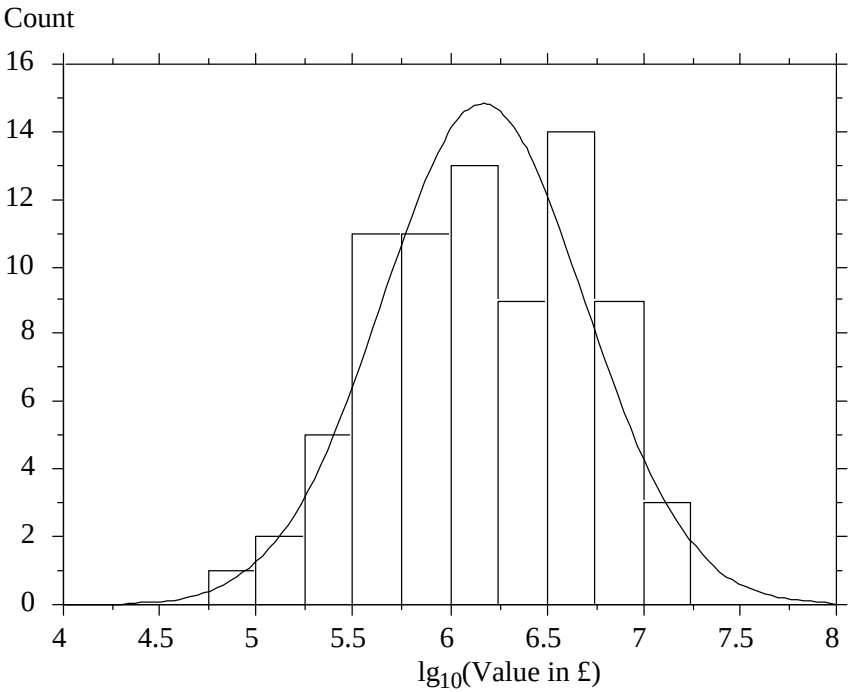
but for environmental policy one needs to know what damage is caused by each of the **pollutants emitted** (by cars, power plants etc):

- primary particles from combustion (apparently very toxic),
- NO_x (precursor of nitrate aerosols, hardly any data on toxicity),
- SO_2 (precursor of sulfate aerosols, apparently toxic).

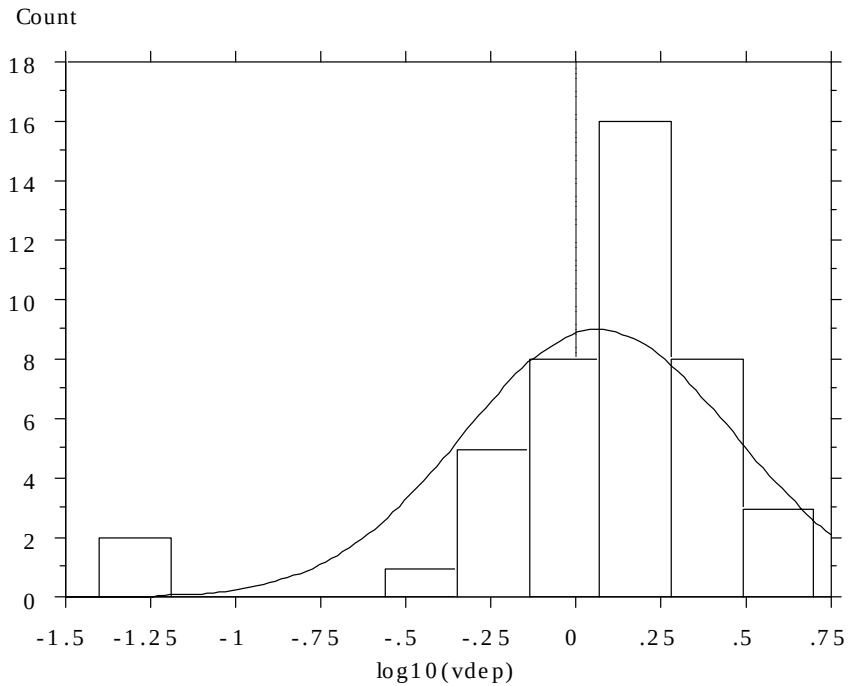
At the present time epidemiologists and toxicologists are not yet very certain about causal links between individual pollutant and impacts

$\Rightarrow$ Large uncertainty about contribution of individual pollutants
but overall cost of health damage is quite firm

Shape of the Distributions



Distribution and **lognormal** fit of **VSL**, in $£_{1990}$, in review of 78 studies [data of Ives, Kemp and Thieme 1993]



Distribution and **lognormal** fit of values for dry **deposition velocity** [in cm/s] of SO_2 over different surfaces [data of Sehmel 1980].

Simple Model

Calculation is approximately **multiplicative**

Uncertainty of product $y = x_1 x_2 \ldots x_n$

Uncertainty of sum $\ln(y) = \ln(x_1) + \ln(x_2) + \ldots + \ln(x_n)$

Central limit theorem

$\Rightarrow$ lognormal distribution is "natural" distribution for products

(if y=ln(u) is lognormal, u=exp(y) is normal).

$\Rightarrow$ **distribution of errors** is approximately **lognormal**

(unless dominated by a distribution that is very different from lognormal)

characterized by **geometric standard deviation** σ_g

$\Rightarrow$**Multiplicative confidence intervals**

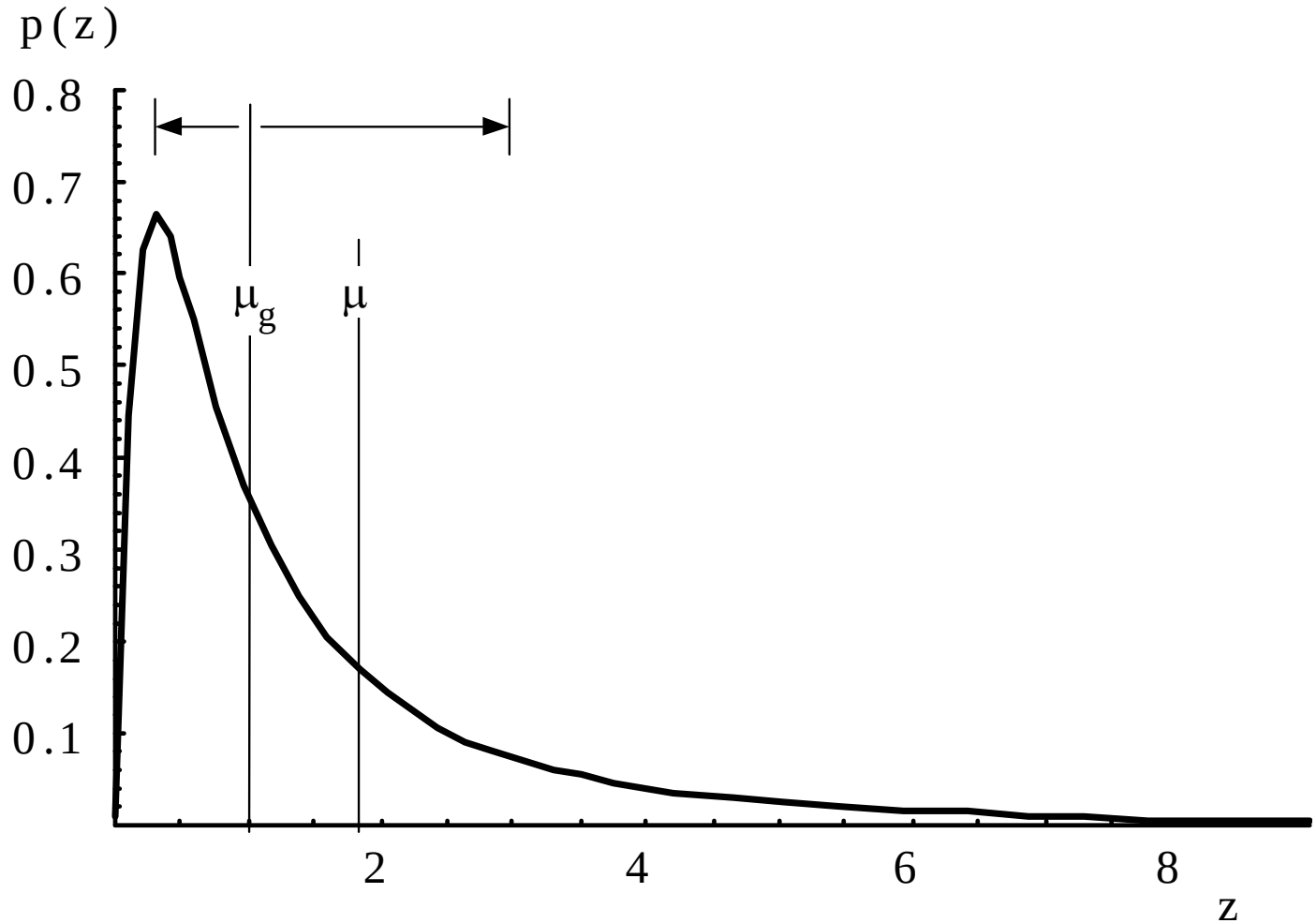
about **median** $\mu = \mu_g$ (=geometric mean)

68% between μ_g/σ_g and $\mu_g \sigma_g$

95% between μ_g/σ_g^2 and $\mu_g \sigma_g^2$

Lognormal Distribution

Probability density of lognormal distribution with $\mu_g = 1$ and $\sigma_g = 3$. Mean $\mu = 1.83$. The arrows indicate the 68% confidence interval (1 σ_g interval).



Uncertainty of the Steps of the Analysis

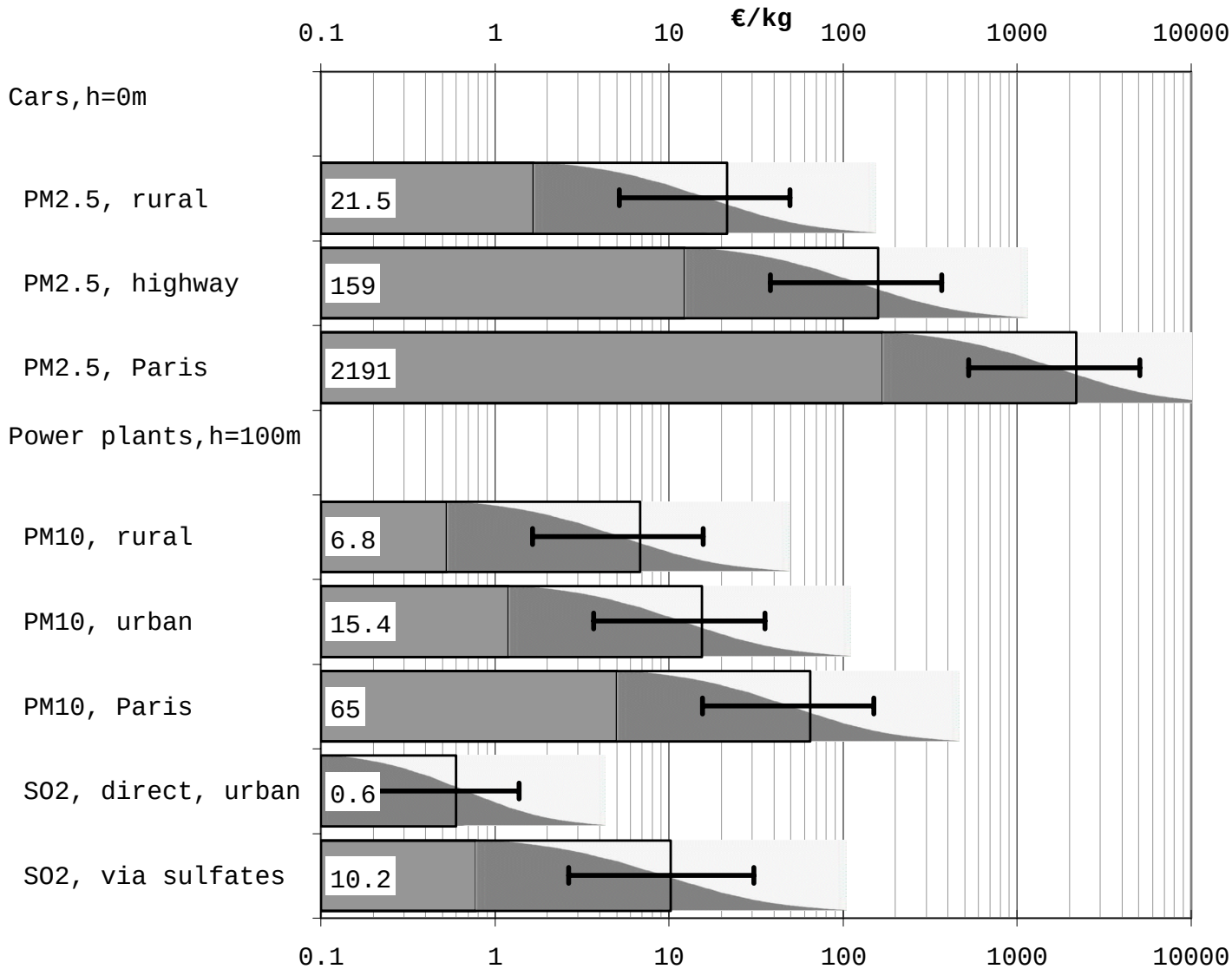
example for PM10

	lognormal?	σ_{gi}	$ln(\sigma_{gi})^2$
Exposure calculation			
Dispersion	*yes*	1.5	*0.164*
Chemical transformation	*yes*	1	*0.000*
Background emissions	*no*	1	*0.000*
CRF			
Relative risk	*no*	1.3	*0.069*
Toxicity of PM components	*?*	1.5	*0.164*
YOLL, given relative risk	*no?*	1.3	*0.069*
Monetary valuation			
Value of YOLL (VOLY)	*yes*	2	*0.480*
Total σ_g		**2.65**	***0.95***

But multiplicative confidence interval about **median** (geometric mean) μ_g, lower than the mean μ! ExternE results are means

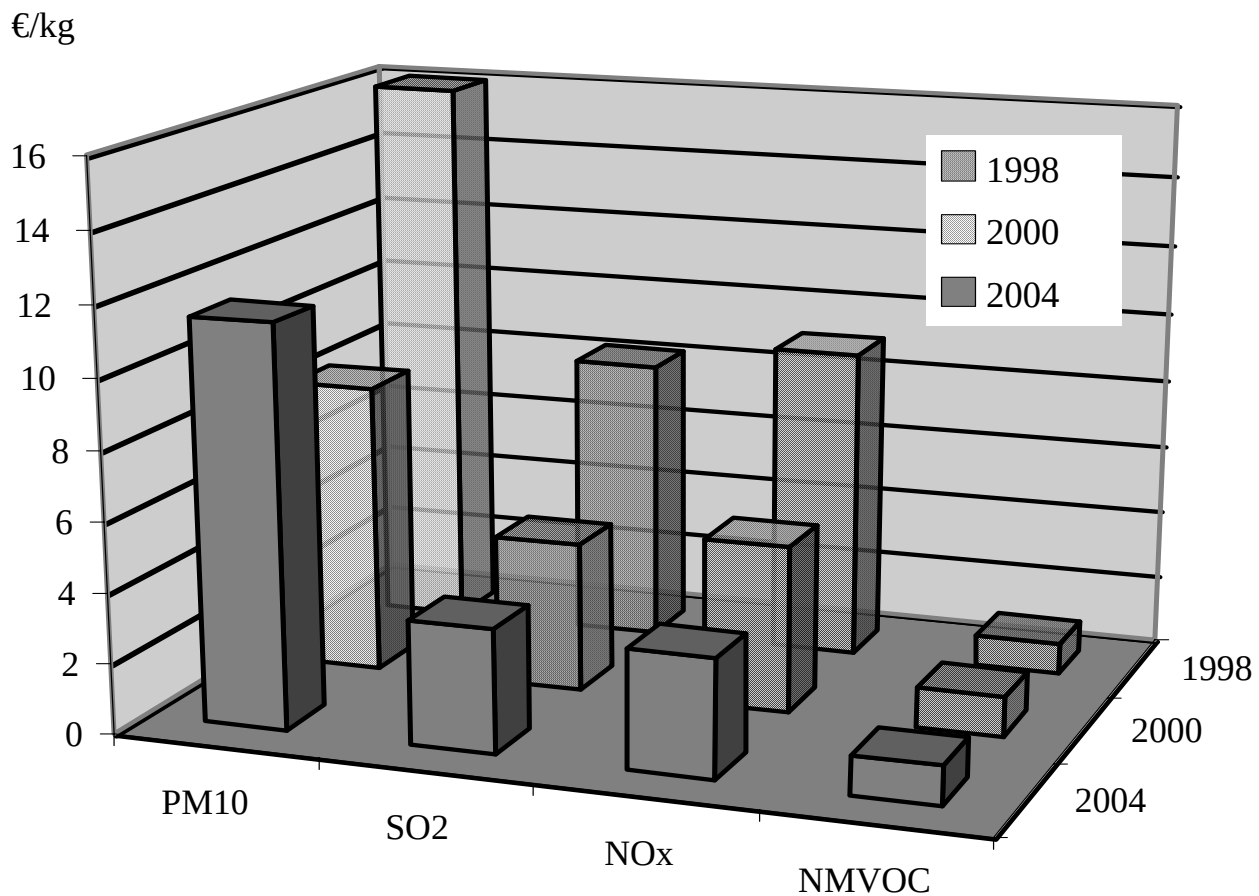
$\Rightarrow$ on log scale intervals are symmetric about μ_g, not μ.

Some Results



Evolution of damage cost estimates
(due to scientific progress, especially epidemiology and monetary valuation)

€/kg, different phases of ExternE



changes are within the published uncertainty intervals [Rabl & Spadaro 1999]**]**

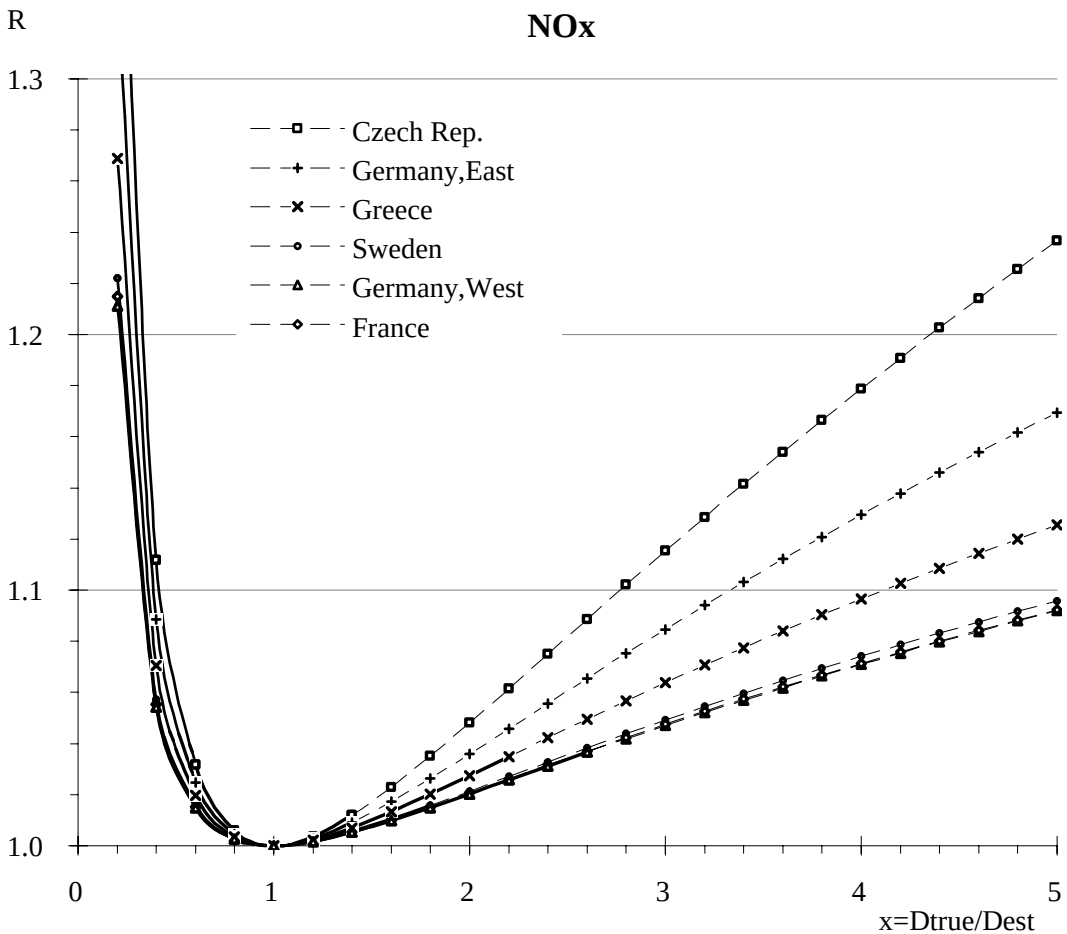
How Much Do Uncertainties Matter?

Key question: what is cost penalty for wrong decision?

For continuous choices, e.g. National Emission Ceilings:

Cost penalty R (=cost with wrong choice/cost with right choice)

vs **$x = D_{est}/D_{true}$ = error of damage cost estimate**



⇒ Penalty <15% with uncertainties of ExternE

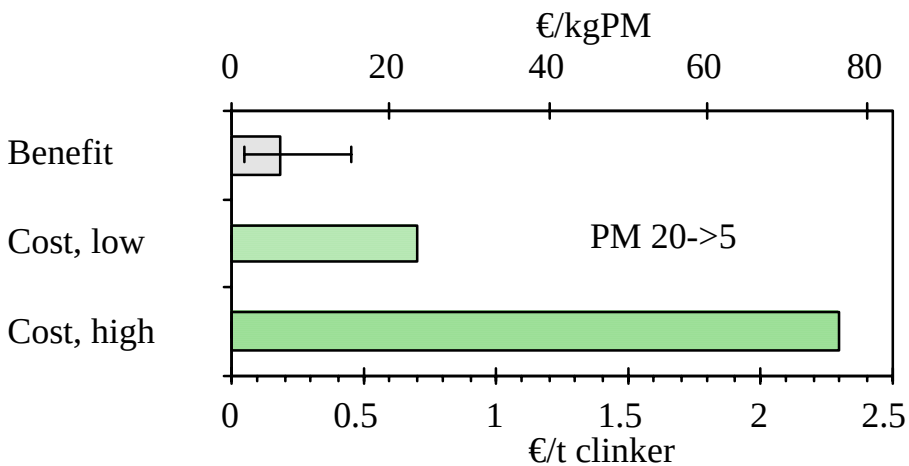
How Much Do Uncertainties Matter?
Cont'd

Key question: what is cost penalty for wrong decision?

For **discrete choices**, e.g. nuclear or coal:

No cost penalty if ranking not affected by uncertainties

Example of cement kilns: Comparison benefits for a reduction of average emission from 20 to 5 mg/m^3 (of emission limit from 50 to 15 mg/m^3). Costs and benefits are shown on two scales: per $t_{clinker}$ (bottom) and per kg_{PM} (top). Error bar indicates uncertainty of benefit. The uncertainty of the cost is indicated by a high and a low estimate.



Gaps in Current Assessments

Impact categories **included** in the numbers so far

- Global warming
- Health impacts
- Damage to buildings and materials
- Loss of agricultural production

Impact categories **not yet** (or incompletely) **included**

- Acidification and eutrophication *(but beginnings of analysis)*
- Reduction of visibility *(no monetary values for Europe)*
- Visual intrusion *(extremely site-specific)*
- Noise *(but have some results)*
- Accidents *(already internalized?)*
- Employment *(already internalized?)*
- Depletion of resources *(already internalized?)*
- Land use
- Storage of waste
- Nuclear proliferation and risks of terrorism

Global Warming

ExternE 1995:
Literature review

ExternE 1998:
Calculations by ExternE team: 3.8-139 €/t_{CO2}
18-46 €/t_{CO2} ("restricted range", geometric mean **29 €/t_{CO2}**)
ExternE 2000:
New calculations by ExternE: **2.4 €/t_{CO2}**

ExternE 2003:
Extended extended impact pathway approach: **19 €/t_{CO2}**

Large uncertainty!

the NEEDS project [2004-08]:
New calculations by ExternE team

Land use, waste storage

Land use:

Serious impact on ecosystems and biodiversity

(biodiversity decreases if size of an ecosystem is reduced, e.g. if it is cut by a road)

Very site-specific.

So far not taken into account by ExternE

Storage of waste (nuclear and conventional):

The problem: damage **depends on future management** of storage, with new technologies leakage during the operation of the facility are negligible, but what will happen in the future?

$\Rightarrow$ *need scenarios*

ExternE 1995: assessment for nuclear

So far no assessment for fossil fuel chains

Nuclear Power

ExternE 1995 and 1998: **Very low damage costs**
(lowest of all except wind and for some sites hydro)

but …

Risks of nuclear proliferation and terrorism:
Temptation to increase profit and economies of scale by selling the technology to countries that lack sufficient safeguards
(the link nuclear power -> military is undeniable)

Risks of major nuclear accident:
ExternE 1995: Extremely small with new technologies, but public perception?

Long term storage of waste:
No problem as long as storage site is supervised. But is our society stable enough in the long term?