Ingénieurs du Génie Sanitaire

Promotion : **2008–2009**

Date du Jury : **Septembre 2009**

Évaluation économique des impacts sanitaires « morbidité » de la production d'électricité

European Institute For Energy Research (EIFER)

Référent pédagogique EHESP: Olivier THOMAS

Référent dans l'établissement d'accueil : Marie-Eve STOECKEL

Rémi Terrasson

Acknowledgements

For allowing the realization of this internship at the research institute EIFER, I would like to thank Dr. Frédéric Baron, director of the institute, as well as Dr. Antoine Aslanides, deputy director, and Prof. Dr. Ute Karl, group manager.

I am thankful for the support and guidance Dr. Marie-Eve Stoeckel, supervisor of the internship at EIFER, provided throughout the internship period, which were of much help.

I am also grateful to Dr. Olivier Thomas, supervisor of the internship from EHESP, for supervising this project and for his advice.

I would also like to thank the whole staff of the department, in which the internship took place, and particularly Ms. Camille Payre, for their help.

Index

List of Acronyms

ACS: American Cancer Society

ATS: American Thoracic Society

AHSMOG: Adventist Health Smog

CAFE: Clean Air For Europe

CAPI: Computer-Assisted-Personal-Interview

CAWI: Computer-Assisted-Web-Interview

CBA: Cost-Benefit Analysis

COI: Cost Of Illness

COPD: Chronicle Obstructive Pulmonary Bronchitis

EIFER: European Institute For Energy Research

EPA: Environmental Protection Agency

ERF: Exposure-Risk Functions´

ERS: European Respiratory Society

HC: Human Capital (approach)

HEIMTSA: Health and Environment Integrated Methodology and Toolbox for Scenario Assessment

IPA: Impact Pathway Approach

MRAD: Minor Restricted Activity Days

NEEDS: New Energy Externalities Development for Sustainability

OECD: Organization of Economic Co-operation and Development

ORNL/RFF: Oak Ridge National Laboratory and Resources for the Future

PM: Particulate Matter

RAD: Restricted Activity Days

RHA: Respiratory Hospital Admissions

RR: Risk Ratio

UNECE: United Nations Economic Commission for Europe

VOLY: Value Of a Life Year

VSL: Value of Statistical Life

WLD: Work Loss Days

WTA: Willingness To Accept

WTP: Willingness To Pay

YOLL: Years Of Life Lost

WHO: World Health Organization

List of Figures

List of Tables

Introduction

Electricity generation produces air pollution, which causes health effects among exposed populations. The price of electricity is currently based on the costs of production (i.e. costs of materials, reactors, workers' wages…) and do not compensate for the health effects induced by the emitted pollution. The idea of "social costs" has been introduced, and includes all the costs which are related to the process of interest, regardless of the nature of the entity bearing them (company, general population…). Social costs are divided into two components: internal (or private) costs, and external costs (or externalities).

Since the beginning of the 1990's, several projects have been conducted by the European Commission to improve the economic valuation of adverse effects related to electricity generation. Among those, ExternE was the first one and set the ground assumptions, on which follow-up projects were based: NEEDS (New Energy Externalities Development for Sustainability) and NewExt (New Elements for the Assessment of External costs from Energy Technologies. These projects developed the Impact Pathway Approach, a "bottom-up approach" converting quality change of air, soil or water into physical impacts, by running a dispersion model and inputting dose-response or exposure-risk functions. Moreover, EcoSense, a tool for calculating the impacts of adverse effects related to electricity production, was developed. It also introduced the Impact Pathway Approach, which is a new take on impact simulation.

However, these projects mostly focused on the mortality impacts and costs, and methods were developed for that purpose. Morbidity impacts were computed but need to be developed further to improve the valuation of health impacts.

The work conducted during this internship was limited to the health impacts of the air pollution due to electricity production. Other impacts on health of the electricity production (occupational accident for example) were not considered, not because they are not important, but because their economic assessment is based on other approaches.

The global aim of this report is to give an insight of the issues relative to the economic valuation of morbidity impacts of air pollution.

Firstly, a few important methodological steps are reviewed in order to indentify the limits of the current approach. This concerns the health impact assessment steps which are a medical topic as well as the economic valuation steps. Secondly, a practical work was conducted in order to allow more robust economic valuation of particular endpoints (chronic obstructive pulmonary disease).

The internship took place in EIFER (European Institute For Energy Research), which deals with concerns arising from relationships between electricity generation and the environment. This research institute is organized in 4 departments:

Energy in cities and territories

Renewable energy – Geographic energy planning

Distributed Generation

Energy – environment economics

(EIFER website)

The internship took place in the environment economics group, which is constituted by experts in the field of environmental economics, specifically as regards impact valuation, and interacts with EDF (French electricity company), and especially with its Medical Studies Department for the studies described in this report.

The two first parts of this report are focused on different methodological points and are based on literature review. They are not meant to be a comprehensive description of used methods and data but addresses specific questions in order to highlight the possibilities and limitations of current impact valuation. A review of the tools used for economic valuations is performed in the first part, in order to determine which are the more relevant in the context of economic valuation of morbidity. Then, a specific method used by most recent research projects was examined: differential quantification.

The second part of this report deals with the review and analysis of exposure-risk functions, which connect the exposure level with foreseen health effects. A short discussion about the shortcomings of the selection or studies of those functions concludes this part.

The third part of this study analyzes results from the CAFE program, dedicated to quantifying health impacts due to air pollution. European and national data are observed in order to estimate the costs of morbidity effects, and compare them to the estimates of mortality effects from the literature.

Finally, a fourth part summarizes the practical work achieved during this internship as a participation in the European research project called HEIMTSA (Health and Environment Integrated Methodology and Toolbox for Scenario Assessment). Several test surveys were conducted in three French cities to collect data regarding the general population's valuation of health, and specifically its preferences as concerns air pollution. This iterative testing process helped to improve a questionnaire aimed at measuring the willingness to pay to avoid chronic obstructive pulmonary disease in order to have a more robust economical valuation of this endpoint.

1 Methods

1.1 Several Approaches

A very important notion in economics is the utility, which is the ability of a good or a service to satisfy one or more needs of a consumer. This concept was introduced by Daniel Bernoulli in 1738. The first principle of this concept is that people's utility is not linearly related to wealth; the second one is that a person's valuation of a risky venture is not the expected return of that venture, but rather the expected utility from that venture.
Even though it is hard to measure one's utility, it may be indirectly determined with consumer behavior theories, which assume that consumers will strive to maximize their utility. Thus, decision-making is provided with an extra indicator of the population needs, expressed as a monetary unit.
Measuring the utility value of a good or service is not the aim of economic valuation because that value does not give decision-makers any incentive. A variation in the utility of a good or service will most certainly do, as it shows that the level of satisfaction provided by that good or service is varying: it is usually deteriorated through overexploitation, pollution… (Bontems P., Rotillon G., 1998)

In the interest of a producer, a private resource should be sustainably managed, in order to ensure a long-lasting production. However, if there is a free public access to that resource, each producer's interest is to increase the natural resource exploitation, without consideration of its depletion. That fact referred to as the "Tragedy of the Commons", which was first used by Garrett Hardin and published in the journal Science in 1968. (Bontems P., Rotillon G., (1998); Hardin G., (1968))

The goal of economic valuation is to address a monetary value to environmental changes, so that they may be compared on the same basis, as financial costs and benefits. Thus, one can express preferences for changes in the state of the environment, by measuring one's Willingness To Pay (WTP) for avoiding, or one's Willingness To Accept (WTA) for compensating, any change in utility, so as to always keep the latter unchanged (Pearce D. W., Seccombe-Hett T., 2000). Several valuation methods were developed to help determine values of WTP or WTA.

1.1.1 Cost Of Illness Approach

Two types of costs are considered in the Cost Of Illness (COI) approach: direct costs incurred for medical goods and services (medication, doctor visits, hospitalization…) and indirect (or human capital) costs related to the absence of production due to an adverse health effect (Kuchler and Golan, 1999).

A) Direct Costs Of Illness

The direct costs of illness, including expenditures on medicines, health services, and defensive goods and services, provide an indication of individual welfare loss through the foregone utility resulting from the shift in expenditure patterns. Those expenditures do not induce a drop in income or consumption for the economy as a whole, but stimulate activity in a few sectors of the economy. Therefore, those amounts do not represent a simple drop in social welfare (Kuchler and Golan, 1999).

B) Human Capital Approach

The human capital (HC) approach considers the value of an individual as the value of his or her earnings. Thus, the value of preventing someone's statistical death[1] or injury is equal to the gain in the present value of his or her future earnings.

A few disturbing consequences are noteworthy: the statistical life of retired people has no value; discounting[2] future earnings induces a statistical life value of children smaller than that of adults in or near their best period of earnings; people whose value for production is not reflected by wage payments, such as house makers, are also difficult to handle in the HC framework (Johansson, 1995).

Also, the HC approach is based on two assertions: changes in health status are reflected in changes in national income, and national income is a valid measure of well-being. But earnings and national income do not always match health status, and national income is not a reliable indicator of social welfare. Therefore, the HC approach is not suitable for a measuring social welfare, and hence is not appropriate for use in cost-benefit analysis (Kuchler and Golan, 1999).

This approach does not account for the "costs of suffering", and is more suitable for the economic valuation of mortality impacts than that of morbidity ones.

1.1.2 Willingness To Pay Approach

The following few methods provide each a means of determining the WTP of a population in order to avoid risking health conditions. Individuals' preferences are measured through

---

[1] Statistical Death: The death of an unknown person at an unknown future date.

[2] Discounting: Calculating the present value of expected yearly benefits and costs. This procedure reflects the time value of money and the view that costs and benefits are worth more when experienced sooner.
Multihazard Mitigation Council, National Institute of Buildings Sciences, 2005, Mitigation Savings Report. Available at (http://www.nibs.org/MMC/), accessed 17.08.09

WTP: each individual values the virtual avoidance of a given risk. After aggregating the exposed population's WTP for avoiding that risk, decision-makers either take measures for reducing the population's exposure to that risk.

A) Compensating Wage Method

The compensating wage method has been the predominant empirical approach to assess the willingness to pay for risk reduction of premature death. It is one of the revealed preferences methods.

Assuming that workplace risks are well-known by workers, and that additional wages workers receive when they undertake more risky operations reflect risk choices, the compensating wage method helps retrieve a value of WTP from the inputted risk choices.

Put in other words, that method relies on the assumption that workers will accept exposure to some level of risk in return to some compensation (Rainer, 2004).

A few difficulties arise from that method:

a) Omitted variables bias

Determinants of a worker's wage as described above may not be captured, which may induce biased results if the unobserved variables are correlated with observed ones. Indeed, dangerous jobs are often unpleasant in other respects.

b) Endogeneity

Several variables are depending on one another: for instance, wage is explained by, among others, the risk variable, which simultaneously depends on wealth (Viscusi, 1978).

B) Avertive Behavior Method

The advertive behavior method is based on the assumptions that individuals aim at reducing the risk of adverse effects by selecting more costly types of behavior, such as greater time requirements, restrictions or “defensive expenditures” (for instance installing air filters), and that these expenses are pursued to the point where their marginal costs equals the marginal value of reduced risks of adverse effects. Thus, those expenses can be used to value an individual's WTP to reduce the risk of adverse effects. This method is also one of the revealed preferences ones.

Complications arise in the practical application of that method: the costs of the avertive behavior are not clearly observed as each component can either represent only a part of the actual costs (typically double-glazing increasing indoor tranquility, but not reducing noise level outdoor) or create joint products (double-glazing and energy conservation). Therefore, distinguishing the determinant behavior that is of interest, and the costs of the various components, might not be an easy matter in practice (Pearce et al., 2006).

C) Contingent Valuation Method

The contingent valuation method was designed to estimate demands for good that are not or rarely traded. That method involves asking people directly in a survey to state their preferences in hypothetical or contingent markets, and can be used to estimate both use (values derived from actual use of a good or service, even indirectly) and non use values (also called “passive values”, values that are not associated with actual use, or even the option to use a good or service). This is a stated preferences method.

A representative sample of individuals affected by the impact to be valued is constructed; those are asked about a change in government policy, and to imagine there is a market in which they could buy an improvement of environmental conditions. Respondents are given a detailed of the market and the good being evaluated, before being asked the price they would be willing to pay to receive the amenity, so as to participate in a hypothetical cash transaction as if there were a market.

After collecting information on the demographic and socioeconomic characteristic of respondents, analysts draw inferences about the entire population of beneficiaries and the aggregate WTP for amenities (Rainer, 2004).

The greatest weakness of the contingent valuation method is the hypothetical nature of the survey, which can induce a lack of trustworthiness on the respondents’ part. In order to minimize that bias, contingent-valuation practitioners have developed guidelines. Contingent valuation studies evaluating less severe health impacts are relatively consistent once differences in reporting are controlled (Kenkel et al., 1994), but for severe health symptoms, the use of the contingent-valuation technique is more questionable since respondents are not adequately familiar with most life-threatening illnesses (Kuchler and Golan, 1999).

D) Chained Method

This is a 4-stage method, based on stated preferences, which aims at avoiding shortcomings inherent to the contingent valuation method. Those are summed up after the description of the routine:

The first stage consists in regular contingent valuation questions designed to elicit the respondent’s willingness to pay to avoid a non-fatal health condition (or willingness to accept compensation for sustaining the same condition)

Assuming the respondent’s underlying preferences obey minimal conditions of consistency and regularity, a broad order of magnitude, at least, of the implicit marginal rate of substitution of wealth for risk of the non-fatal injury can be inferred in the second stage.

In the third stage, a slightly modified variant of a conventional standard gamble question aims at estimating the ratio mD/mI. mD stands for the respondent's marginal rate of substitution of wealth for risk of death related to the non-fatal injury, and mI the respondent's marginal rate of substitution of wealth for risk of the non-fatal injury.
Finally, the fourth stage is meant to "chain" the estimate of mI, from the second stage, to the ratio mD/mI from the third stage, in order to infer the respondent's implicit marginal rate of substitution of wealth for risk of death as a result of the situation potentially causing the non-fatal injury. That is: mD = (mD/mI) mI

The shortcomings from the contingent valuation method avoided in the chained methods are the difficulties encountered when conceptualizing a severe health status like death, the lack of pragmatism of the offered treatment (complete remission without risk of failure, in the contingent valuation method), and the closeness to public goods problems (taking the focus off the respondent's own circumstances).

1.1.3 Particular issues

A) VOLY vs. VSL

There are two different concepts used for the interpretation of the collected data for mortality. The first one consists in assigning a monetary value to the change in longevity and is recommended for the valuation of chronic mortality impacts. The change in longevity, which is usually expressed in Years Of Life Lost (YOLL), is aggregated across the studied population, and then valued by means of the Value Of a Life Year (VOLY).
The second one deals with premature deaths as an impact of the situation under study. Based on cohort studies, the quantification of "premature attributable deaths" is followed by their valuation, using the Value of a Statistical Life (VSL).

The choice of one of those concepts as a universal standard for valuation still represents an issue, but considering both concepts gives an insight of the importance of uncertainties related to them (Watkiss et al., 2005).

B) Different views on methods

Since cost valuation is not only performed in the field of economics, different definitions for useful terms are used. For instance, in the field of public health, Seethaler (1999) defines social costs, internal costs and external costs as follows:

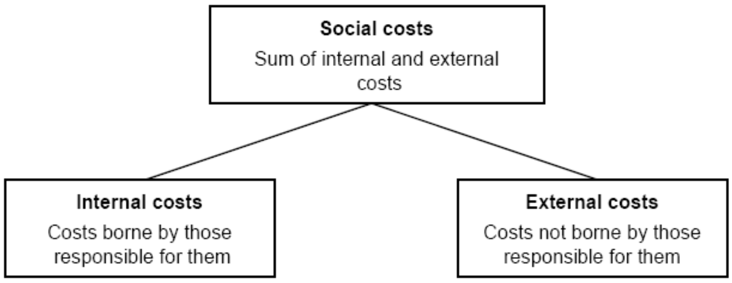

Figure 1: Social, internal and external costs (Sommer et al., 1999)

In the field of economics, the following definitions are often used (Seethaler, 1999):

Social costs are costs borne by society, that is to say total costs (for example, total cost for electricity production);

Private costs, also sometimes called internal costs, are costs borne by the individual (or company) responsible for the pollution;

External costs, or externalities, are costs generated by a polluter but borne by someone else.

A careful reading (or use) of these terms is necessary, because they can have several meanings, depending on the field in which they are utilized. For example, in the field of epidemiology, social costs might sometimes be used to designate external costs (from the economics), and private costs an individual's expenses for his/her health, which are a part of external costs, as shows the following figure.

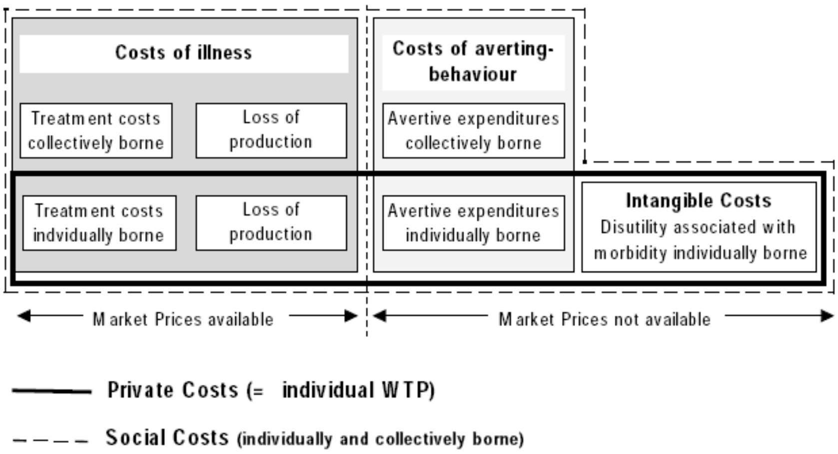

Figure 2 : Overview of the costs of morbidity (Sommer et al., 1999)

Other terms used in economical health impact assessment are:

Damage costs: "Damage cost is the cost incurred by repercussions (effects) of direct environmental impacts (for example, from the emission of pollutants) such as the degradation of land or human—made structures and health effects. In environmental accounting, it is part of the costs borne by economic agents."(OECD, 2001);

Avoidance costs: "Avoidance costs are actual or imputed costs for preventing environmental deterioration by alternative production and consumption processes, or by the reduction of or abstention from economic activities" (OECD, 2001).

1.2 Differential Quantification

1.2.1 Introduction

It has been proven that Particulate Matter (PM) causes adverse effects on public health (Spengler et al., 1997). However, particulates can be of numerous natures; indeed, PM is a mixture of pollution components, which are specifically toxic. There is no strong evidence whether the adverse effects of PM are induced by its chemical components or by its physical properties (Hurley et al., 2007).

Since populations are constantly exposed to a mix of pollutants, epidemiologists struggle to attribute a particular health impact to a particular pollutant. Thus, they see each pollutant merely as an indicator of ambient pollution. Gordon (2007) and Gerlofs-Nijland et al. (2007) highlighted the variety of health effects induced by particulates, depending on the source of pollution.

Indeed, particles from different sources and/or different characteristics have different toxicities; also, typically, a pollution mixture is significantly different from the general urban air pollution that has been studied epidemiologically.

Evidence is limited, but was considered sufficient to stress the importance of differential quantification, which means disaggregating the pollution mixture under study into several components, estimating the effects of each component by means of separate Exposure-Risk Functions (ERF), take account of the fact that theses components are experienced as parts of the mixture, and finally re-aggregating the effects across components (Hurley et al., 2007).

1.2.2 Rationale

The rationale has been depicted in Hurley et al. (2007), and a step-by-step explanation of the equation is also provided.

The ExternE project series aimed at formulating its specific model, taking account of all individual pollutants in a single equation:

$$\Delta I = \sum_i s_i \times \Delta c_i$$

ΔI is the incremental impact for a particular endpoint (e.g. a specific disease related to air pollution) as a sum of the contributions of the individual pollutants i (each with ERF slope si and concentration increment Δci). The assumption was made that all ERF are linear and without threshold. The Task Force on Health aspects of air pollution (TFH) of WHO-

UNECE (United Nations Economic Commission for Europe) decided that, in the core analyses, the effects of daily ozone on mortality should be quantified only at ozone concentrations higher than 35 ppb (70 µg/m3), considered as a daily maximum 8-hour mean ozone concentration. In practice, this means that effects are quantified only on days when the daily ozone concentration (maximum 8-hour mean) exceeded 70 µg/m3, and then only the increment exceeding 70 µg/m3 is used for quantification.The unit of I is cases per year per average person.

The ratio of ERF slopes $s_{PM_{10}} / s_{PM_{2.5}}$ was determined according to the typical value of the ratio of PM concentrations (0.6) (Sun et al., 2006). This assumption is still currently used: $s_{PM_{2.5}} / s_{PM_{10}} = 1.67$ (Hurley et al., 2007)

The ExternE reports of 1999 tried to differentiate between primary and secondary particulates, and the assumption was made that the toxicity of all sulphates is that of the $PM_{2.5}$ mixture and the toxicity of particulate nitrates is that of PM_{10}.
Primary particles are directly released into the atmosphere by wind, combustion processes, or human activities. Secondary particles are those that form in the atmosphere from other gaseous pollutants; particularly sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds. (http://www.greenfacts.org/glossary/)

Also, primary particulates have been differentiated: those from internal combustion engines are $PM_{2.5}$, while those from power plants are mostly PM_{10} or even larger.
To summarize the assumptions made in the former ExternE series (ExternE, 1998), the following equation was used:

$$\Delta I = s_{PM_{10}} \left(\Delta c_{PM_{Power}} + 1.67 \Delta c_{PM_{Trans}} + 1.67 \Delta c_{Sulf} + \Delta c_{Nitr} \right) + s_{O_3} \Delta c_{O_3} + s_{SO_2} \Delta c_{SO_2} + s_{CO} \Delta c_{CO} + other$$

$\Delta c_{PM_{Power}}$ is the concentration due to primary combustion PM from power plants;

$\Delta c_{PM_{Trans}}$ is the concentration due to primary combustion PM from transport;
"other" stands for carcinogens such as benzene.

A more recent ExternE report (ExternE, 2005) has defined new assumptions as regards the toxicity of the various PM types, based on a review of the latest epidemiological and toxicological literature. Thus, coefficients must be updated, as follows:

$$\Delta I = s_{PM_{10}} \left(\Delta c_{PM_{Power}} + 2.5\Delta c_{PM_{Trans}} + \Delta c_{Sulf} + 0.5\Delta c_{Nitr} \right) + s_{O_3}\Delta c_{O_3}$$

Note that primary particles are now considered 1.5 times as toxic as $PM_{2.5}$, that is 2.5 (1.67*1.5) times as toxic as PM_{10}. Also, direct effects of CO, SO_2 and NO_x are no longer taken into account.

In order to provide a finer estimate of the impacts, NEEDS (2007) suggested that modifying factors (fi) be added before each term of the equation, and that both the oxidizing and particulate effects of each pollutant be considered, and set in the global equation.

Since too few ERF can be found in the literature, assumptions need to make up for the lack of information:

$$s_{Sulf} = s_{Nitr,P} = s_{HNO_3,P} = s_{PM_{10}} = s_{Metal} = s_{OM}$$

Also, according to Gauderman (2004):

$$s_{Nitr,O} = s_{HNO_3,O} = s_{O_3}$$

ΔI is now equal to:

$$\Delta I = s_{PM_{10}} \begin{pmatrix} f_{PM_{Power}}\Delta c_{PM_{Power}} + f_{PM_{Trans}}\Delta c_{PM_{Trans}} + f_{Sulf}\Delta c_{Sulf} + f_{Nitr,P}\Delta c_{Nitr} \\ + f_{HNO_3,P}\Delta c_{HNO_3} + f_{OM}\Delta c_{OM} + f_{Metal}\Delta c_{Metal} \end{pmatrix}$$
$$+ s_{O_3}(f_{O_3}\Delta c_{O_3} + f_{Nitr,O}\Delta c_{Nitr} + f_{HNO_3,O}\Delta c_{HNO_3}) + s_{SO_2} f_{SO_2}\Delta c_{SO_2}$$
$$+ s_{NO_2} f_{NO_2}\Delta c_{NO_2} + s_{CO} f_{CO}\Delta c_{CO}$$

However detailed the equation looks, the recommendation of CAFE and NEEDS (2007) for the core analysis is to consider all pollutants as toxic as PM_{10} (only the toxicity of $PM_{2.5}$

is valued 1.67 times as high as that of PM_{10}, and oxidizing effects are discarded, as well as effects of SO_2, NO_2 and CO).

The following table is a reminder of all the modifying factors used in the ExternE project series, and the related applications (such as CAFE).

	PM10	Sulphates	Nitrates	HNO3	Métaux	SO2
ExternE 1998	1	1.67	1	1	1	0
ExternE 2005	1	1	0.5	0.5	1	1
CAFE - NEEDS "Core"	1	1	1	1	1	0
NEEDS "Sensitivity"	1			2.2	2.2	2.2
	1	1.2	1.2		1.2	

Table 1: Choice of the modifying factors fi for chronic mortality
Source: Hurley et al. (2007)

Note that in the equation PM_{Power} stands for PM_{10}, and PM_{Trans} for $PM_{2.5}$; the modifying factor for $PM_{2.5}$ has always been 1.67, which is the typical value of the ratio of PM.

In sensitivity analyses, on the other hand, Hurley et al. (2007) recommends the application of different weighting factors to different pollutants, according to the up-to-date evidence. A set of modifying factors is proposed:
Primary particulates weighted by 1.3 times the factor of $PM_{2.5}$
Secondary particulates weighted by 0.7 times the factor of $PM_{2.5}$
It should be emphasized that differential quantification in sensitivity analyses is used for illustrative or exploratory purposes only, as there is no consensus about the toxicity values. It is also noteworthy that differential quantification has only been developed for mortality impacts so far; morbidity impacts may also be more precisely estimated if that approach were adapted accordingly (see Assessment).

1.2.3 Assessment

Since air pollution in a given place and at a given time is an original mix of several pollutants, differential quantification should account best for all those components. But the effects of the mixture never equal the sum of the effects of each of its components. Indeed, interactions between the various pollutants occur, and need to be considered in the methods. Although Hurley et al. (2007) indicated one should take account of the fact that theses components are experienced as parts of the mixture as a step of the quantification using differential quantification, this procedure is unclear. Since all epidemiological studies are based on particular air pollution mixtures, outlining a trend in the interaction between each couple of components is a difficult matter.
Also, the modifying factors proposed in Hurley et al. (2007) for the core analysis are often rough estimates, which do not seem to stand accurately for the actual situation. For

instance, in CAFE, all kinds of particulate matter have been assigned the same modifying factor. Admittedly, there is too little evidence in the literature to assign specific modifying factors (WHO, 2004), but assuming all pollutants will equally affect human health must induce a significant uncertainty. Studies using differential quantification as is might not be considered reliable, as their assumptions are very unlikely to match the actual situation. It would take more dedication from air pollution scientists to develop more accurate modifying factors.

Another frame of development could be the extension of the differential quantification method to morbidity impacts. This would require much work for determining modifying factors because unlike mortality, morbidity consists of many endpoints for each of which specific factors must be inferred.

2 Exposure-Risk Functions (ERF)

An exposure-risk function is the link between the ambient concentration in a given pollutant and the impacts it induces on the exposed population. As it is shown on figure [IPA], this link is necessary to quantify impacts from collected data that is previously processed in the model used in the IPA.

There are specific exposure-risk functions for each pollutant and each health endpoint. In the next paragraph, those functions have been reviewed for all health endpoints involved in the impact quantification performed in NEEDS (Hurley, 2007).

Impacts can be either caused by short-term or long-term exposure. The former induces health effects after a short time, and usually involves greater levels of concentration. The latter usually occurs with lesser levels of concentration, and health effects appear after a longer period.

Note that those functions have several denominations in the literature, like exposure-response functions or concentration-response functions, which might confuse the reader, but those names always refer to exposure-risk functions in this report.

2.1 Review

2.1.1 Particulate matter (PM)

A) Mortality

See Appendix 2.

B) Morbidity

Usually expressed as a change percentage in endpoint per 10 µg/m^3 of PM_{10} (or $PM_{2.5}$), the estimate of the effects of PM on morbidity can also be converted into excess cases, events, or days per unit population per 10 µg/m^3 annual average of PM_{10} (or $PM_{2.5}$) per annum.

For many health endpoints, reliable data on background rates of morbidity in the target population are not available. Therefore, another approach was developed, which is based on the estimation of impact functions from epidemiological studies, and transfer that function to the target population.

Both approaches have been used in the CAFE-NEEDS methodology (Hurley et al, 2007).

a) Chronic bronchitis, long-term exposure

An estimated impact function has been inferred from several papers, in the US Seventh Day Adventists study (AHSMOG: Adventist Health Smog). Almost 4,000 Adventists[3] have been examined in two occasions: in 1977 and in 1987/88. Cases of chronic bronchitis were defined was defined as reporting chronic cough or sputum, for at least three months per year, for at least two years. Excess cases of chronic bronchitis were defined as those meeting the criteria in 1987/88, but not in 1977.

Thus, using a ERF from Abbey et al. (1995a, table 6), and a background incidence rate of 0.378% estimated from Abbey et al. (1993, 1995a), Hurley et al. (2005a) derived an estimated impact function of excess cases of chronic bronchitis per year per 100,000 adults aged 27 or more: 26.5 (95% CI -1.9–54.1) per 10 µg/m^3 of PM_{10}.

b) Chronic vascular disease

Only one study on the incidence of chronic vascular disease is available, in which 65,893 postmenopausal women without previous cardiovascular disease in 36 U.S. metropolitan areas were examined from 1994 to 1998. The women's exposure to air pollutants was assessed, using the monitor located nearest to each woman's residence. Hazard ratios were estimated:

24% change in the risk of a cardiovascular event (95% CI 9–41%) per 10 µg/m^3 of $PM_{2.5}$.

(Miller et al., 2007)

That ERF is applied to the general population, males and females (the underlying assumption is that both genders have the same risk factor, as regards the incidence of chronic vascular diseases).

c) Respiratory Hospital Admissions (RHA)

The acute effects of PM_{10} on human health have been studied in the European Program Apheis (Air Pollution and Health: a European Information System). The Apheis program

---

[3] Adventists are a Christian community, whose habits are interesting for studies of health impacts of air pollution, since they value their health, do not drink alcohol and do not smoke. Thus, any increase in health risk stems entirely from an outer cause.

was created in 1999 for the stated purpose of "providing European policy makers, environment and health professionals, the general public and the media with up-to-date, easy-to-use information on air pollution and public health to help them make better-informed decisions about the political, professional and personal issues they face in this area" (Apheis third year report, 2004).
The aim of that program was to analyze the impact of air pollution on public health in 26 cities in 12 European countries. In each city, measurements of several substances have been conducted: PM_{10}, $PM_{2.5}$ and black smoke (BS). For the health impact assessment, the acute effects of PM_{10} and BS on premature mortality and hospital admissions have been analyzed, and the impacts of long-term exposure to PM_{10} and $PM_{2.5}$ on premature mortality have been estimated.

The latest impact function used in NEEDS is based on the review for the Cost-Benefit Analysis (CBA) in CAFE and Apheis-3. Indeed, Atkinson et al. estimated a risk variation of 1.14% (95% CI 0.62–1.67%) per 10 µg/m^3 of PM_{10} in the appendix 4 of the Apheis-3 report.

City-specific incidence rates were given in Apheis-3, which ranged from 511 to 708 per 100,000 inhabitants per year, with an average value (arithmetic mean) of 617 per 100,000 inhabitants per year.

CAFE CBA inferred the following impact function from the collected data:
(617 RHA / 100,000 inhabitants / year) * 1.14% risk change per 10 µg/m^3 of PM_{10}
= 7.03 RHA (95% CI 3.83–10.30) per 10 µg/m^3 of PM_{10} per 100,000 people per year

d) Cardiac Hospital Admissions

According to CAFE-NEEDS (Hurley, 2007), the effects of daily variations of PM air pollution on cardiac admissions at all ages were studied and quantified in Apheis-2, and a ERF was developed in Apheis-3, based on Aphea-2 (Air Pollution and Health: a European Approach) data from eight European cities. That function was:
0.6% risk change (95% CI 0.3–0.9%) per 10 µg/m^3 of PM_{10}

e) General practitioner consultations

Time series analyses were based on numbers of consultations among about 282,000 registered patients from about 45 London practices contributing to the General Practice Research Database during 1992-94 (Hajat 1999, 2002). But the transferability of those results within Europe remains an issue.

Impact functions for daily consultations for asthma are expressed separately by age-group, for warm season (adjusted for other factors), and derived from Hajat (1999):

1.18 consultations (95% CI 0–2.45) for asthma, per 1000 children aged 0-14

0.51 consultations (95% CI 0.2–0.82) for asthma, per 1000 adults aged 15-64

0.95 consultations (95% CI 0.32–1.69) for asthma, per 1000 adults aged 65+

per 10 μg/m^3 PM_{10}, per year

Also for daily consultations for upper respiratory diseases, excluding allergic rhinitis, analyses by Hajat (2002) were adjusted for season, day-of-the-week effects and climate, and impact functions were derived:

4.0 consultations (95% CI -0.6–8.0) per 1000 children aged 0-14

3.2 consultations (95% CI 1.6–5.0) per 1000 adults aged 15-64

4.7 consultations (95% CI 2.4–7.1) per 1000 adults aged 65+

per 10 μg/m^3 PM_{10}, per year

f) Restricted Activity Days (RAD) and Work Loss Days (WLD)

Two studies are widely considered a milestone as regards the quantification of Restricted Activity Days (RAD) and Work Loss Days (WLD): those are Ostro (1987) and Ostro and Rothschild (1989).

The former was based on a sample of 7,111 people for WLD and on a sample of 12,783 people for RAD, and the latter was a multistage probability survey of 50,000 households, in several metropolitan areas in the USA. Data for both studies were obtained from the annual Health Interview Surveys in 1976-81, which were conducted by the National Center for Health Statistics.

NEEDS (2007) derived impact functions from the coefficients estimated in Ostro (1987) and Ostro and Rothschild (1989), and from the background rates for RAD in ORNL/RFF (1994), and for WLD and MRAD in Hurley et al. (2005):

Change of 902 RAD (95% CI 792–1013) per 10μg/m^3 $PM_{2.5}$

Change of 207 WLD (95%CI 176–238) per 10μg/m^3 $PM_{2.5}$

Change of 577 MRAD (95% CI 468–686) per 10μg/m^3 $PM_{2.5}$

per year per 1000 adults aged 18-64

g) Use of bronchodilator for asthmatic people

« The recent Delfino et al. (2003) study from California found that effects of PM_{10} on asthma worsening were completely explained by elemental and organic carbon » WHO (2004). Impact functions, based on the WHO meta-analysis (Anderson et al., 2004), were proposed in Hurley et al. (2005) for variations of medication use by asthmatic children aged 5-14 years, although associations were not statistically significant:

Change of 180 days of bronchodilator usage (95% CI -690–1060) per 10µg/m^3 PM_{10} per year per 1,000 children meeting the PEACE (Pediatric Asthma Clinical Effectiveness) study criteria.

An impact function was derived in the appendix 1 of the NEEDS RS1b/WP3 report (Hurley, 2007), based on an ERF from the WHO meta-analysis (Anderson et al., 2004) for adults aged 20 years and older:
Change of 912 days of bronchodilator usage (95% CI -912–2774) per 10µg/m^3 PM_{10} per year per 1,000 adults aged 20 years and older with well-established asthma.

h) Lower Respiratory Symptoms [4](LRS)

Adults with chronic respiratory symptoms:
A random effects meta-analysis of results from five panels was linked to both estimates of the mean daily prevalence of LRS based on the studies underlying the ERF, and estimates of the percentage of people qualifying for such panels, using data from European Community Respiratory Health Study (ECRHS, 1996) to infer an impact function:
Change of 1.30 (95% CI 0.15–2.43) symptom days (LRS, including cough) per 10µg/m^3 PM_{10} per year per adult with chronic respiratory symptoms (about 30% of the adult population)

Children:
According to Ward and Ayres (2004), effects of PM on respiratory symptoms should be quantified for all children, regardless of their health condition. An ERF from Ward and Ayres (2004) was combined in Hurley et al. (2005) with an estimate of the mean daily prevalence of LRS based on two general population Dutch studies of children (van der Zee et al., 1999; Hoek and Brunekreef, 1995), to estimate an impact function:
Change of 1.86 (95% CI 0.92–2.77) symptom days per 10µg/m^3 PM_{10} per year per child aged 5 – 14 years

i) Acute respiratory symptoms in general population

Hurley et al.(2007) proposed, for sensitivity analysis solely, estimates of the effect of PM on symptom days in general population, based on Krupnick et al. (1990):
Change of 4650 (95% CI 210–9090) symptom days per 10µg/m^3 PM_{10} per year per 1,000 people

---

[4] LRS are symptoms that relate to the lower respiratory tract, i.e. lungs, trachea and bronchi. Those symptoms suggest the presence of asthma, an allergic reaction, or an infection (GreenFacts glossary website).

This function is likely to overestimate the effects of PM on respiratory symptoms, especially when applied in Europe, but represents a glimpse of the potential extent of those effects.

2.1.2 Ozone (O_3)

There is no strong evidence that long-term exposure to ozone is associated with health effects additional to those of short-time exposure aggregated over time (Hurley et al., 2005).

Although there is no evidence for a threshold in the relationship between variation in ambient ozone concentration and mortality, the effects of daily ozone concentration on mortality should be quantified only at concentrations higher than 35 ppb (70µg/m^3), considered as a daily maximum 8-hour mean ozone concentration (WHO, 2003, 2004). However, in those WHO studies, an estimation of the effects with a cut-off of zero in the sensitivity analysis is recommended.

A) Mortality from short-term exposure

See Appendix 2.

B) Morbidity

a) Respiratory Hospital Admissions (RHA)

Data from five cities in Western Europe were used in the WHO meta-analysis (Anderson et al., 2004) to estimate an ERF. Only the association for adults aged 65 years or older was close to statistical significance; therefore an impact function was derived for that age group solely, using background rates from Aheis (2002):
12.5 RHA (95% CI -5.0–30.0) per 10 µg/m^3 O_3 (8-hour daily average) per 100,000 people aged 65 years or older.

b) Cardiovascular Hospital Admissions / Emergency Room Visits

No statistically significant association between daily variations in ozone concentration and cardiovascular hospital admissions or emergency room visits has been uttered in the literature.

c) Consultations for allergic rhinitis with general practitioner

Consultations for allergic rhinitis with a general practitioner have the strongest association with ozone concentration when using a cumulative index including O_3 concentrations over four consecutive days (with lags of 0 to 3 days), according to Hajat et al. (2001).

However, those results have been linked, as if they were relative to the pollution of a single day, to daily numbers of consultations and numbers of registered patients, in order to infer estimated impact functions (Hurley et al., 2005):
3.03 consultations (95% CI 1.89–4.29) per 1000 children aged 0-14
1.60 consultations (95% CI 1.22–2.03) per 1000 adults aged 15-64
per year per 10 µg/m^3 O_3 (8-hour daily average)

The transferability issue has been raised, as results above stem from studies led in the Greater London Area, and given the differences in health care systems (NEEDS RS1b WP3 report).

d) Minor Restricted Activity Days (MRAD)

Ostro and Rothschild (1989) stated that MRAD among urban workers aged 18-64 years were associated with ozone concentration (two-week averages of the daily 1-hr max, in µg/m3) and used the mean background rate determined in the same study (7.8 MRAD per year) in order to provide an impact function for ozone:
Change of 115 MRAD (95% CI 44–186) per 10 µg/m^3 O_3 (8-hr daily average) per year per 1,000 people

e) Use of bronchodilator for asthmatic people

In Hurley et al. (2005), several impact functions for increased medication use were derived from several ERF found in different studies for children and adults.
First, an 82-asthmatic-children study (Just et al., 2002) proposed an ERF, and background rates were found in Gielen et al. (1997). Those results were combined to estimate an impact function:
Change of 124 days of bronchodilator use (95% CI 18–227) per 10 µg/m^3 O_3 per 1,000 children aged 5-14 years (general population) in Northern and Eastern Europe
Change of 310 days of bronchodilator use (95% CI 44–569) per 10 µg/m^3 O_3 per 1,000 children aged 5-14 years (general population) in Western Europe

Those impact functions are based on a single small-sample study and have been applied to the general population, while effects only occur in asthmatic children. Therefore, they might not be representative as they are overestimating the effects of ozone, but are still recommended to be considered in sensitivity analysis, since this is an important health end point (Hurley et al., 2005).

As concerns adults (aged 20 years or older), an impact function was derived in NEEDS RS1b WP3 (2007) from an odds ratio calculated in Hiltermann (1998) and a background rate estimated with the results from Hiltermann (1998), in which 60 nonsmoking, asthmatic patients were studied over a 96-day period, and (ECHRS, 1996).

Change of 730 days of bronchodilator use (95% CI -255–1570) per 10 µg/m^3 O_3 per 1,000 adults aged 20 years or older with well-established asthma (about 4.5% of the adult population).

f) Acute respiratory symptoms in children in the general population

The findings of a small general population study of 91 children (Declerq and Macquet, 2000) were linked in Hurley et al. (2005) with backgrounds rates from Hoek and Brunekreef (1995). The following impact functions were thus inferred:

Change of 0.93 (95% CI -0.19, 2.22) cough days and 0.16 (95% CI -0.43, 0.81) days of LRS (excluding cough) per child aged 5-14 years (general population), per 10 µg/m^3 O_3, per year

2.1.3 Selection

The following tables form a summary of the exposure-response functions from the literature considered most recent and reliable, for a valuation of the effects of air pollution on public health, in Europe.

Mortality:

Endpoint	Pollutant	Age group	Risk group fraction	CRF (95% CI)	Units
Chronic mortality					
Life expectancy reduction	PM2.5	30+	1	651 (127; 1194)	YOLL per 10 µg/m³ per 100 000 people
Infant mortality					
Increased mortality risk	PM10	0-1	0.4%	4% (2%; 7%) 18	attributable cases per 10 µg/m³ YOLL per 10 µg/m³ per 100,000 people
Acute mortality					
Increased mortality risk	O3/SOMO35	all	0.99%	0.30% (0.1%; 0.43%) 0.75	attributable cases per 10 µg/m³ YOLL per case

Morbidity: Core Functions - PM:

Endpoint	Pollutant	Age group	Risk group fraction	CRF (95% CI)	Units
New cases of chronic bronchitis	PM10	27+	0.376%	26.5 (-1.9; 54.1)	per year, per 10 µg/m³, per 100,000 adults aged 27+
Respiratory hospital admissions	PM10	all	1	7.03 (3.83;10.3)	per year, per 10 µg/m³, per 100,000 people
Cardiac hospital admissions	PM10	all	1	4.34 (2.17; 6.51)	per year, per 10 µg/m³, per 100,000 people
Medication use / bronchodilator use	PM10	5-14	PEACE criteria (15% N&E-EU) (25% W-EU) Medication use 10%	180 (-690; 1060)	per year, per 10 µg/m³ per 1000 children meeting the PEACE criteria
	PM10	20+	Asthmatics 4.5% Daily medication use probability 50%	912 (-912; 2774)	per year, per 10 µg/m³ per 1000 adults 20+
Lower respiratory symptoms	PM10	adults	symptomatic adults (30%)	1.3 (0.15; 2.43)	symptom days per year, per 10 µg/m³ per adult with chronic respiratory symptoms
	PM10	5-14		1.86 (0.92; 2.77)	symptom days per year, per 10 µg/m³ per child 5-14
Restricted activity days (RAD)	PM2.5	15-64	1	902 (792;1013)	per year, per 10 µg/m³ per 1000 adults 15-64
Work loss days (WLD)	PM2.5	15-64	1	207 (176; 208)	per year, per 10 µg/m³ per 1000 adults 15-64
Minor restricted activity days (MRAD)	PM2.5	18-64	1	577 (468; 686)	per year, per 10 µg/m³ per 1000 adults 18-64

Table 2: Set of chosen ERF in NEEDS project

Source: Hurley et al., 2007

Core Functions - O3:

Endpoint	Pollutant	Age group	Risk group fraction	CRF (95% CI)	Units
Respiratory hospital admissions	O3/SOMO35	65+	1	12.5 (-5; 30)	per year, per 10 µg/m³ per 100 000 people 65+
MRAD	O3/SOMO35	18-64	1	115 (44; 186)	per year, per 10 µg/m³ per 1000 adults 18-64
Medication use / bronchodilator use	O3/SOMO35	20+	Asthmatics 4.5%	730 (-225; 1570)	per year, per 10 µg/m³ per 1000 asthmatic adults 20+
LRS excluding cough	O3/SOMO35	5-14	1	0.16 (-0.43; 0.81)	days of LRS per year, per 10 µg/m³ per child 5-14
Cough days	O3/SOMO35	5-14	1	0.93 (-0.19; 2.22)	cough days per year, per 10 µg/m³ per child 5-14

Sensitivity Analysis:

Endpoint	Pollutant	Age group	Risk group fraction	CRF (95% CI)	Units
New cases of chronic bronchitis	PM2.5	27+	0.376%	53.3 (-1.7; 113.4)	per year, per 10 µg/m³, per 100,000 adults aged 27+
Asthma	PM10	0-14	1	1.18 (0; 2.45)	per year, per 10 µg/m³ per 1000 children 0-14
	PM10	15-64	1	0.51 (0.2; 0.82)	per year, per 10 µg/m³ per 1000 adults 15-64
	PM10	65+	1	0.95 (0.32;1.69)	per year, per 10 µg/m³ per 1000 adults 65+
Upper respiratory diseases	PM10	0-14	1	4 (-0.6 ; 8)	per year, per 10 µg/m³ per 1000 children 0-14
	PM10	15-64	1	3.2 (1.6-5)	per year, per 10 µg/m³ per 1000 adults 15-64
	PM10	65+	1	4.7 (2.4-7.1)	per year, per 10 µg/m³ per 1000 adults 65+
Acute respiratory symptoms	PM10	all	1	4650 (210; 9090)	symptom days per year, per 10 µg/m³ per 1000 people
Consultations with primary care physicians for allergic rhinitis	O3/SOMO35	0-14	1	3.03 (1.89; 429)	per year, per 10 µg/m³ per 1000 children 0-14
	O3/SOMO35	15-64	1	1.6 (1.22; 2.03)	per year, per 10 µg/m³ per 1000 adults 15-64
Medication / bronchodilator use Northern and Eastern Europe	O3/SOMO35	5-14	1	124 (18; 227)	per year, per 10 µg/m³ per 1000 children 5-14
Medication / bronchodilator use Western Europe	O3/SOMO35	5-14	1	310 (44; 569)	per year, per 10 µg/m³ per 1000 children 5-14

Table 3: Set of chosen ERF in NEEDS project (continued)

Source: Hurley et al., 2007

2.1.4 Discussion

The lack of significance of several functions exposed above is obvious, since the 95% confidence interval for those functions contains negative or null values. For instance, the association between PM_{10} and new cases of bronchitis among adults aged 27 years or older is not statistically significant (as in $p<.05$). However, no other function is currently available to quantify the related impacts in the literature. Furthermore, the assumptions made so as to run the present calculations already are numerous. Therefore, either those end points are put aside and not valued, which induces an underestimation of the impacts, or there are included in the valuation despite the lack of significance, which adds up to the overall uncertainty.

Another issue regarding these studies is the transferability of those functions: the distribution of effects induced by air pollution is time, site and technology specific. Therefore, functions derived from data stemming from a location will not be as accurate for quantifying impacts in a different location. An expected decrease of the significance and reliability must be taken into account when transferring the ERF. However, the overall significance of an economic valuation might be better off with a transferred, highly significant ERF than with a non-transferred, poorly significant ERF. Therefore, the use of transferred functions is not to be discarded before comparing the available prospects.

The methods available for such quantification are still being developed, so axes of improvement remain, as noted above, but estimates need to be currently calculated to help decision-makers promote adequate policies.

3 Distribution of Costs

The analysis of the distribution of costs due to air pollution related to electricity generation intends to show the relative importance of estimated costs of morbidity impacts over the estimated total costs of health impacts.

3.1 CAFE Cost Benefit Analysis – EU-25

The program Clean Air For Europe (CAFE) was initiated by the European Commission in 2001. It was an implementation of the ExternE method and, according to Watkiss et al. (2005) this program was meant “to develop a long-term, strategic and integrated policy advice for achieving levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment”. Two situations were compared: the situation in 2000, using available meteorological data gathered in 1997, and the projected situation in 2020, assuming that the implementation of the current air pollution legislation in all countries of the EU-25 is effective, that each Member State meets its climate policy obligations under the Kyoto Protocol and carries on implementing greenhouse gas reduction policies until 2020. The comparison of those two situations outlines the impact of current policies from 2000 to 2020. (Watkiss et al., 2005)

This study has been conducted regarding the European situation in 2000 and is based on reliable data. Furthermore, it enables the comparison of estimates between states of the European Union, with potentially different policies implemented, so as to analyze effects of decision-making in similar environmental conditions.

The model called RAINS has been used to run a simulation of PM concentration over Europe. This model is a tool for the integrated assessment of alternative strategies to reduce acid deposition in Europe and Asia (Alcamo et al., 1990); changes in the anthropogenic contribution to ambient concentrations of $PM_{2.5}$ in Europe resulting from changes in emissions of primary $PM_{2.5}$, SO_2, NO_x, and NH_3. Contribution from natural sources and changes in concentrations of secondary organic aerosols associated with anthropogenic emissions are not included in the model.

The cost-benefit analysis conducted in the CAFE project is organized according to several stages. First, the emissions are quantified, and the pollution dispersion across Europe is described. Then, the exposure of affected people, environment and buildings is quantified, as well as the impacts induced. Finally, those impacts are valued and uncertainties are described (Watkiss et al., 2005).

Both VOLY and VSL were considered in that program in order to show the inherent uncertainty related to these concept (Watkiss et al., 2005).
The following figure shows the implications of choosing the VOLY or the VSL concept:

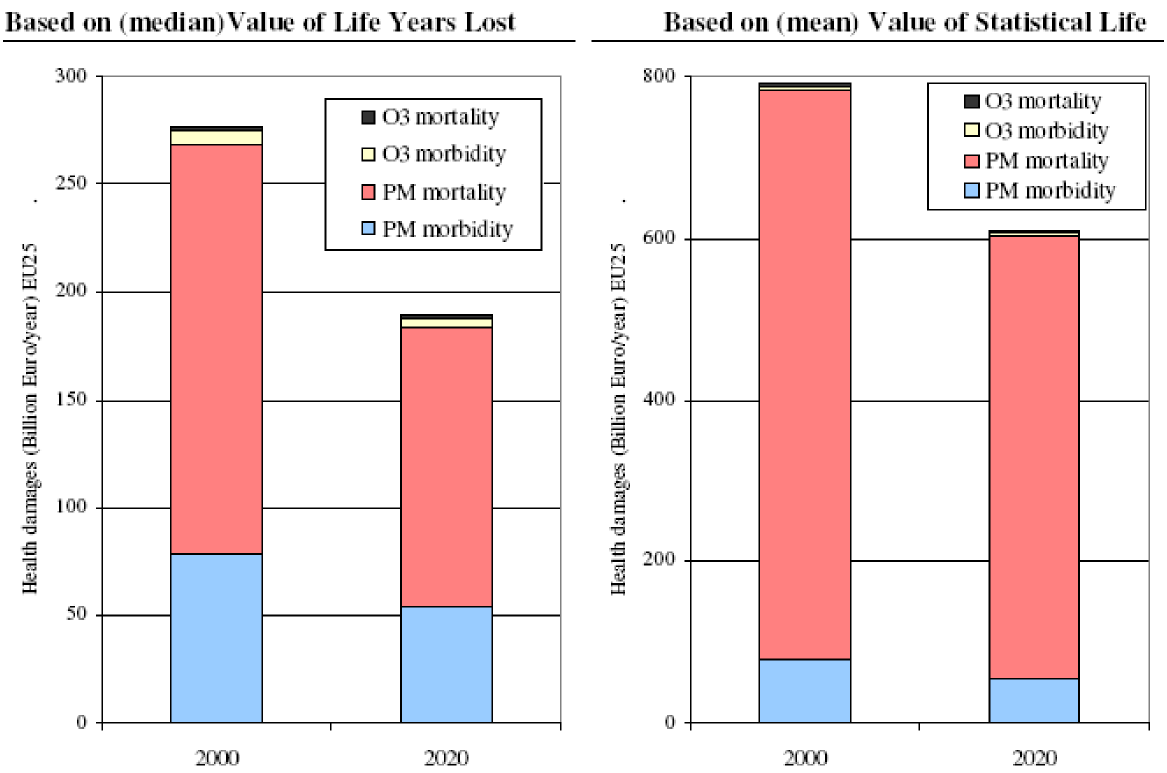

Figure 3: Estimated health damages of air pollution in EU 25 – VOLY vs. VSL concepts
Source: Watkiss et al. (2005)

Those two graphs show that results reflect the choice of concept when valuing the health impacts (and specifically the mortality impacts). A thorough consideration of the methods followed in economic valuation studies is essential when interpreting those studies.

Note that results are, as in most studies of this kind, split into mortality impacts on one hand, and morbidity impacts on the other hand. Morbidity impacts are sorted out by health end point and mortality impacts by exposure route (chronic and acute), infant mortality is dealt with separately.

The following tables are a summary of the results for the EU-25 area; the first one is relative to morbidity, and the second one to mortality. The figures are expressed in million Euros per year, but only represent costs borne by stakeholders, in no way do they stand for compensating payments addressed to the population.

It is obvious when analyzing the tables in Appendix 3 that mortality impacts seem to induce greater costs than morbidity ones. Also, effects of PM seem to have greater consequences on the overall costs than those of ozone.
The variation of mortality costs is rather important between the valuations based on the VOLY or VSL concept: their values range between 100 and 1000 billion Euros for 2000 in

the EU-25. This rough estimate may be more noteworthy than precise figures since the magnitude of uncertainties is unknown, due to the lack of evidence.

3.2 CAFE Cost Benefit Analysis – National Data

The following table represents of national results in the EU-25, collected in Watkiss et al. (2005). Total health costs are expressed using several statistical concepts. Morbidity costs equal the sum of costs related to all health endpoints considered in the CAFE study.

	€million/year					Average Morbidity / Total Costs
	Total Health Costs Using:				Included:	
	VOLY median*	VOLY mean*	VSL median*	VSL mean*	Morbidity	
Austria	4573	8477	6850	12582	1433	20,1%
Belgium	10301	19298	15726	29115	3066	18,9%
Cyprus	267	491	317	561	87	23,3%
Czech Republic	6911	12867	11055	20505	2121	19,2%
Denmark	2334	4349	3930	7331	714	18,7%
Estonia	405	757	740	1395	121	17,7%
Finland	1046	1953	1568	2892	317	19,4%
France	36733	68451	52733	96650	11218	20,0%
Germany	57741	107417	91643	169760	17798	19,3%
Greece	5513	10215	8863	16410	1732	19,6%
Hungary	7928	14784	15087	28493	2413	17,8%
Ireland	1109	2071	1485	2702	335	20,3%
Italy	38578	71409	62183	115102	12179	19,7%
Latvia	1253	2343	1687	3073	376	20,1%
Lithuania	1108	2074	2490	4774	329	16,4%
Luxembourg	310	579	411	746	95	20,7%
Malta	205	378	256	457	65	22,1%
Netherlands	13853	25910	19443	35610	4156	19,8%
Poland	26909	50321	40442	74675	8074	19,2%
Portugal	3784	7025	6152	11418	1176	19,3%
Slovakia	3577	6669	5280	9713	1089	19,7%
Slovenia	1333	2473	1975	3625	416	20,1%
Spain	16839	31155	25008	45838	5326	20,4%
Sweden	2506	4669	3997	7414	768	19,2%
United Kingdom	30720	57532	47980	89040	9157	18,8%
EU-25	275836	513667	427303	789878	84561	19,4%

Table 4: Valuation of the annual health damage due to air pollution in 2000 in each of the EU-25 countries
Adapted from Watkiss et al. (2005)

The value of national health impact is obviously associated with the size of the local population. The national value of morbidity impacts varies between 65 million and 17.8 billion Euros across the EU-25. That of mortality impact also depends on the chosen concept, and varies between 205 million and 169.8 billion Euros. But since mortality has already been intensely studied, the ratio of morbidity costs over total health costs would settle whether morbidity should be more thoroughly studied.

The column at the right end in Table 4 shows the national ratio of morbidity costs over total health costs.

The national ratio of morbidity costs over total health costs range from 6.9% (with VSL, mean value in Lithuania) to 32.6% (with VOLY, median value in Cyprus). Since these values are spread over such a wide range, it seems wise to consider the mean value of the four calculations. That latter varies between 16.4 and 23.3%, and the average value across the EU-25 is 19.4%.

These data show that about a fifth of total health costs were related to morbidity in EU-25, in 2000. It would therefore benefit the economic valuation of health effects if those of morbidity were further studied, and hence better valued.

3.3 Discussion

The plenty methods used for quantification and valuation of health effects tend to confuse the general population and decision-makers, while they should provide them with advice. The attempt of the European Commission to create a universal method (ExternE series) has been unanimously acknowledged, but this method raises issues.

The differential quantification method brings forward several of those issues. First, its complexity might induce misuse and misleading conclusions. Using this method requires know-how, understanding of the principles and great care. Even so, results can be misinterpreted or misunderstood by decision-makers, and lead to inadequate policies. Secondly, the unlikely modifying factors add on to the uncertainty of the method. It is hardly believable that all components of air pollution be equally toxic, as claimed in the CAFE and NEEDS “core analysis”. Finally, the interactions between pollutants are not yet accurately accounted for. Thus, that method is still being developed and modifying factors are still to be studied.

Morbidity effects are an important part of health effects induced by air pollution since they account for about 20% of the health costs. Further studies could develop more accurate means of quantification for those effects.

4 Economic valuation study within the HEIMTSA project

4.1 Background and context

The HEIMTSA (Health and Environment Integrated Methodology and Toolbox for Scenario Assessment, HEIMTSA 2009) project was funded by the European Union, and comes under the European Union Sixth Framework Program – Priority 6.3: Global Change and Ecosystems. Twenty-one partners from research and user organisations in Europe, building up an international team of scientists in the areas of epidemiology, environmental science, biosciences and economy, take part in this project. The goal is to develop and apply new, integrated approaches to the assessment of environmental health risks in support of European policy in transport, energy, agriculture, industry, household and waste treatment and disposal.

A work stream of this project, the work stream 4 called "Monetary Valuation", is devoted to economical valuation. In this work stream, a study is conducted to assess monetary valuation of health impacts of air pollution. The partners of this study are: Charles University Environment Center (Czech republic), Institute of Occupational Medicine (United Kingdom), Department of Economics & International Development (United Kingdom), Norwegian University of Life Sciences (Norway), SWECO NORGE (Norway), European Institute for Energy Research (in Germany but for France). EIFER is not an official partner in this survey but since EIFER has competencies in economic valuation of health impacts of air pollution it was asked to participate nevertheless.

At the end of April 2009 a meeting took place in Oslo to settle the conditions of the survey, with all the members of this work package. The aims of the meeting were to make common choices for the study in order to be able to aggregate the results to get a European value from the surveys conducted in different countries. So the questionnaire, the health endpoint and the conditions of the practical implementation of the survey have to be as close as possible in all countries.

The chosen health endpoint is Chronicle Obstructive Pulmonary Bronchitis (COPD). Indeed, COPD is a major cause of mortality and morbidity even if these obstructive diseases are not well known by the public. These diseases have a high cost for the society (Miller et al., 2005). Due to the fact that COPD is not a single disease but an umbrella term (see definition in section 4.2.1), different health states corresponding to different states of severity of the illness have to be valuated.

The target population is the general adult population (above 18 years old), healthy or ill. Indeed the whole population can be affected by air pollution and can suffer from COPD in the future. For the survey, representative sample of the country population will be sought. Into practice stratified sample[5] with quotas for cities/regions will be considered in order to achieve representativeness.

The next point was the choice of the valuation method. Two were possible (see definition in section 1.1.1A)):

- direct CV of a few health end points;

[5] « A sample selected from a population which has been stratified, part of the sample coming from each stratum." Ie the global population is cut into categories, and sample for the survey is made

- a combination of direct CV questions with chained approach.

The second method will be tested in the pre-test. If the results of the pre-test are not conclusive, the classical contingent valuation could be used. Moreover, the second part (the standard gambling) allows validating some results of the first part.

For the contingent valuation method, the payment vehicle is the price of a medicament for the describe illness. The determination of the amount will be made by the respondent by sorting cards with monthly amount and for the total duration (10 years).

The last point was the administration of the survey. The different possibilities are as shown in Figure 4.

Method	Advantages	Disadvantages
Mail surveys Printed questionnaires are posted to potential respondents	**Relatively inexpensive** Lack of interviewer bias Easier to answer sensitive questions Can be completed at respondent's own pace	**Low response rates 25-50%** Self-selection bias Time-consuming Little control over who fills the questionnaire Fixed question order No clarification or probing possible Restricts the use of visual aids Respondent can alter earlier responses
Telephone interviews Interviewers call potential respondents	Complex questionnaire structures are possible **Cheaper than face to face interviews** Permits probing and clarification Relatively quick to administer Easy to monitor **60-75% response rates**	No use of visual aids Restricts use of lengthy scales Respondent may get tired Respondents may not answer sensitive questions Non-telephone or non-listed respondents not sampled
Face-to-face interviews Interviews take place one-to-one between the interviewer and the respondent either at home or another location relevant to the study (intercept survey)	Highly flexible Complex questions and questionnaire structures are possible Permits probing and clarification Larger quantity of data can be collected Potential for extensive use of visual and demonstration aids **High response rates 70% +** Greatest sample control	**Relatively expensive** Possible interviewer bias Intercept surveys: samples normally not representative and self-selection bias Intercept surveys: questionnaires have to be short
Mixed methods: drop off survey The questionnaire is mailed prior to a visit by the interviewer	Initial personal contact gives survey a 'human face' Shares the advantages of mail and face-to-face methods	Survey form may be lost in interval before calling back **Expensive**
Mixed methods: mail + telephone surveys The questionnaire is mailed prior to a phone call by the interviewer	Gives personal touch to the survey Can complete mailed questionnaire in own time	Shares some of the limitations of mail surveys **Relatively expensive**
Computer assisted interviews Interviewer records responses directly to computer and/or respondent may respond to questions on computer screen	Subsequent analysis is quicker since data inputting stage is not necessary Permits more complex interviews Permits use of e-mail and internet	Possible rejection of 'computer technology' E-mail/internet may preclude random sample unless wide coverage of PCs

Figure 4: Main Data collection methods

according to this categories [1] OECD. Glossary of statistical terms. 2001 depend on the term

Computer assisted interviews will be conducted or per internet or in combination with personal interviews depending on the countries. The computer-assisted-web-interview (CAWI) method will be used in United Kingdom, Italy, Norway and France where internet penetration is high and representativeness of panel population is sufficient. In Czech Republic computer-assisted-personal-interview (CAPI) will be used as the main survey instrument, with web interview for control. Each country team should control internet-penetration by sex and age for their country to be sure to get a representative sample of the general population. By this way, not only costs and budgets constraints of the survey but also representation of the sample of the global population could be achieved.

A standard questionnaire in English will be made, each team translating in its own language. All the following tests, such as the survey, will be made on the translation.

4.2 Description of the health end points studied in the project

Air pollution can induce or worsen cardiac conditions (such as arrhythmia, atherosclerosis, thrombosis, myocardial infarcts), lung cancer and other respiratory diseases (such as asthma and bronchitis). In the study, as perilously said, it was focused on Chronic obstructive lung disease (COPD, called in French broncho-pneumopathie chronique obstructive).

4.2.1 Definitions

The American Thoracic Society (ATS) and the European Respiratory Society (ERS) give the following definition in their guide about COPD (ATS, ERS, 2009) [2]: “Chronic obstructive lung disease (COPD) describes a group of lung conditions (diseases) that make it difficult to empty the air out of the lungs. This difficulty can lead to shortness of breath (also called breathlessness) or the feeling of being tired. COPD is a word that can be used to describe a person with chronic bronchitis, emphysema or a combination of these. COPD is a different condition from asthma, but it can be difficult to distinguish between COPD and chronic asthma.” Another definition is given by the World Health Organisation (WHO) (WHO, 2009) [3]: “Chronic Obstructive Pulmonary Disease (COPD) is not one single disease but an umbrella term used to describe chronic lung diseases that cause limitations in lung airflow. The more familiar terms 'chronic bronchitis' and 'emphysema' are no longer used, but are now included within the COPD diagnosis.”

COPD can also be referred to as (but actually belongs to) Chronic Obstructive Lung Diseases (COLD), Chronic Obstructive Airway Diseases (COAD), Chronic Airway Limitations (CAL) and Chronic Obstructive Respiratory Diseases.

[cited 2009 18 aout]; Available from: http://stats.oecd.org/glossary/index.htm, A normal chronic bronchitis (CB) exists when people regularly cough up sputum (more than three months per year within two consecutive years). It is a reversible inflammatory illness. The obstruction part of the COPD comes when the airways in the lungs become narrowed, which leads to a limitation of the flow of air to and from the lungs causing shortness of breath. The confusion is often made with chronic bronchitis, which was also a former name of COPD.

4.2.2 Symptoms

The main symptoms of COPD are cough, sputum and shortness of breath [1]. The diagnostic is confirmed by a spirometry test which estimates the level of obstruction by measuring the quantity of air in the lung. The degradation of the lung and alveoli is irreversible

COPD also has consequences on cardiac, muscular, bone diseases, and also on patients' social life because of the activity restriction [4]. Obstructive chronic bronchitis and emphysema can also cause high blood pressure and lead to heart diseases. The risk of dying of dyspnoea, cough or sputum is also well known. (Frostad et al., 2006). Asthma is often associated with COPD, but is a different disease [5].

COPD is always preceded by chronic bronchitis and has several stages [6] which are shown on the Figure 5.

Stage	Characteristics
I: Mild	$FEV_1/FVC < 70\%$ $FEV_1 \geq 80\%$ predicted
II: Moderate	$FEV_1/FVC < 70\%$ $50\% \leq FEV_1 < 80\%$ predicted
III: Severe	$FEV_1/FVC < 70\%$ $30\% \leq FEV_1 < 50\%$ predicted
IV: Very severe	$FEV_1/FVC < 70\%$ $FEV_1 < 30\%$ predicted Or $FEV_1 < 50\%$ predicted plus chronic respiratory failure

FEV_1, forced expiratory volume in one second; FVC, forced vital capacity.

Figure 5: Classification of the severity of chronic obstructive pulmonary disease, based on post-bronchodilator FEV1

One problem for our work is that although there are international definitions, each doctor or institution has a personal view of the disease, with his own definitions of every stage. Theses differences conduct to confusion when comparing different health stages and when speaking with partners or interviewees. Moreover it can lead to double counting when registering the widespread of the disease because of the same cases counted many times under different names.

4.2.3 Relationship between COPD and air pollution

The main cause (90%) of the COPD is smoking (with a relative risk (RR) for smokers of 13, according to Andreas et al., 2009), active or passive smoking: up to about 50% of the smokers develop a COPD (Andreas et al., 2009)[4]. Other causes are environmental factors, such as air pollution (indoor - e.g. from cooking and heating- or outdoor), chemicals, and genetics. Occupational causes, combined with smoking, can also be a source for COPD.
The other identified factors are (Bousquet et al., 2007) allergens, diseases such as schistosomiasis or sickle cell disease, living at high altitude.

To determine the relationship between air pollution and respiratory symptoms and the cause of COPD (tobacco or air pollution) a cohort was constituted by seventh-day Adventists, a population who have a healthy lifestyle and do not smoke according to religious principles (Abbey et al., 1995)[7]. So they are a very good population to study the effects of atmospheric pollution on the health without routine confounding factors, such as tobacco. A cohort of 3914 people was followed between 1977 and 1987. The air pollution was approximated by the concentrations of PM_{10} (particles of 10 micrometers or less in aerodynamic diameter) estimated by the place of residence and work (available for all studies' members). Tests show that the precision of the extrapolation is good.
The risks associated with for PM_{10} at level above 100µg/m^3 of air are as follow:

- New cases of airway obstructive disease: RR= 1.17, with CI95%= [1.02, 1.33];
- New cases of definite chronic bronchitis: RR= 1.17, with CI95%= [1.01, 1.35];
- New cases of definite symptoms of asthma: RR= 1.30, with $CI_{95\%}$= [0.97, 1.73].

The first two results are significant, that is to say they show PM_{10} as a cause of respiratory (obstructive and non obstructive) diseases.

For our work, the confusion of cases due to air pollution with those due to tobacco can be a problem because tobacco is by far the first cause of COPD. To try to determine the cause of COPD, it is useful for this chained contingent valuation study to ensure that respondents are smokers or not.

Exposure risk functions are a link between an indicator of pollution (which could represent a mixture of pollutant) and a health impact, that is to say a number of ill people. It is different from a dose-response function, which is a link between the quantities of a substance to which people are exposed, and its consequences on an organ or physical function. In the NEEDS program (c.f. section 2.1), no function refers to COPD. Another European program, European Study of Cohorts for Air Pollution Effects (ESCAPE, Work Package 4, (ESCAPE, 2009) [6]), will develop concentration or dose – response functions for the COPD. This program begun in June 2008 and results are waited for the end of 2009.

One question is to know if the functions were determined for new cases (so concerning all the population) or for worsening of existing cases (that is to say, evolution of the illness, just already ill people are concerned). Often, dose-response functions are figure from doctor's consultation and/or from medication consumption. The results depend on the dose response function, so it has to be checked.

4.2.4 Prevalence

COPD represents about 15% of the chronic bronchitis cases. In Europe and Northern America, 8 to 13% inhabitants are suffering from COPD. It is the fifth cause of death and becomes steadily more important (Andreas et al., 2009; Hurley et al., 2005). Adults over 40 years old, and particularly over 65 years old, are particularly at stake (Warren, 2004). Females are more often ill, earlier and harder than men. The COPD prevalence sex ratio male/female is 0.6. In almost all countries, the poorest people's risk of developing chronic respiratory diseases is the greatest (greater exposure to risks and more difficult access to health service). From a global health perspective, more than 50% of the people affected by avoidable chronic respiratory diseases are deprived populations (or live in low or average income countries) (Biron et al., 2005).

A point for the HEIMSTA chained contingent valuation study is that only adults can be affected COPD, not children. So this survey will only value the health impact of air pollution among adults. For children, other health endpoints have to be chosen (such as those used in NEEDS, c.f. section 2.1).

4.2.5 Treatment and outcomes

Treatments do not stop the disease nor cure it. They can slow the evolution. Smokers are strongly advised to quit smoking. The use of bronchodilators, anti-inflammatory drugs and antibiotics can help to ease the air flow and prevent possible infections. Corticoids can also reduce irritation, swelling and mucus production. Vaccination against pneumonia may reduce the risk of inflammation and hence the risk of COPD. Intermittent or permanent

---

[6] http://www.escapeproject.eu/. The exposure risk functions and the monetary valuation found in this survey will be combined to update the CAFE directive (see section 3.1)

oxygen therapy can be used as ultimate treatment. The lung use can also be improved: patients should keep having regular activities in order to avoid losing any more lung power.

Chronic Respiratory Disease account for 7% of deaths and 4% of Disability Adjusted Life Years (DALY[7]) worldwide (Bousquet et al., 2007). The projected global deaths and disability adjusted life years in 2005 are represented on the Figure 6.

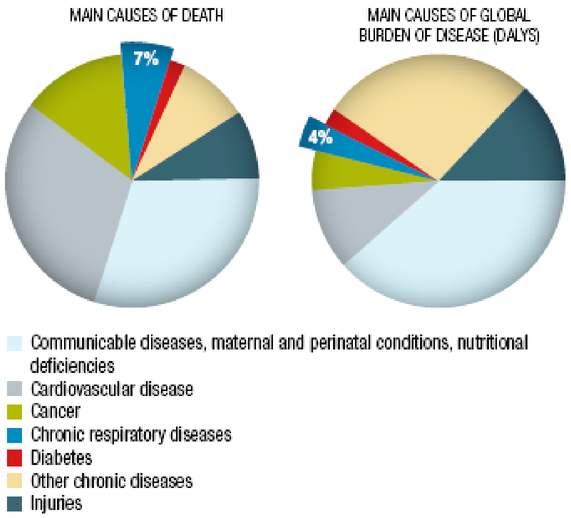

Figure 6: Projected global deaths and disability–adjusted life years (DALYs) in 2005

The risk of dying from COPD depends on the age of the patient, stage of the disease, smoking habits, health status (diabetes), way of living and treatment.

When considering the economic valuation of COPD due to air pollution, morbidity and mortality costs could be mixed up. Indeed, several COPD lead to death (mortality part) after a long time suffering (morbidity part). Furthermore, these two parts interact with each other: in case of a better air quality, the decrease in morbidity implies a decrease in the mortality due to the illness causing those. So confusion between the costs of morbidity (studied here) and mortality can appear.

4.3 Testing of the survey questionnaire

The main point of the work executed in the training period consisted in iterative testing the questionnaire. The objectives of these tests are to assess whether the questionnaire is easily understandable by anyone and that confusions are as few as possible, in order to

[7] «DALYs, disability adjusted life years, are an aggregated indicator which takes into account morbidity and mortality [8] Essink-Bot M-L. Dalys in Europe. Statistical Journal of the UN Economic Commission for Europe. 1999;16(1):19., which 1 being death (or extreme disability) and 0 being perfect health.

limit associated bias. If the respondents' answers are consistent and regular enough, the questionnaire will be considered usable for the study.

The tests were made in three rounds, in three French cities (Paris, Strasbourg and Haguenau). Between each round, the questionnaire was improved in order to be better adapted to the French population, as the original questionnaire was in English, designed for Czech Republic.

The first round of testing, in Paris, was made with an as exact as possible French translation of the common HEIMSTA questionnaire. It was standard one to one interviews conducted in a quiet room with people recruited in the street. Sixteen interviews were conducted in this way, showing the strong and weak points of this questionnaire in its application for France. This questionnaire was presented in a paper form, i.e. with long text read by the interviewer and the questions in the middle of this text. During the first testing round most respondents:

- had trouble processing the quantity of information given in the cards;
- found the whole questionnaire too long, with too many explanations read by the interviewer;
- found it difficult to believe in the scenarios because:
    - they wanted to know the names of the illnesses;
    - they found the amounts on the payment cards unrealistic;
    - they found the payment vehicle for cough inconsistent: paying over 10 years makes no sense for a single-day illness.

Some problems were aslo encountered with phrasing or translations.

Regarding these first results, the questionnaire has been modified for the second round of the survey (in Strasbourg, recruited as in Paris) to be more adapted to France (adaptation to the target population is essential for a sufficient understanding and consistent results) and to a web survey. Therefore, a "power point book", close to an internet presentation, was made, with very short phrasing. Respondents read this book and give the answers to the interviewer, who write them. The interviewer speaks as little as possible, just noting the answers of the respondent, and his questions or difficulties.

In the third round, the same presentation was retained, with other adaption according to the results of the second testing round. Tis round was conducted in Hageunau, in a Tennis club.

Remarks:

The second and third testing rounds contained 3 additional open questions (see part 2) which will not figure in the final questionnaire.

The Asthma WTP part was not tested.

A) Assessment of the interviews' quality and duration

For the first testing round (Paris), it was very difficult to recruit people in the streets. But, once recruited, the respondents appeared to be very interested in the questions addressed in the questionnaire. The interest rate, which was assessed by the interviewers, was 3.77 / 5. Moreover, an even greater interest was apparent during the description of the health states, which was rated at 4.08 / 5. The respondents were also very serious during the WTP assessment (rate: 4 / 5).

However, the concentration throughout the survey obviously decreased quite much. Indeed, the questionnaire was obviously too long: length varied from 32 to 76 Minutes.

The second and third testing rounds were faster: length varied from 15 to 55 Minutes.

B) Description of the sample

The samples of all testing round is not meant to represent the global French population. For example, for the first round (in Paris), it was brought together in a single day and only 16 respondents have been taken into account. Therefore, no statistical interpretation of the collected data would be relevant. Due to the small number of respondents, no trend could be outlined as regards the correlation between age, education level, gender and amount of WTP.

But the main goal of this test is to ensure that the questionnaire is understandable to anyone and that it is adapted to French people, their way of life and habits. Even if our sample is not representative of the French population (for example 62% of the respondents are female), we interviewed very different categories of people as showed below.

Since major changes were made in the presentation of the questionnaire to the respondents between the first round in Paris and the two other ones, the sample structures were grouped accordingly if relevant for the question.

In Strasbourg, 21 people answered to the questionnaire, and 19 in Haguenau.

Educational qualification	Exam after 9 years at school (Year 10 / Ninth grade)		Professional exam after 11 years at school (17 years old students)		Baccalauréat (end of secondary or high school, 18 years old students)		College or university (more than 12 years of studies)	
Age	Men	Women	Men	Women	Men	Women	Men	Women
60 +	0	1	0	0	0	0	2	2
40-59	0	0	0	0	1	0	1	1
30-39	0	0	1	1	0	0	0	2
18-29	0	0	0	1	0	0	0	2
Total	0	1	1	2	1	0	3	7

Table 5: Structure of the sample, first testing round (Paris)

Educational qualification	No diploma		Exam after 9 years at school (Year 10 / Ninth grade)		Professional exam after 11 years at school (17 years old students)		Baccalauréat (end of secondary or high school, 18 years old students)		College or university (more than 12 years of studies)	
Age	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
60+	0	0	0	0	0	0	0	0	2	1
40 - 59	0	1	1	0	2	2	2	0	3	2
30 - 39	0	0	0	0	0	1	0	2	3	3
18 - 29	1	0	0	0	1	0	2	0	4	7
Total	1	1	1	0	3	3	4	2	12	13

Table 6: Structure of the sample, second and third rounds (Strasbourg and Haguenau)

More than 31% of the respondents are older than 60 years old, which might come from the lack of time of younger people, as shown in Table 7. We had similar result in the second testing round, as shown in Table 8.

Age	Frequency	Percentage
70 +	2	12.5%
70 – 79	1	6.3%
60 – 69	2	12.5%
50 – 59	2	12.5%
40 – 49	2	12.5%
30 – 39	4	25.0%
18 – 29	3	18.8%
Total	16	100%

Table 7: Age distribution, first testing round (Paris)

Age	Frequency	Percentage
60+	3	7.5%
50 – 59	2	5.0%
40 – 49	11	27.5%
30 – 39	9	22.5%
18 – 29	15	37.5%
Total	40	100%

Table 8: Age distribution, second and third round (Strasbourg + Haguenau)

C) Content of the survey

a) Part 1: Introduction

The respondents are told that the survey is part of a European project. They were also explained that there are no good or bad answers. Finally, they are informed that response will just be used for research.

b) Part 2: Health Status

Knowledge of the health states

In the second and third rounds, the respondents were asked questions about chronic, serious, and respiratory illnesses in order to understand what the meaning of such diseases then is. About half of the respondents though that chronic illnesses are long-lasting and recurrent illnesses, and around 20% think those are hardly curable. Approximately 10% of the respondents have unexpected conception of chronic illnesses, such as “serious illnesses”, “affecting bronchi“, “requiring hospitalization” or “inducing fever”.

A serious illness is defined as a fatal illness by about 45% of the respondents, an incurable one by 17% of them, and as an illness which affects the daily life by 15% of them.

When asked what a respiratory illness was, asthma (60%) and bronchitis (39%) were the most frequent answers. Lung cancer was also quite often quoted (about 22% of the respondents).

So COPD is not well known by the public. Very few information were given to the respondents (excepted health cards, see Appendix 1), to keep the knowledge of the sample on the average level.

Assessing own health state

About 45% of the respondents consider their health status average, 29% of them consider theirs above average, and 18% well above average. The respondents were asked whether they had been diagnosed with serious or chronic illnesses. 50% of them had no any illness, 25% suffer from allergies to airborne allergens, 18% from rheumatisms, and 12.5% from hypertension. Two respondents were diagnosed with chronic bronchitis over the three rounds. There doesn't seem to be any strong correlation between age and own health status assessment.

But their relatives are said to suffer from allergies to airborne allergens (43%), rheumatisms (41%), asthma (39%), cancer (37%) and hypertension (30%).

c) Part 3: Ranking Symptoms

Four health conditions are presented to the respondents (cf. Appendix 1 for the cards with description of the illnesses):

- T for "Toux" (cough);
- B for "Bronchite" (bronchitis);
- M for "Bronchite chronique obstructive modérée" (moderate chronic obstructive bronchitis) ;
- S for "Bronchite chronique obstructive sévère" (severe chronic obstructive bronchitis).

The respondents were asked to rank these illnesses according to their severity, with the descriptions of the cards. This is a consistency check question, meant to ensure the respondents' understanding of the questionnaire.

As previously said, respondents had trouble processing the quantity of information given in the cards. So health card were simplified between the first and the second round (the last version is presented in Appendix 1).In the second and third rounds, respondents claimed they found the cards understandable.

d) Part 4: Willingness To Pay

The willingness to pay was determined as follow. A description of the illness (order randomly chosen between the four, knowing that each respondent value the four illnesses) and of its material conditions (a treatment which guaranties total recovery without side effect is available, but without any refund from neither any social health care nor insurances, but no wage loss) was given. Then, only in the second and third rounds, the respondent is asked if he want to pay to have this treatment or not because not asking this question and directly making the WTP game could create a bias because it "forces" respondents to pay something (at least a small amount) even they don't really want to. If not, he is asked why. If yes, the principle of the payment is explained: the respondent will have to pay the chosen amount in one time or monthly over ten years (for the bigger amounts). Cards with both amounts are given to help the respondent to chose. The respondent sorts them in three categories: Definitely would pay, definitely would not pay and unsure. After this sorting, the interviewer remembers to the respondent the highest amount he is ready to pay, the lowest he is not ready to pay. Then the interviewer asks to the respondent which amount he is ready to pay (open ended question to get the real amount the respondent is ready to pay). The Table 9, Table 10 and Table 11 give the response of this last question.

---	Mean value	Minimum value	Maximum value	Answers
WTP disease T	907.69	0	6000	13
WTP disease B	18128.57	0	100000	14
WTP disease M	25553.85	360	180000	13
WTP disease S	81682.86	720	360000	14

Table 9: WTP answers in euros, first round

---	Mean value	Minimum value	Maximum value	Answers
WTP disease T	3038	20	15000	10
WTP disease B	11013.33	240	48000	18
WTP disease M	23338.95	1200	120000	19
WTP disease S	23850	0	120000	20

Table 10: WTP answers in euros, second round

---	Mean value	Minimum value	Maximum value	Answers
WTP disease T	4050	0	12000	8
WTP disease B	15188.89	1000	60000	18
WTP disease M	21252.63	6000	60000	19
WTP disease S	39157.89	6000	240000	19

Table 11: WTP answers in euros, third round

e) Part 5: Standard Gamble

Three different situations are presented to the respondent. There are no monetary aspects anymore. For each of them, they are asked to estimate the chances they are willing to take a medication that is not certain to have the expected effects. Indeed, according to the standard gamble principle (see Chained Method), a choice is to be made between the certainty of a slight improvement of health condition, and the chance of a complete and definite recovery against a risk of deterioration of health condition.

The tested chained were:

- first round:
    - first situation: T->CB;.
    - second situation: , CB->O
    - third situation: CB->S
- second round:
    - first situation: T->CB, ,
    - second situation: CB->O
    - third situation: O->S
- third round:
    - first situation: T→ CB
    - second situation: CB → O
    - third situation: O → S

The results are shown in Table 12, Table 13 and Table 14, for each of the three rounds.

First Situation	
Risk	Freq.
< 0.1%	3
0.1 - 1%	4
1 - 5%	2
5 - 10%	0
10 - 20%	1
20 - 30%	2
30 - 40%	0
40 - 50%	2
50 - 60%	1
60 - 70%	0
70 - 80%	0
80 - 90%	0
90 - 95%	0
95 - 99%	0
> 99%	0
Total	15

Second Situation	
Risk	Freq.
< 0.1%	2
0.1 - 1%	2
1 - 5%	4
5 – 10%	2
10 – 20%	1
20 – 30%	1
30 - 40%	1
40 - 50%	0
50 - 60%	0
60 - 70%	0
70 - 80%	0
80 - 90%	0
90 - 95%	0
95 - 99%	0
> 99%	0
Total	13

Third Situation	
Risk	Freq.
< 0.1%	4
0.1 - 1%	2
1 - 5%	2
5 - 10%	1
10 - 20%	0
20 - 30%	0
30 - 40%	1
40 - 50%	0
50 - 60%	2
60 - 70%	1
70 - 80%	0
80 - 90%	0
90 - 95%	0
95 - 99%	0
> 99%	0
Total	13

Table 12: Standard gamble, first round

First Situation	
Risk	Freq.
< 0.1%	12
0.1 - 1%	2
1 - 5%	0
5 – 10%	2
10 - 20%	0
20 - 30%	2
30 - 40%	0

Second Situation	
Risk	Freq.
< 0.1%	2
0.1 - 1%	2
1 - 5%	2
5 – 10%	2
10 - 20%	3
20 - 30%	1
30 - 40%	1

Third Situation	
Risk	Freq.
< 0.1%	2
0.1 - 1%	1
1 - 5%	1
5 - 10%	3
10 - 20%	0
20 - 30%	1
30 - 40%	1

40 - 50%	2	40 - 50%	2	40 - 50%	5
50 - 60%	0	50 - 60%	3	50 - 60%	2
60 - 70%	1	60 - 70%	0	60 - 70%	1
70 - 80%	0	70 - 80%	1	70 - 80%	2
80 - 90%	0	80 - 90%	0	80 - 90%	0
90 - 95%	0	90 - 95%	0	90 - 95%	0
95 - 99%	0	95 - 99%	0	95 - 99%	0
> 99%	0	> 99%	1	> 99%	1
Total	21	Total	20	Total	20

Table 13: Standard gamble, second round

First Situation		Second Situation		Third Situation	
Risk	Freq.	Risk	Freq.	Risk	Freq.
< 0.1%	6	< 0.1%	2	< 0.1%	0
0.1 - 1%	4	0.1 - 1%	0	0.1 - 1%	1
1 - 5%	1	1 - 5%	2	1 - 5%	0
5 - 10%	2	5 - 10%	2	5 - 10%	1
10 - 20%	4	10 - 20%	1	10 - 20%	4
20 - 30%	1	20 - 30%	5	20 - 30%	3
30 - 40%	1	30 - 40%	2	30 - 40%	4
40 - 50%	0	40 - 50%	1	40 - 50%	1
50 - 60%	0	50 - 60%	3	50 - 60%	1
60 - 70%	0	60 - 70%	1	60 - 70%	1
70 - 80%	0	70 - 80%	0	70 - 80%	1
80 - 90%	0	80 - 90%	0	80 - 90%	0
90 - 95%	0	90 - 95%	0	90 - 95%	1
95 - 99%	0	95 - 99%	0	95 - 99%	0
> 99%	0	> 99%	0	> 99%	1
Total	19	Total	19	Total	19

Table 14: Standard gamble, third round

f) Part 6: Asthma

As already said, since there were no asthmatic respondents in the first round and this part was not included in the two following rounds.

g) Part 7: Socioeconomic characteristics

Level of education

Level of education	Freq.	% (sample)	% (whole french population)
No Answer	1	1.79%	
No Diploma	2	3.57%	14%
Exam after 9 years at school (Year 10 / Ninth grade)	2	3.57%	19%
Professional exam after 11 years at school (17 years old students)	9	16.07%	31%
Baccalauréat (end of secondary or high school, 18 years old students)	7	12.50%	11%
College or university (more than 12 years of studies)	35	62.50%	25%
Total	56	100%	100%

Table 15: Level of education, three rounds (study+ OECD, 2007)

The higher educated social class is clearly overrepresented in the three samples (c.f. Table 15). Therefore, the questionnaire might be better understood during the test phase than in the general population.

Occupation

	Freq.	% (sample).
Liberal occupation	9	16.1%
Full-time employee	23	41.1%
Part-time employee	6	10.7%
Student	9	16.1%
Home-maker	0	0.0%
Retired	6	10.7%
Unemployed	3	5.4%
On medical/sick leave or disabled	0	0.0%
Other	0	0.0%
Total	56	100%

Table 16: Occupation, three rounds

Income

The income level is an utmost important factor for WTP. Indeed, people with high income can more easily find money for new expenses (e.g. by decreasing superficial expenses) than people with low income. The following table is a summary of the incomes the respondents claim to receive. In the first round, respondents were asked for the household gross annual income (c.f. Table 17).

	Freq.	Percent.
No answer	8	50%
Lower than 8 900€	0	0%
Between 8 901 and 17 700€	0	0%
Between 17 701 and 26 600€	2	12.5%
Between 26 601 and 35 400€	1	6.3%
Between 35 401 and 44 300€	2	12.5%
Between 44 301 and 53 200€	0	0%
Between 53 201 and 62 000€	2	12.5%
Between 62 001 and 70 900€	0	0%
Between 70 901 and 79 700€	1	6.3%
Higher than 79 701€	0	0%
Total	16	100%

Table 17: Household gross annual income, first round

In France, respondent are not used to express their income this way, but rather in monthly net income. That is why in the second and third rounds, they were asked for monthly net income of the household (c.f. Table 18)

	Freq.	Percent.
No answer	2	5.0%
Lower than 600€	0	0.0%
Between 600 and 1 000€	1	2.5%
Between 1 000 and 1 500€	0	0.0%
Between 1 500 and 2 000€	6	15.0%
Between 2 000 and 3 000€	6	15.0%
Between 3 000 and 5 000€	14	35.0%
Between 5 000 and 10 000€	10	25.0%
Higher than 10 000€	1	2.5%
Total	40	100%

Table 18: Household net monthly income, second and third round

More than 50% of respondents live in a household earning more than 3000€ monthly. As the mean income in France in 2007 was 2661 euros, the sample, even if not representative, was not so far from the global French population.

The respondents were also asked whether they were thinking of their personal income, their household income or both, when eliciting their WTP. Most of them (around 58%) were thinking of their personal income. As both (personal and household) incomes are asked, the statistical treatment could be made with the income; the respondent said he had thought about. However, it will be very complicated from a statistical point of view.
Few respondents (about 12%) claimed they were not thinking of any of those incomes when eliciting their WTP. In the survey, it will be necessary to rule out these respondents from the study to have a better strength, even if it will reduce the sample, ie the result will be less significant.

h) Part 8: Behaviour and Lifestyle

Sport habits

The respondents were first asked about their sport habits, that is to say the frequency of their practicing any sport (over 30 minute-long taken into account). The trends of the results are very different from one city to another. The first round was held in the streets of Paris and the sample included more elderly people than in the other rounds. The second round took place in the street of Strasbourg, but a rather younger sample answered the questionnaire. Finally, the third one occurred in Haguenau, at a tennis club, and most of the respondents occasionally played tennis. Those different sample characteristics could explain the following results:

- In the first round, 25% of the respondents claimed they never practice any sport, while around 69% of them answered they have such activities at least once a week;
- In the second round, 10% of the respondents claimed they never practice any sport, while 85% of them answered they have such activities at least once a week;

- In the third round, about 10% of the respondents claimed they never practice any sport, while almost 90% of them answered they have such activities at least once a week.

Pollution exposure

The following question dealt with the respondents impressions about the air quality around their home. The results are gathered in Table 19.

	Freq.	Percent.
Highly polluted	11	19.64%
Somewhat polluted	11	19.64%
Slightly polluted	29	51.79%
Not polluted	5	8.93%
Total	56	100%

Table 19: Level of air quality as perceived by respondents

Unexpectedly, respondents in Paris answered they did not feel the air was highly polluted. Two reasons may explain this fact: first, respondents might live outside of the inner city, in a place where the air pollution level is lower than in Paris; secondly, many politics in Paris were made to decrease air pollution which can have influence the feeling of the respondents.

Comparison of air pollution levels

The respondents were asked to compare the air pollution level around their home with air pollution in others European cities of approximately the same size, and also with air pollution in others french cities. In the two first rounds of testing, the two questions were asked in this order (first: Europe, second: France). Confusion among the respondents was felt because they did not expect the second question and seemed to answer the first one by comparing to French cities only, as shown by the resemblance of Table 20 and Table 21.

	Freq.	Percent.
Much better than average	4	10.8%
Better than average	8	21.6%
Average	11	29.7%
Worse than average	9	24.3%
Much worse than average	4	10.8%
Does not know	1	2.7%
Total	37	

Table 20: Air quality compared to French cities, first and second rounds

	Freq.	Percent.
Much better than average	2	5.6%
Better than average	8	22.2%
Average	12	33.3%
Worse than average	11	30.6%
Much worse than average	2	5.6%
Does not know	1	2.8%
Total	36	

Table 21: Air quality compared to European cities, first and second rounds

So in the third round, the order of the questions was changed so as to answer the one about French cities first and European cities afterwards. Then respondents seem to understand better, as shown in Table 22 and Table 23.

	Freq.	Percent.
Much better than average	1	5.3%
Better than average	6	31.6%
Average	11	57.9%
Worse than average	1	5.3%
Much worse than average	0	0%
Does not know	0	0%
Total	19	

Table 22: Air quality compared to French cities, third round

	Freq.	Percent.
Much better than average	2	10.5%
Better than average	4	21.1%
Average	10	52.6%
Worse than average	3	15.8%
Much worse than average	0	0%
Does not know	0	0%
Total	19	

Table 23: Air quality compared to European cities, third round

More than 74% of the respondents feel the air quality level over their home is at least as good as that over European cities of approximately the same size, and almost 68% of them feels the same way when comparing the air level quality to other French cities.

Smoking habits

About 75% of the respondents claimed to be non-smokers, and almost 45% of them declared they had never smoked.

i) Debriefing

At the end of the questionnaire, a few debriefing questions indicate respondents understanding level of the scenarios, and data credibility (those provided throughout the questionnaire). The understanding level thus indicated is very good, since 100% of the respondents claimed they understood the scenarios. The credibility of the provided information is fairly good as well: 75% of the respondents declared they found it credible.
Note that the comprehension questions were asked in the two last rounds only; in the first round, respondents were asked whether they were provided enough information instead.

D) Open issues

Even if the tests gave many indications, some questions are still asked:

- the translation of the questionnaire for the different countries could still be a problem because this translation has in the same time to keep the meaning of the question (for the comparison between countries) and to be comprehensible by the respondents in each countries (to have strong answers);
- The willingness to pay is given by each respondent in the currency his country, that is to say: euro for France and Italy, pounds for United Kingdom, Norwegian Kroner for Norway, Czech Koruna for Czech Republic. There are different ways to change the currencies: just with exchange rate, or by taking into account the

difference of life standing (the purchasing power parity[8]). The problem is these rates change every day (or almost) which lead to poor adaptation of the results with the time.

[8] The purchasing power parity (PPP) theory uses the long-term equilibrium exchange rate of two currencies to equalize their purchasing power. Practically, it allows equalizing the purchasing power of different currencies in their home countries for a given basket of goods. It is often used to compare the standard of living between countries, rather than a per-capita gross domestic products comparison at market exchange rates.

Conclusion

The most important finding in this report is that the average value of morbidity costs due to air pollution across the European Union, estimated for the year 2000 by the project CAFE (2005), is around 20% of the total health costs for the same year. This fact shows that morbidity is not a negligible impact and should be considered when conducting health impacts quantifications and valuations to help designing environmental policies or computing external costs of electricity production. Otherwise, an important underestimation of the total health costs could mislead decision-makers.

Economic valuation methods were subjected to numerous developments by researchers to improve the external costs valuation of health impacts. Mortality impacts have been thoroughly studied for the past couple decades, as shown by the numerous theories and methods available for quantifying and valuing those effects. Morbidity impacts were not studied in such a detailed way. Therefore, propositions can be made in order to improve methods for valuing those effects. For instance, the extension of the application range of differential quantification to include morbidity impacts would possibly lead to finer estimates of morbidity-related costs.

Exposure-response functions are available for most health conditions related to air pollution, but were generally not derived for the general population. Conducting new studies, deriving exposure-response functions of particulate air pollutants on a sample representing the general population, would bring a major improvement of the valuation method.

Regarding the economical valuation, the HEIMTSA study on chronic obstructive pulmonary disease will provide more relevant economical values for different stages of chronic obstructive pulmonary disease.

Thus, the HEIMTSA study will result in the determination of up-to-date and more robust WTP values. The different tests conducted in France led to a range of improvement of the questionnaire.

Several questions of the testing permits to better apprehend the knowledge and perception of the respondents regarding chronic diseases and especially respiratory diseases. This helped optimize the phrasing used in the questionnaire. The descriptions of considered health points were adapted for a better understanding by respondents. The iterative testing also helped improve the acceptability of the payment conditions (by a better phrasing). The tests allowed to improve the standard procedure and finally showed that respondents are able to follow the proposed procedure for choosing the level of risk they accept.

The final round of tests shows the possibility to conduct:

- Internet survey. Indeed, the “Internet-like” version of the questionnaire seems adapted to a survey without the presence of an interviewer to provide additional information;

Internet interviews in less than 20 minutes. But the questionnaire should not be larger and therefore additional questions (or health endpoints as asthma) should not be added.

Finally, most improvements of the questionnaire achieved though the intensive and iterative testing in France were implemented in the English version of the HEIMTSA study which will be used in all the countries (Italy, United Kingdom, Norway, Czech republic) after careful translation. The next step of the study will be to test the Internet pilot for the survey (realised by the Czech Team).

The survey will take place in November 2009 and final results will be available at the end of February 2010.

In the long term, those results could be used for different computations of external costs due to air pollution. The economical value of the COPD endpoint as measured in HEIMTSA could be combined to improve ERF as assessed in other research projects funded by the European commission (for example the ESCAPE project[9]); All these new results could be used as input for the cost benefit analysis which will be conducted in the scope of the revision of the CAFE programme in 2012.

[9] “The ESCAPE study will investigate long-term effects on human health of exposure to air pollution in Europe. “. http://www.escapeproject.eu/. The ERF will be determined in the work package 4 which deals with respiratory disease.

Bibliography

Abbey D.E., Petersen F., Mills P.K. et al., 1993, Long-term ambient concentrations of total suspended particulates, ozone and sulfur dioxide and respiratory symptoms in a non-smoking population. Arch Env Health; 48: 33-46.

Abbey D.E., Hwang B.L., Burchette R.J., 1995, *Estimated Long-Term Ambient Concentrations of PM10 and Development of Respiratory Symptoms in a Nonsmoking Population*, Archives of Environmental Health, 1995 March/April, 50(2), 14.

Anderson H.R., Atkinson R.W., Peacock J.L. et al., 2004, Meta-analysis of timeseries studies and panel studies of particulate matter (PM) and ozone (O3). Report of a WHO task group. World Health Organization.

Andreas S., Hering T., Mühling S., at al. 2009 „Tabakentwöhnung bei chronisch obstruktiver Lungenerktrankung“ *Deutsches Ärzteblatt*.vol.106, n° 16, pp.276-282

APHEIS (Medina S., Plasència A., Artazcoz L. et al.), 2002, APHEIS Health Impact Assessment of Air Pollution in 26 European Cities. Second year report, 2000-2001. Institut de Veille Sanitaire, Saint-Maurice, France. (Apheis-2).

Atkinson R.W., Anderson H.R., Sunyer J. et al., 2001, Acute effects of particulate air pollution on respiratory admissions: results from APHEA 2 project. Air Pollution and Health: a European Approach. Am J Respir Crit Care Med. 2001 Nov 15; 164(10 Pt 1): 1860-6.

Berger, M., Blomquist, G., Kenkel, D. et al., 1994, “Framework for Valuing Health Risks”, in: Tolley, G., Kenkel, D. and Fabian, R. (Eds.): *Valuing Health for Policy: An economic approach*, The University of Chicago Press, Chicago.

Biron E., Carré P., Chanez P. et al. 2005 « Programme d’actions en faveur de la broncho-pneumopathie chronique obstructive (BPCO), 2005 – 2010, « Connaître, prévenir et mieux prendre en charge la BPCO ». Paris: Ministère de la Santé et des Solidarités

Bontems P., Rotillon G., *L’économie de l’environnement,* Paris, Ed. La Découverte, collection Repères, nouvelle édition novembre 2003.

Bousquet J., Khaltaev N., Global surveillance, prevention and control of Chronic Respiratory Diseases. A comprehensive approach. Genève: World Health Organization; 2007.

Declerq C., Macquet V., 2000, Short-term effects of ozone on respiratory health of children in Armentieres, North of France, *Rev Epidemiol Sante Publique*, 48 Suppl 2: S37-43.

Essink-Bot M-L., 1999, *Dalys in Europe*, Statistical Journal of the UN Economic Commission for Europe, 16(1):19.

Frostad A., Soyseth V., Haldorsen T. et al., 2006, Respiratory symptoms and 30-year mortality from obstructive lung disease and pneumonia, *Thorax*, 2006 29 June;61(11):7.

Gerlofs-Nijland M., Dormans J., Bloemen H. et al., 2007, “Toxicity of coarse and fine particulate matter from sites with contrasting traffic profiles”, *Inhal Toxicol*, 19: 1055-69 cited in ERPURS (2008).

Gielen M.H., Van der Zee S.C., Van Wijnen J.H. et al., 1997, Acute effects of summer air pollution on respiratory health of asthmatic children, *Am J Respir Crit Care Med*, 155: 2105-2108.

Gordon T. Linking health effects to PM components, size, and sources. *Inhal Toxicol*, 2007; 19 Suppl 1: 3-6 cited in ERPURS (2008).

Hardin G., 1968, "The Tragedy of the Commons", *Science*, 162(1968):1243-1248.

Hajat S., Haines A., Goubet S. et al., 1999, Association of air pollution with daily GP consultations for asthma and other lower respiratory conditions in London. *Thorax*; 54: 597-605.

Hajat S., Anderson H.R., Atkinson R.W. et al., 2002, Effects of air pollution on general practitioner consultations for upper respiratory diseases in London, *Occupational and Environmental Medicine*; 59: 294-299.

Hiltermann T.J.N., Stolk J., Zee S.C. et al., 1998, Asthma severity and susceptibility to air pollution, *European Respiratory Journal*, 11: 686-693.

Hoek G., Brunekreef B., Goldbohm S. et al., 2002, Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. *Lancet*, 2002; 360(9341): 1203-9.

Hughes G, Lovei M, 1999, "Economic reform and environmental performance in transition economies", technical paper number 446 (World Bank, Washington, DC)

Johansson P-O., 1995, *Evaluating Health Risks: An Economic Approach.* Cambridge, United Kingdom: Cambridge University Press.

Kuchler F., Golan E., 1999, Assigning Values to Life: Comparing methods for valuing health risks. Agricultural Economic Report no. 784, US Department of Agriculture.

Miller J.D., Foster T., Boulanger L. et al., 2005, “Direct costs of COPD in the U.S.: an analysis of Medical Expenditure Panel Survey (MEPS) data”, *COPD*, 2005 Sept, vol.2, n°3, pp.311-318.

Miller K.A., Siscovick D.S., Sheppard L. et al., 2007, “Long-Term Exposure to Air Pollution and Incidence of Cardiovascular Events in Women”, *N Engl J Med*; 356: 447-458.

ORNL/ RFF, 1994, Estimating Externalities of the Coal Fuel Cycle, Report 3 on the external costs and benefits of fuel cycles, A study by the US Department of Energy and the commission of the European Communities, Prepared by Oak Ridge National Laboratory and Resources for the Future, McGraw Hill.

Ostro B.D., 1987, Air pollution and morbidity revisited: A specification test, *J Environ Econ Manage*; 14: 87-98.

Ostro B.D. and Rothschild S., 1989, Air pollution and acute respiratory morbidity: An observational study of multiple pollutants, *Environ Res*; 50: 238-247.

Pearce D., Atkinson G. and Mourata S., 2006, Cost Benefit Analysis and the Environment, Recent Developments, OECD (ISBN 92-64 01004-1).

Pearce D. W., Seccombe-Hett T., “Economic Valuation and Environmental Decision-Making in Europe", *Environmental Science and Technology* 34(8): 1419-25 (2000).

Pope C.A. III, Dockery D.W., 2006, “Health effects of fine particulate air pollution: lines that connect”, *JAir Waste Manag Assoc*, 2006; 56: 709-42.

Pope, C.A. III, Burnett R.T., Thun M.J. et al., 2002, “Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution”, *Journal of the American medical association*; 287: 1132 - 1141.

Rainer F., 2004, *New Elements for the Assessment of External Costs from Energy Technologies.*

Seethaler R., 1999, Austria, France, Switzerland: Health costs due to road traffic-related air pollution, An impact assessment project of Austria, France and Switzerland, Synthesis report, WHO Ministerial Conference on Environment and Health, London World Health organisation 1999.

Spengler J. D., Wilson R., 1997, Letter to the Editor: Health effects of exposure to low levels of particulate matter, *Environment International*, Volume 23, Issue 4, 573-575

Sommer H, Seethaler R, Chanel O et al., 1999, Austria, France, Switzerland: Health costs due to road traffic-related air pollution, An impact assessment project of Austria, France and Switzerland, Technical report on economy, WHO Ministerial Conference on Environment and Health, London World Health organisation 1999.

Sun Y., Zhuang G., Tang A.A. et al., 2006, “Chemical characteristics of PM2.5 and PM10 in haze-fog episodes in Beijing”, *Environ Sci Technol*, 2006;40(10):3148–3155.

Warren E. Chronic obstructive pulmonary disease. 2004.

Woodruff T.J., Grillo J., Schoendorf K.C., 1997, “The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States”, *Environ Health Perspect*, 105: 608-612.

Websites and electronic documents:

APHEIS (Air Pollution and Health: A European Information System; 2004). Health impact assessment of air pollution and communication: Third Year Report, 2002-2003 (Apheis-3), [accessed 06.08.09], available at http://www.apheis.net/Apheis3NEW1.pdf.

Business Dictionary website, [accessed 08.07.09], available from:
http://www.businessdictionary.com/definition/economic-utility.html

European Study of Cohorts for Air Pollution Effects (ESCAPE) study website, [accessed 18.08.09], available from: http://www.escapeproject.eu/.

EIFER institute website, accessed 06.08.09, available at: http://www.eifer.uni-karlsruhe.de

Global Initiative for Chronic Obstructive Lung Disease (GOLD). Pocket Guide to COPD Diagnosis, Management, and Prevention 2008, [accessed 17.08.09], available from:
http://www.goldcopd.com/Guidelineitem.asp?l1=2&l2=1&intId=2002.

GreenFacts glossary website, accessed 19.08.09, available at:
http://www.greenfacts.org/glossary/

Investopedia website, accessed [08.07.09], available from:
http://www.investopedia.com/terms/u/utility.asp?viewed=1.

Multihazard Mitigation Council, National Institute of Buildings Sciences, 2005, Mitigation Savings Report, accessed 17.08.09, available from: http://www.nibs.org/MMC/

OECD. Glossary of statistical terms. [accessed 18.08.09], available from: http://stats.oecd.org/glossary/index.htm

OECD, 2007, Regards sur l'éducation, [accessed 20.08.09], available from :
http://www.oecd.org/document/43/0,3343,fr_2649_39263238_39251563_1_1_1_1,00.html

THE HISTORY OF ECONOMIC THOUGHT website, [accessed 08.07.09], available from:
http://homepage.newschool.edu/het//essays/uncert/bernoulhyp.htm

WHO, 2001, Quantification of the health effects of exposure to air pollution. WHO, European Centre for Environment and Health, Bonn, accessed 06.08.09, available at:
http://www.euro.who.int/document/e74256.pdf.

WHO, 2004, Health aspects of air pollution –answers to follow-up questions from CAFE. Report on a WHO Working Group meeting, Bonn, Germany, 15-16 January 2004. World Health Organisation, accessed 06.08.09, available at:
http://www.euro.who.int/document/e82790.pdf.

List of appendices

Appendix 1: Health State Cards

Toux 1 jour

Symptômes	Toux persistante avec glaires
Fréquence	Plusieurs fois par jour
Durée	1 jour
Conséquences	Pas de baisse de la qualité de vie générale
Si fumeur	
Evolution possible	Retour à la normale

Bronchite chronique

Symptômes	Toux persistante avec des glaires
Fréquence	Chaque jour
Durée	3 mois par an, pendant 2 ans
Conséquences	Pas de baisse de la qualité de vie générale Impossibilité certains jours de faire des activités astreignantes (tel que sport, course à pied, soulever des objets).
Si fumeur	Dégradation progressive de la respiration Conseil : arrêter de fumer
Evolution possible	Possibilité de persistance des symptômes au delà de deux ans Sinon : retour à la normale

Bronchite chronique obstructive modérée

Symptômes	Essoufflement dès que activité physique modérée, par exemple : marche rapide à plat ou en légère montée Toux avec glaires
Fréquence	Presque chaque jour
Durée	Le reste de votre vie
Conséquences	Essoufflement dès la pratique d'une activité physique modérée Mais les activités quotidiennes restent possibles Rendez-vous réguliers chez le médecin Prise de médicaments pour diminuer les symptômes et éviter l'aggravation Conseil : faire tout de même de l'exercice
Si fumeur	Dégradation progressive de la respiration Conseil : arrêter de fumer
Evolution possible	Aggravation de l'essoufflement avec le temps. En période d'aggravation des symptômes : encore plus de médicaments

Bronchite chronique obstructive sévère

Symptômes	Essoufflement important, au point de ne pas pouvoir sortir Toux importante Sifflement lors de la respiration et poitrine compressée Sensation de fatigue ou d'épuisement Hospitalisation nécessaire par moment
Fréquence	Presque chaque jour
Durée	Le reste de votre vie
Conséquences	Activités quotidiennes limitées. Obligation de rester au domicile Besoin d'aide pour les taches quotidiennes (habillement, toilette). Régulièrement besoin d'un appareil à oxygène pour respirer Conseil : faire tout de même de l'exercice
Si fumeur	Dégradation plus rapide de la respiration Conseil : arrêter de fumer
Evolution possible	Risque de mourir prématurément augmenté

Appendix 2: Review of Exposure-Risk Functions for mortality effects

Mortality from long-term exposure to PM (adults aged 30 years or more)

The Pope et al. (2002) update of the American Cancer Society (ACS) cohort study stands as a reference for quantifying the effects on mortality of long-term exposure to PM. The following ERF was used in the CAFE CBA:

6% change in mortality hazards (95% CI 2–11%) per 10 µg/m^3 of $PM_{2.5}$

That study is based on data collected by the ACS as part of the Cancer Prevention Study II, an ongoing prospective mortality study of approximately 1.2 million adults. Participants resided in all 50 states of the United States, were aged 30 years or older and were members of households with at least 1 individual aged 45 years or older.

An alternative estimate from that study is as follows:

4% change in mortality hazards (95% CI 1–8%) per 10 µg/m^3 of $PM_{2.5}$

A coefficient of 5%, i.e. the average of the two functions mentioned above, was applied for adults aged 30 or more in recent ExternE-based valuations, such as NewExt.

Mortality from long-term exposure to PM (infants aged less than 1 year)

Woodruff et al. (1997) studied the association between particulate air pollution and mortality among children, in a cohort study of approximately 4 million infants born between 1989 and 1991 in the United States. “Data from the National Center for Health Statistics-linked birth/infant death records were combined with measurements of particulate matter […] (PM_{10}) from the EPA's Aerometric Database” (Woodruff et al., 1997). The mean of the PM levels for the first two months of each infant’s life was considered in this study, in order to avoid overestimating the association between PM concentration and mortality. The following ERF resulted from the collected data:

4% change in mortality hazards (95% CI 2% - 7%) per 10 µg/m^3 of PM_{10}

Mortality from short-term exposure to PM (at all ages)

The WHO meta-analysis of studies in Europe (Anderson et al, 2004) provides a suitable coefficient estimate (double-counting avoided):

0.6% change in mortality hazards (95% CI 0.4–0.8%) per 10 µg/m^3 of PM_{10}

The guidelines for study selection were discussed and determined at a meeting of the WHO Task Group, and include a few requirements, such as the inclusion of studies from Europe solely, a focus upon single-pollutants model results based upon an all-year analysis, and the selection of the latest and largest study in case a city has been studied several times.

In a previous literature review, Dockery and Pope (1994) inferred a higher slope for that ERF: 1.0% risk change (ranging from 0.7 to 1.6%) for each 10 µg/m^3 variation of PM_{10}. Despite the good consistency of the review, a transferability issue remains between data from the United States and the valuation of hazards in the European population. Also, Anderson et al. (2004) is more up-to-date and hence more reliable.

Mortality from short-term exposure to O_3

The WHO meta-analysis (Anderson et al., 2004), provided the following ERF:

0.3% risk change (95% CI 0.1–0.43%) per 10 µg/m^3 increase in the daily maximum 8-hour mean O_3

That ERF is relative to all-cause mortality; two recent studies provided several ERF related to cardiovascular and respiratory mortality (Bell et al., 2004; Gryparis et al., 2004).

	1-hr max	**8-hr max**	**daily average**
NMMAPS (Bell et al. 2004)*	0.17 (0.11-0..23)	0.21 (0.14-0.29)	0.26 (0.14-0.39)
APHEA (Toulomi, 1997)	0.58 (0.2-0.8)		
APHEA2 (Gryparis, 2004)#			
Summer	0.33 (0.17-0.52)	0.31 (0.17-0.52)	
Winter	0.09 (-0.25-0.37)	0.12 (-0.12-0.37)	
WHO meta-analysis		0.3 (above 35 ppb)	

Summary of findings in recent studies

Source: NEEDS RS1b – WP3 report (Hurley, 2007)

Appendix 3: Results of the CAFE study

End point	End point	Function	Poll.	Baseline in 2000	Current legislation in 2020 (including Climate Policy)	Difference from 2000 to 2020
Respiratory hospital admissions	Cases	Core	O_3	28	40	-12
Minor Restricted Activity Days (MRADs)	Days	Core	O_3	2071	1629	442
Respiratory medication Use (Children)	Days	Core	O_3	20	12	8
Respiratory medication Use (Adults)	Days	Core	O_3	8	8	1
Cough and LRS (children)	Days	Core	O_3	4152	2508	1644
Total O_3 morbidity				**6280**	**4197**	**2082**
Chronic bronchitis	Cases	Core	PM	30687	24011	6677
Respiratory hospital admissions	Cases	Core	PM	124	85	40
Cardiac hospital admissions	Cases	Core	PM	77	52	24
Restricted activity days (RADs)	Days	Core	PM	28997	18515	10482
Respiratory medication Use (children)	Days	Core	PM	4	2	2
Respiratory medication Use (adults)	Days	Core	PM	26	20	6
LRS (including cough) among children	Days	Core	PM	7405	3413	3992
LRS in adults with chronic symptoms	Days	Core	PM	10962	7974	2988
Total PM morbidity				**78283**	**54071**	**24211**
TOTAL MORBIDITY BENEFITS				**84562**	**58269**	**26294**

Valuation of the annual health damage (morbidity) due to air pollution in 2000 and in 2020 in the EU-25 (figures in €million in a year)

Source: Watkiss et al. (2005)

End point MORTALITY	End point output	Function Group		Baseline in 2000	Current legislation in 2020 (inc CP.)	Difference from 2000 to 2020
Acute Mortality *(VOLY median)**	Premature deaths	Core	O_3	1119	1085	34
Acute Mortality *(VOLY mean*)*	Premature deaths	Core	O_3	2512	2435	77
Total Ozone Mortality						
VOLY median*				**1119**	**1085**	**34**
VOLY mean*				**2512**	**2435**	**77**
Chronic Mortality *(VOLY median)**	Life years lost	Core	PM	189203	129000	60203
Chronic Mortality *(VOLY mean*)*	Life years lost	Core	PM	424690	289556	135134
Chronic Mortality *(VSL median)**	Premature deaths	Core	PM	340670	265965	74706
Chronic Mortality *(VSL mean*)*	Premature deaths	Core	PM	700901	547200	153701
Infant Mortality (0-1yr) *(VSL median)**	Premature deaths	Core	PM	952	495	457
Infant Mortality (0-1yr) *(VSL mean*)*	Premature deaths	Core	PM	1903	990	914
Total PM Mortality						
VOLY median*				**190155**	**129495**	**60660**
VOLY mean*				**426593**	**290546**	**136048**
VSL median*				**341622**	**266459**	**75162**
VSL mean*				**702804**	**548190**	**154614**
TOTAL Mortality						
VOLY median*				**191274**	**130580**	**60694**
VOLY mean*				**429105**	**292981**	**136124**
VSL median*				**342741**	**267544**	**75197**
VSL mean*				**705316**	**550625**	**154691**

Valuation of the annual health damage (mortality) due to air pollution in 2000 and in 2020 in the EU-25 (figures in €million in a year)

Source: Watkiss et al. (2005)

TERRASSON	Rémi	28-09-09

Ingénieurs du Génie Sanitaire

2009

Évaluation économique des impacts sanitaires « morbidité » de la production d'électricité

Résumé **:**

La production d'électricité provoque des atteintes à l'environnement et des impacts sanitaires qui ont un coût pour la société. L'estimation des coûts des effets sanitaires totaux liés à la pollution atmosphérique pour l'an 2000 s'élève à plusieurs centaines de milliards d'euros pour l'Union Européenne. Ceci représente donc un enjeu majeur et il convient d'évaluer les impacts liés à la production d'électricité. Ces impacts sanitaires se découpent en deux groupes : la morbidité et la mortalité. Bien que la morbidité représente presque 20% des coûts totaux, elle est moins étudiée que la mortalité. Cette étude s'est intéressée aux impacts sanitaires de la pollution atmosphérique.
L'évaluation des coûts sanitaires se fait en deux temps selon la méthode de cheminent d'impact. Les travaux réalisés pendant le mémoire portent sur ces deux aspects : la détermination des impacts sanitaires puis la détermination des coûts pour la société (coûts externes) liés à ces impacts.
Concernant l'évaluation des impacts sanitaires, les fonctions expositions-risques utilisées ne sont pas toujours adaptées à la population étudiée. Le recensement effectué dans ce rapport montre que de nombreuses approximations sont réalisées pour appliquer ces fonctions à l'ensemble de la population. Le développement de fonctions E-R plus adaptées sont en cours dans le cadre de projets de recherche européens.
Concernant l'évaluation des coûts sanitaires, elles nécessitent des valeurs propres à chaque maladie. Il n'y a pas de donnée actuelle pour les coûts engendrés par la pollution atmosphérique. La partie pratique du travail a consisté en la participation à un projet européen (HEIMTSA) visant à déterminer la valeur économique de la broncho-pneumopathie chronique obstructive à travers une évaluation contingente. A cette fin, un questionnaire a été développé au niveau européen et nous avons amélioré la version française par des séries de tests successifs.

Abstract :

Costs associated to morbidity impacts due to air pollution account for almost 20% of the total health impacts for the year 2000 in the European Union. Even if the economic valuation of these costs has already been conducted in different research projects, many improvements in the valuation methodology and necessary data are still needed. On the other hand, the uncertainty of the estimates will be reduced by a better valuation of the willingness to pay for avoiding impacts. This is the aim of a study (conducted in the scope of the HEIMSTA project) which focuses on chronic obstructive pulmonary bronchitis.

Key Words **:**

Air Pollution, economics, morbidity, mortality, Cost-Benefit Analysis, Life Valuation, Economic, Risk Assessment, Electricity

Mots Clé **:**

Pollution atmosphérique, Economie santé, Mortalité, Morbidité, Analyse coût bénéfice, Coût vie humaine, Mesure risque, Impact, Électricité