# ECONOMIC COSTS OF AIR POLLUTION-RELATED HEALTH IMPACTS

## An Impact Assessment Project of Austria, France and Switzerland*


Rita K. Seethaler[1], Künzli N.[2], Sommer H.[3], Chanel O.[4], Herry M.[5], Masson S.[6], Vernaud J-C.[7], Filliger P.[8], Horak F.Jr.[9], Kaiser R.[10,11], Medina S.[10], Puybonnieux-Texier V.[12], Quénel P.[10], Schneider J.[13], Studnicka M.[14], Heldstab J.[15]

1). The Urban Transport Institute, PO Box 363, Alexandra, Vic 3714, Australia
2). Institute for Social and Preventive Medicine, University Basel, Switzerland and Preventive Medicine Department, Division of Occupational and Environmental Health, University of Southern California, Los Angeles, USA
3). ECOPLAN, Economic and Environmental Studies, Berne/Altdorf, Switzerland
4). French National Center for Scientific Research, Economic Department GREQAM, Marseille, France
5). Max Herry, Consultancy Dr. Max Herry, Vienna, Austria
6). Economic Department, BETA, Strasbourg, France
7). French National Center for Scientific Research, Economic Department, EUREQUA, Paris, France
8). Swiss Agency for Environment, Forests and Landscape, Berne, Switzerland
9). University Childrens' Hospital, Vienna, Austria
10). National Institute for Public Health Surveillance, Environmental Health Department, Saint-Maurice, France
11). Epidemic Intelligence Service, Epidemiology Program Office and National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, USA
12). Université Paris 7 – LED, Paris, France
13). Federal Environment Agency, Department of Air Quality Control, Vienna, Austria
14). Center for Pulmonary Disease, Vienna, Austria
15). INFRAS, Infrastruktur-, Umwelt- und Wirtschaftsberatung, Zurich, Switzerland



*This project has been cofunded by the Austrian Federal Ministry for Environment, Youth and Family Affairs, co-ordinated with the Austrian Federal Ministries for Labour, Health and Social Affairs as well as for Science and Transport and the Austrian Medical Association; the Federal Environment Agency of Austria; the Agency for Environment and Energy Management ADEME Air and Transport Direction, France; the Federal Department of Environment, Transport, Energy and Communications, Switzerland.

Published in *Clean Air and Environmental Quality*, Vol. 37, No. 1, February 2003, pp. 35-43



## Summary

The quantification of environmental-related health effects and their valuation in monetary units play a key role for a sustainability-oriented planning of policy measures. The present paper demonstrates the calculation of air pollution-related health costs using the tri-national study of Austria, France and Switzerland on health costs due to transport-related air pollution, that was conducted on behalf of the Third WHO Ministerial Conference (London, 1999). The epidemiological information on exposure-response functions (effect estimates) and health outcome frequencies (mortality and morbidity; prevalence, incidence, or person-days) combined with the air pollution exposure of the population, provides the number of attributable cases to total air pollution and to traffic-related air pollution. For the assessment of health costs, two different methods are available. The main method consists of the willingness-to-pay approach, that assesses the willingness to pay for a reduction in risk, that is for the prevention of a (statistical) fatality or illness. This approach includes the material costs as well as intangible cost elements, i.e. for pain, suffering and the loss of life quality. A partial method is the human-capital approach that estimates the medical costs and the loss of income, production or consumption arising due to premature mortality or morbidity and which only covers the material cost elements. Accross the three countries (74 million inhabitants) the health costs due to traffic-related air pollution for the year 1996 amount to some 27 billion €. This amount translates to approximately 1.7% of GDP and an average of 360€ per capita per year. In all three countries, the premature mortality is predominant, accounting for about 70% of the costs.



*Keywords*: air pollution; particulate matter PM10; health risk assessment; monetarization of health effects; willingness-to-pay approach.

# 1. Introduction

## 1.1. The context of the tri-national study on air pollution-related health costs of Austria, France and Switzerland

At the Third WHO Ministerial Conference for Environment and Health (London, 1999), the WHO released a Charter on Transport, Environment and Health, which claims that one of the key elements for sustainability oriented policy design is the quantification of environmental-related health effects and their valuation in monetary terms (WHO, 1999). The present paper demonstrates the calculation of air pollution-related health costs using the tri-national study of Austria, France and Switzerland on health costs due to transport-related air pollution, that was conducted on behalf of the Third WHO Ministerial Conference in London, 1999 (WHO, 1999). The main partners for this tri-national project were the Austrian Federal Ministry of Environment, Youth and Family Affairs and the Federal Environment Agency, the French Agency for Environment and Energy Management and for Switzerland the Federal Department for Environment, Transport, Energy and Communications.

## 1.2. The general structure of the tri-national study

In this project **three scientific disciplines** worked together: Physics, Epidemiology and Economics.

- The air pollution team had to assess the exposure of the residential population and identify the transport-related share of air pollution exposure
- The epidemiologic team had to identify the relevant health effects related to air pollution and establish exposure-response functions that would allow to calculate the number of attributable cases.
- The economic team had to identify the different cost components related to the health impacts and determine a way of valuing them in monetary terms.

In addition to the population exposure to the annual average of total air pollution as it was registered in 1996 for the three countries, a hypothetical situation without the traffic-related share of air pollution exposure was established. Knowing the air pollution exposure of the study population in both situations and the relationship between exposure and frequency of health outcomes, the number of mortality and morbidity cases due to air pollution could be calculated for both situations: for the total air pollution and the hypothetical situation without the traffic related air pollution. The difference between the two situations corresponds to the health impacts attributable to traffic-related air pollution, which constitutes one of the key interests for the transport policy in the three countries involved in this project. Finally, for each health outcome the costs had to be established.

Wherever assumptions had to be made in one of the three scientific domains, the more conservative alternative was chosen resulting in an "at least approach". This means that the results must be considered as an "at least to be expected level".

# 2. Estimation of the Population Exposure

## 2.1. General objectives

In the domain of air pollution, the annual mean exposure of the residential population had to be assessed. The result is a geographic mapping of different levels of exposure and the number of persons in each exposure class. It has to be considered that the emission source is not only transport but other sources as well, such as industry and households.

Important epidemiological studies, that were available at the time of the project, establish the exposure-response function for the annual average outdoor exposure to PM10. Therefore, PM10 was chosen as the main indicator representing the ambient air pollution mix . PM10 are particulate matter with a diameter lower than 10 micro-meter that pass the larynx and can reach the lower air ways.

## 2.2. Common methodological framework for the exposure assessment

In spite of major differences in their monitoring networks of ambient air pollution and the availability of emission inventories in the three countries, a common methodological framework was established, which contained the following steps:

- Acquisition and analysis of data on the ambient concentration of particulate matter: Monitoring networks for Black smoke, Total Suspended Particulates (TSP) and PM10, where available. Use of these measurements for model comparison where modelled values are checked against measured values or for the analysis of correlations between different particle measurement methods. PM10 measured by gravimetric filter samplers as proposed by the European Standardisation Office is used as a reference.
- Production of a PM10 map for each country, by means of

a) spatial interpolation between the measurement stations using statistical methods, setting up a relationship between measured concentration and land use parameters (e.g. industrial area, traffic area, agricultural area, built-up area, altitude). The advantage of the statistical method is that it can be used in cases where no emission inventory is available.

b) using empirical dispersion based on emission inventories: Spatially disaggregated emission inventories are used to calculate the dispersion of primary particles using simple dispersion profiles (Gaussian model). The secondary particles are estimated by using relationships between precursors and secondary particle concentrations. The PM10 measurements are used to validate and calibrate the model.

In addition, both approaches had to treat the European long-range transported fraction of PM10 separately.

- Estimation of the road traffic related PM10 fraction is performed by using different approaches:

a) Based on emission inventories for primary particles and for the precursors of secondary particles. Where re-suspended road dust is not included in the emission inventory, a substantial portion of PM10 emissions from traffic is missing.

b) Based on receptor models using atmospheric particle measurements to provide a quantitative estimate of the contribution of different sources to particle mass, using factorial analysis or chemical mass balance. In the tri-national study no primary receptor studies have been performed but information from existing receptor studies have been taken into account.

c) Based on dispersion models that have the advantage that they are able to establish the link between emission source and receptor concentration and provide the apportionment to the different sources. However, the quality of the result strongly depends on the quality of the emission inventory.

- The calculation of the population exposure can be performed by:

a) location of residence, or

b) personal exposure.

Since the epidemiological exposure-response functions are based on the ambient annual average level of air pollution rather than personal exposure, the average annual PM10 concentration maps were laid over the residential population distribution maps.

For the three countries, the modelled PM10 concentration values were generally in good agreement with measured values. In this European context, the determination of regional PM10 background concentration from large-scale trans-boundary dispersion was critical. The estimates for the regional background are in all three countries in line with the data measured and modelled from European large-scale models EMEP. The large-scale transported fraction of PM10 is considerable and can reach over 50% at rural sites. Also, the contribution of traffic to PM10 background concentration is substantial and may strongly vary in space (Filliger et al., 1999).

## 2.3 Results: The population exposure to PM10

The first part of the result is the Population Exposure to the total PM10 concentration, as shown in Figure 1. The distribution shows that:

- 50% of the population lives in areas where the average PM10 values are between 20 and 30 micro-grams per cubic meter,
- one third lives in areas with values below 20 micro-grams PM10,
- the rest is exposed to PM10 concentration above 30 micro-grams per cubic meter, whereby these high concentrations are found exclusively in large urban areas.

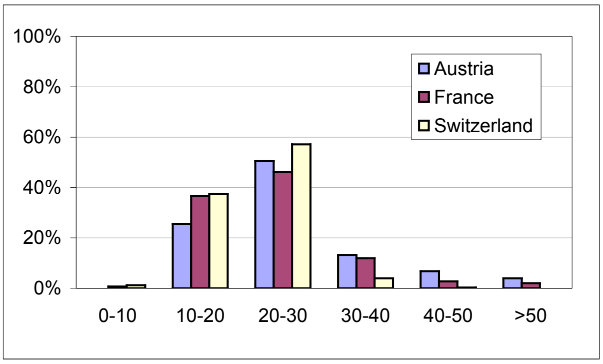



FIGURE 1 Total PM10 exposure

The second part of the result is the population exposure to PM10 without the traffic-related share, as shown in Figure 2. Compared to the total exposure, the frequency distribution changes considerably. Most people would now live in areas with annual average PM10 concentration values of less than 20 µg/m$^3$. In France and Switzerland less than 3% of people would now live in areas with more than 20 µg/m$^3$ PM10 annual mean concentrations. In Austria this proportion is higher because of a higher regional background concentration from neighbouring Eastern European countries. But for all three countries the percent reduction in the high exposure classes is substantial and indicates that road traffic contributes considerably to these classes.

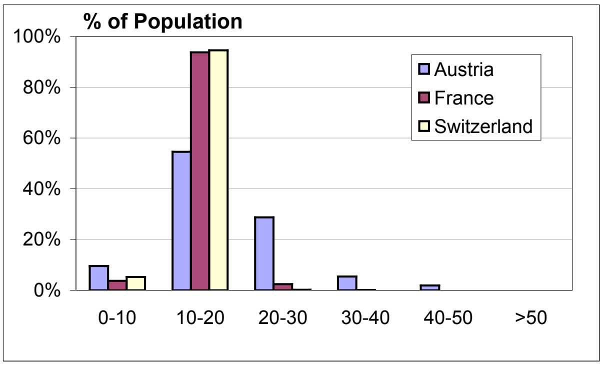



FIGURE 2 PM10 exposure without traffic share

The results from the air pollution assessment are once again summarized in Table 1 that presents the population weighted annual averages for total PM10 exposure, PM10 exposure without road traffic-related fraction and the road traffic related fraction alone.

TABLE 1 Population weighted annual PM10 averages for Austria, France and Switzerland (1996)

| | PM10 concentration in _g/m$^3$ (annual mean) | | |
|---|---|---|---|
| | Austria | France | Switzerland |
| Total PM10 | 26.0 | 23.5 | 21.4 |
| PM10 without road-traffic related fraction | 18.0 | 14.6 | 14.0 |
| PM10 due to road traffic | 8.0 | 8.9 | 7.4 |

The interpretation of the results has to take into account that road-traffic related PM10 exposure varies considerably in space. The relative contribution of road traffic to total PM10 concentrations is higher in city centres. Typical values are 40-60% in cities and <30% in rural areas (Swiss model).

# 3. Epidemiological assessment of air pollution-related health impacts

## 3.1. General objectives

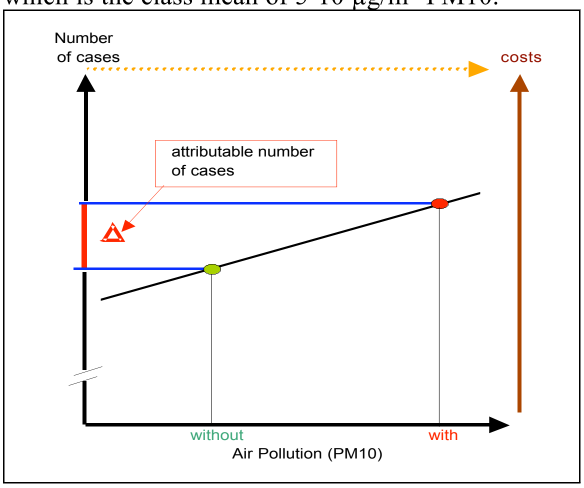
The epidemiological calculations require knowledge about the exposure-effect relationship between air pollution and health. In recent years, a large number of epidemiologic studies have been conducted in all three countries and in many other nations around the world. Overall, these studies give strong evidence for a variety of acute short-term as well as long-term effects of air pollution on health. Based on this information, the number of additional cases attributable to air pollution had to be assessed for each level of exposure.

## 3.2. Common methodological framework

Figure 3 illustrates a simplified model of an exposure-response function. Two elements are important for its determination:

- the gradient or effect estimate indicating the additional cases for each increase in concentration of PM10, and
- the base line frequency of cases at a concentration level where no impacts are to be expected.

The WHO recommends that no lower threshold for PM10 be used, indicating that even very low mean annual concentrations may have long-term effects on a population. But there are currently no epidemiological studies available that measure the effects below an annual average concentration of 5 µg/m$^3$ of PM10. The lowest level in this study was therefore chosen at 7.5 µg/m3 which is the class mean of 5-10 µg/m$^3$ PM10.




Note: for illustration purpose a high gradient is chosen

FIGURE 3 Calculation of air pollution attributable cases

It needs to be remembered, that whereas the exposure-response function has the same gradient for every country, the base line frequency (which is the number of cases at lowest measured exposure) varies from country to country due to socio-demographic differences in the populations.

In epidemiological studies the result is normally reported as relative risk based on a multiplicative risk function. For very small relative risks as usually observed for air pollution related health effects, the difference between multiplicative and additive risk functions is however very small across the range of observed exposure.

In this study the relevant health outcomes have been chosen along two criteria:

- Firstly, they are strictly separable from each other by the ICD-codes (international code of disease) in order to avoid double counting.
- Secondly, the chosen health outcomes must describe health endpoints to which a medical treatment and treatment costs are attributed (e.g. asthma). For example, the decrease in lung function is a health indicator with a strong correlation or exposure-response function with regards to air pollution. However it is not a separate health endpoint with a specific medical treatment and was therefore not used in this study.

The included health indicators were:

- Total mortality (due to long-term exposure) in adults (≥ 30 years of age)
- Hospital admissions for respiratory and cardiovascular hospital admissions (all ages)
- Chronic bronchitis in adults (≥ 25 years of age)
- Acute bronchitis in children (<15 years of age)
- Restricted activity days in adults (≥ 30 years of age)
- Days with Asthma attacks in children (<15 years of age)
- Days with Asthma attacks in adults (>15 years of age)

A number of effects for which exposure-response functions exist were not included, such as the acute effects on mortality, emergency room visits, respiratory symptoms, infant mortality, etc. Either these health outcomes are partially included in the categories chosen (such as emergency room visits that end up in a hospital admission) or no specific medical treatment is defined for them (such as decrease in lung function), or there is insufficient epidemiologic evidence currently available (infant mortality).

Where possible, epidemiological studies from the three countries were used and combined with studies from overseas. Where several studies were available, a meta-analysis was performed. Since there was no possibility to conduct a primary epidemiological assessment specifically for this project, this procedure was considered to be more reliable, instead of relying only on one single study at a time. The overall effect estimates were calculated as the variance weighted average across the results of all studies considered. Hence, studies with low standard errors entered into this joint estimate with a higher weight.

Combining the base line frequency (Po) at an exposure level of 7.5 $\mu g/m^3$ PM10 for each health indicator in each country with the relative risk (RR-1) due to an increase of 10 $\mu g/m^3$ PM10, the fixed increment (D10) of additional cases can be calculated for an increase in 10 $\mu g/m^3$ PM10, as shown in equation (1) and Figure 4:

$$D10 = Po * (RR-1) \quad (1)$$

Calculation example of the additional cases per 10 $\mu g/m^3$ PM10 and 1 million inhabitants

e.g. in Switzerland:

| 337 | = | 7 794 | x | 0.043 |
|---|---|---|---|---|
| fixed baseline increment | | expected baseline frequency at exposure of 7.5 $\mu g/m^3$ | | Relative risk for an increase 10 $\mu g/m^3$ |

FIGURE 4 Calculation example of attributable cases

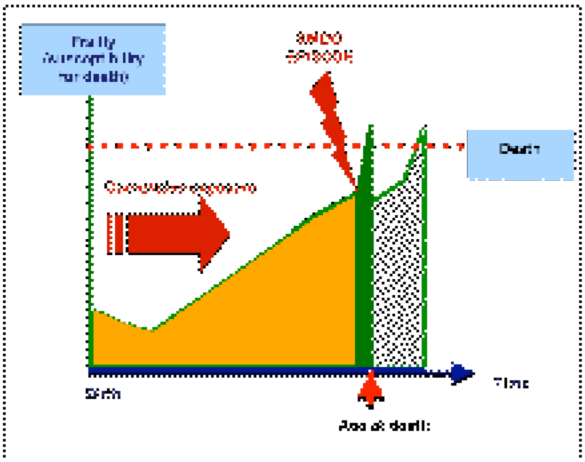
Special attention has to be paid to the issue of mortality. In the present study the long term effect of air pollution on mortality was considered. The relative risk of these effects is assessed by cohort studies that follow a large number of people over many years. In contrast, the effect of a short term variation in air pollution exposure on daily mortality is measured in time series studies and shows a lower relative risk level.

In the present study the health outcome of long term mortality has been chosen, because the effects of air pollution have two dimensions in time.

First, for some people the level of pollution on a given day or week may trigger morbidity or death. These are acute effects, well established in many highly qualified time series studies in Europe, the USA and other countries. These short term effects may move the event of death for a considerable number of people forwards.

There is, however, a further aspect of air pollution, ultimately leading to earlier death: recurrent cumulative exposure may enhance morbidity, including e.g. chronic bronchitis. People with these diseases (to which air pollution contributed) have impaired health and shorter life expectancy. Thus, they may die earlier, although the EVENT of death may not always be closely related to the daily level of pollution. This overall effect of air pollution on life-expectancy is captured by the cohort studies whereas the short-term studies capture only one part of the overall problem.

This distinction between short-term and long-term dimensions can be visualized in a two by two table as shown in Table 2. The frailty or susceptibility of a person to die may be increased due to a long-term exposure to air pollution or due to another cause,




whereas the event of death may be triggered by air pollution or by another cause.

| Long-term Frailty | Event of death: Related to air pollution | Event of death: Not related to air pollution |
|---|---|---|
| Related to air pollution | A | B |
| Not related to air pollution | C | D |

TABLE 2 Long-term frailty and trigger of death

In case A, air pollution contributed via a long-term cumulative exposure to the long-term frailty of a person and was also the trigger of death due to a short term smog episode (Figure 5).

In case B, there is only a long-term contribution of cumulative air pollution exposure to the frailty of a person but the event of death is not triggered by a smog episode but by another cause, e.g. an influenza epidemic. In case C, the frailty of a person is not air pollution related but due to other risk factors, e.g. due to diabetes, and air pollution in the form of a smog episode is only the terminal trigger of death. And finally, in case D neither frailty nor event of death are related to air pollution exposure.

FIGURE 5 Contribution of air pollution: Long-term and terminal term trigger of death (Case A)

In the present study it was decided that a complete assessment of air pollution attributable cases should include those cases, where air pollution contributed to long-term frailty and/or was a trigger of death (A, B, C). Cases with no relation to air pollution (D) should not be included at all. The prospective cohort study type that measures a person's "time to death" is the design that integrates all three cases mentioned above and is considered to provide the most complete estimates for air pollution attributable numbers of deaths (WHO, 2001) .

### 3.3. Results: Cases of air pollution related morbidity and mortality

Combining the exposure-response relationship with the population's exposure to PM10, the impacts of (traffic-related) air pollution can be quantified for the total study population. It is the number and type of additional cases of morbidity and the additional cases of premature death which are attributable to (traffic-related) air pollution.

Across the three countries Austria, France and Switzerland (some 73 Million people), the quantitative results per year attributable to traffic-related air pollution are considerable:

- 300,000 additional cases of acute bronchitis in children,
- 25,000 additional cases of chronic bronchitis in adults ,
- 25,000 hospital admissions for respiratory and cardiovascular problems ,
- 162,000 asthma attacks in children,
- 395,000 asthma attacks in adults,
- 16 million days with restricted activity for adults because of respiratory disease.

A considerable effect attributable to traffic-related air pollution is also the premature mortality due to a long term exposure. In the three countries together 21,000 premature deaths are attributable to the traffic-related air pollution (for detailed results see Appendix A).

In order to understand and interpret the order of magnitude of these results, the premature mortality attributable to road traffic-related air pollution has to be seen in a wider context. Compared to road accidents, an interesting development may be observed, as the example of the three countries shows in Figure 6.

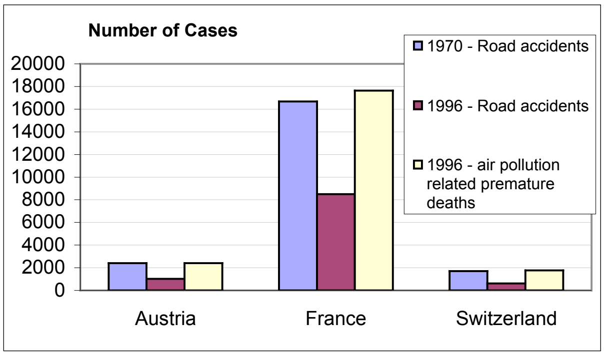



FIGURE 6 Fatal road accidents and air pollution-related mortality

In all three countries the same phenomenon was found: The number of fatal road accidents in 1970 reached the same level as today's premature mortality due to traffic-related air pollution. The policy measures for road safety have been quite successful in the last 30 years. In spite of the massive increase in the transport volume, the number of fatal road accidents has been reduced more than 50%. Today, fatal road accidents are exceeded by the number of premature deaths attributable to traffic related air pollution.

But the comparison needs to consider the number of life years lost, as well. On average, the victims from fatal road accidents are younger and lose 35 years of their lives, whereas the victims of air pollution related mortality have a higher age and lose 10 years of their lives. Multiplying this figure with the absolute numbers of cases in each category, the total loss of life years from today's fatal road accidents and the premature mortality from traffic related air pollution have a similar magnitude (Approx. 350,000 years of life lost due to fatal road accidents and approx. 210,000 years lost due to premature, air pollution-related mortality).

## 4. Economic Valuation

### 4.1. General objectives

Finally, based on the quantitative results of the previous steps, the economic costs have to be assessed for each health outcome separately, for the number of cases due to total air pollution and due to traffic-related air pollution.

### 4.2. Common methodological framework

In the present study, a common methodological framework, the willingness-to-pay approach (WTP) based on individual preferences, was chosen. In this method, the population exposed to air pollution expresses their willingness to pay for a risk reduction of being the victim of a health outcome. It is important to note that the willingness-to-pay value for a (statistically) prevented fatality or morbidity includes not only material costs but also intangible costs for pain, suffering and loss of life quality. The Figure 7 illustrates the different cost components related to health costs.

FIGURE 7 Overview of health cost components

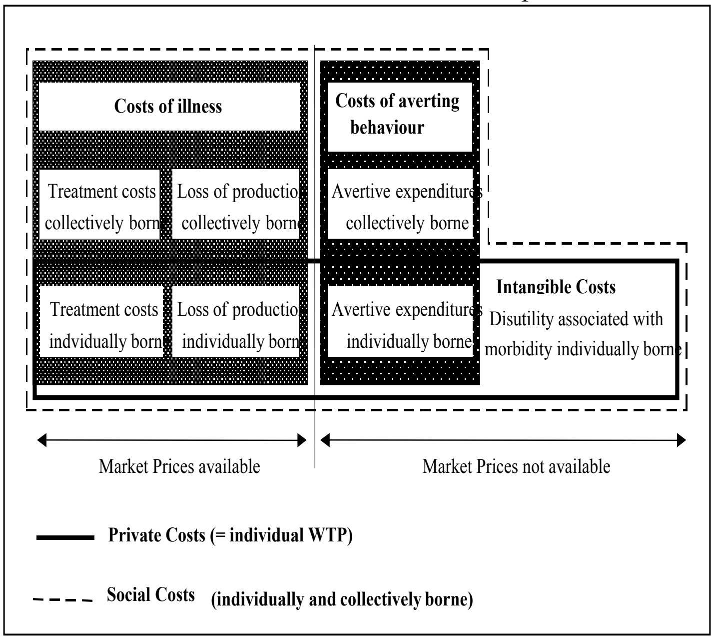



Figure 7 indicates that the willingness-to-pay approach includes the individual material costs and the intangible costs but does not consider the material costs that are collectively born, e.g. due to insurance contributions. The cost factors used in the tri-national study must therefore be considered as being conservative values.

A general remark on the content of the willingness-to-pay approach has to be made at this stage. It has been criticised that willingness-to-pay or other valuation methods are used to value life in monetary terms. This criticism is based on a misunderstanding. Economic valuation does not attempt to value "ex post" the life of a specific person that died in an accident. This would of course be highly problematic on ethical grounds. Instead, what is being valued "ex ante" is a reduction in risk of being a victim of a fatal accident or a fatal illness. That is why in economic theory the term of “value of a prevented statistical fatality” is used.

The following example illustrates how the willingness-to-pay value for a prevented fatality is derived: For example, a public policy measure aims at reducing the road accident risk from 4 cases per 10 000 to 3 cases per 10 000 inhabitants. Given the possibility of being a potential victim, respondents are asked how much they would be willing to pay in order to support the risk reduction from 4 to 3 victims per 10 000 inhabitants, that is a risk reduction of 1/10 000(= 0.0001). If on average, the respondents report a willingness-to-pay of a one time amount of 100 Euro for the 0.0001 risk reduction, an amount of 1 Million Euro for one prevented fatality is estimated.

The willingness-to-pay for a prevented fatality used in this study amounts to some 0.9 million Euro (approx. 1.7 million NZ$). Since no primary study could be performed within this project, several recent European studies were compared and it was decided to consider the British WTP value of 1.4 Million Euro (2.7 million NZ$) for a prevented fatality of road accidents as a point of departure.

Recent studies by Jones-Lee et al. (1995) in the UK have shown that WTP values for accidents and air pollution-related fatalities differ from each other for several reasons. In comparison with road traffic-related accident risk, the air pollution-related mortality risk is

- to a large extent involuntary,
- to a large extent beyond the control of those who are exposed, and
- usually without a direct personal benefit, although air pollution is largely transport induced.

Because of this different risk context, the aversion against air pollution related health impacts is likely to be higher than the aversion against the risk of fatal road accidents. However, sound empirical evidence is missing up to date on the extent of this difference in risk aversion. That is why in the present study the WTP value was not adjusted for the different risk context.

A second difference between the two risks has its origin in the age differences of the victims. Although epidemiological studies do not give direct information about the age structure of air pollution related fatalities, it is however known that these fatalities are mostly related to respiratory and cardiovascular disease and lung cancer. In the three countries, the average age of these fatalities lies between 75 and 85 years whereas the average age of road accident victims is 30-40 years.

Several empirical studies (e.g. UK Department of Health, 1999) have shown a reverse U-shaped relationship between age and willingness-to-pay with lower values for young and old age groups and highest WTP values around the age of 40. Based on these latest findings and the age structure of the air pollution related premature fatalities, the Value of a Prevented Fatality was adjusted downwards to 61% of its initial value which amounts to 0.9 million Euro (approx. 1.7 million NZ$) per prevented fatality. This result may be considered to be a conservative value below the values currently used in Europe: for example the 2-3 Million Euro (approx. 4-5.7million NZ$) used by the ExternE study on behalf of the European Commission (see Table 3). However, this rather moderate value is in line with the "at least approach" followed throughout the entire study.

| WTP-Value | Source |
|---|---|
| 0.9 million € | Tri-national study A, F, CH; adjusted downwards |

| | |
|---|---|
| 1.4 million € | Jones-Lee M. et al. (1998); Fatal road accidents |
| 1.2 million € | UK Department of Health (1999) |
| 2.6 million € | ExternE Project (1995), European Community |
| 3.1 million € | Instiute of Environm. Studies, Norway, ZEW Centre for Europ. Economic Research and ISI Frauenhofer Institute (1997) |

TABLE 3 Willingness-to-pay cost factors used for the monetary assessment of mortality in Europe

The tri-national study also contains a partial estimate of health costs due to traffic-related air pollution, assessing only the material costs. In Austria and Switzerland it was based on a human capital cost approach measured in terms of gross production loss (based on the average national labour income), whereas in France the final consumption loss was used to measure the human capital costs. The choice of the specific approaches was determined by needs to compare the results with former national studies. Thus, for this partial assessment there was not a single method prescribed, since the common methodological framework was considered to be the willingness-to-pay approach.

As in the case of mortality, it was not possible to conduct primary studies on the willingness-to-pay for the different morbidity health indicators within the tri-national study. Instead, from an extensive literature review the WTP values shown in Table 4 were chosen:

| **Health outcome** | **WTP (€)** | **Source** |
|---|---|---|
| Respiratory hospital admission | 7,870/case | ExternE (1995) |
| Cardio-vascular hospital admission | 7,870/case | ExternE (1995) |
| Chronic Bronchitis (adults) | 209,000/case | Chestnut L.G. (1995) |
| Acute Bronchitis (children) | 131/day | Maddison D. (1997) |
| Restricted activity days | 94/day | Maddison D. (1997) |
| Asthma attacks | 31/attack | Maddison D. (1997) |

TABLE 4 Willingness-to-pay cost factors used for the monetary assessment of morbidity in Europe

## 4.3 Results: Health costs due to air pollution-related morbidity and mortality

Applying the above discussed cost factors to the number of cases of each health outcome, the results due to total and traffic-related air pollution also lead to considerable financial consequences, as shown in Table 5.

Due to the size of the population, the results of Austria and Switzerland have a similar order of magnitude. In all three countries, approximately half of the costs are attributable to the health costs of road traffic-related air pollution.

| Inhabitants in million | Austria 8.1 | France 58.3 | Switzerland 7.1 | Total 74.5 |
|---|---|---|---|---|
| Total costs in million € | 6, 700 | 38,900 | 4,200 | 49,700 |
| road traffic related costs in million € | 2,900 | 21,600 | 2,200 | 26,700 |

TABLE 5 Health costs due to air pollution (1996)

According to the willingness-to-pay, across the three countries the traffic-related air pollution causes health costs of some 27 billion Euro per year (approx. 52 NZ$, 43 billion AU $). However, it needs to be remembered that these are not "out of pocket costs" but that this is the perceived welfare loss of the population.

As mentioned earlier, a partial assessment was conducted as well, looking at the material costs only. These include the medical treatment costs and production or consumption losses and amount in total to some 3.5 billion Euro per year across the three countries (approx. 6.7NZ$, 5.6 billion AU$, ). This value is much lower than the willingness-to-pay result. In Austria for example, the gross production loss approach values one year of life lost at some 20,600 Euro. Based on an average loss of life expectancy of 9.5 years that amounts to some 195,700 Euro per fatality (approx. 371,000 NZ$). However, this partial approach does not reflect the intangible costs and the amount that the individuals would be ready to pay for an improvement of their own security by reducing the air pollution related health risk. The most extreme difference is of course registered for mortality that causes no further medical treatment costs but the willingness-to-pay to avoid this risk is high.

According to the willingness-to-pay approach, the total cost for morbidity amounts to some 7 billion Euro (approx. 13.4 Billion NZ$, 11.2 billion AU $), whereby chronic bronchitis with it's severe health impacts and the large number of restricted activity days are causing the highest costs (75% and 22% respectively).

The health costs of traffic-related air pollution based on the willingness-to-pay approach amount to some 1.7% of the GDP across the three countries. This result translates into an average per capita cost of 360 Euro per year (approx. 690 NZ$, 576 AU$). In all three countries, the premature mortality is predominant, accounting for about 70% of the costs.

## 4.4 General discussion of methodology and identification of research needs

Throughout the entire study a number of assumptions and decisions had to be made that include a certain degree of uncertainty. As mentioned earlier, the critical assumptions were always based on an "at least" approach. Given the current level of scientific knowledge, the results reflect therefore the "at least to be expected outcome". The decisions that tend to move the results downwards are the following:

*With regards to the epidemiological assessment:*

- Lowest assessed level of 7.5 _g/m$^3$ for health effects.
- Not all PM10 related health effects are considered (infant mortality, respiratory symptom days etc. are excluded).
- The effect estimate reflects the air pollution mix of an urban environment. Specific independent effects of single pollutants were not considered.
- Seasonally limited air pollution related health effects are not considered (e.g. ozone exposure in summer).

*With regards to the economic valuation:*

- The willingness-to-pay value of fatal road accidents of 1.4 million Euro (approx. 2.7 Mio. NZ$) is reduced to 61% according to the advanced age of air pollution related victims. This WTP value is lower than values used in other European studies (e.g. ExternE: 2.1-3.0 million Euro, 4-5.7 Mio.NZ$).

For future studies, a number of research needs were identified for the three scientific domains, namely:

*With regards to air pollution modelling:*

- Data improvement for the assessment of population exposure and transport-related share: PM10 monitoring networks in all three countries and the establishment of emission inventories for PM10 and other pollutants such as carcinogens and ozone.

*With regards to epidemiological assessment:*

- Improvement in the recording of baseline frequencies of different health outcomes and reduction of misclassification in national health statistics.
- The need to perform studies that establish the age distribution at the time of death in order to get precise information about the life years lost with and without air pollution exposure.
- Assessment of the seasonal health effects of pollution such as ozone (summer smog).
- Assessment of the effects of other pollutants eventually to be added to the effects of particulates.
- Assessment of the effect of toxicity, i.e. the impact of different chemical compositions of particulates with regards to different emission sources (Gasoline or Diesel related particulates, particulates from abrasion and resuspension), and the importance of particle numbers or particle mass.
- Assessment of the effects on special risk groups, e.g. air pollution related effects on infant mortality.
- The assessment of simultaneous exposure to air pollution and noise pollution - often emitted by the same source (traffic) and both affecting human health.
- The transferability of effect estimates from one (several) study(ies) to another population.
- The assessment of time-lags from exposure to effect or, in reverse, from reduction in exposure to improvement of health in a population (WHO, 2001b).

*With regards to economic valuation:*

- With regards to monetary valuation of health impacts, further empirical studies need to be undertaken that determine which cost elements are included in the individual willingness-to-pay judgement and which cost elements are not considered by the respondents (e.g. insurance payments).
- Regarding the transferability of results, recent research indicates that there are different ways of how to use "secondary" data from scientific literature, leading however to differences in willingness-to-pay values and different levels of validity according to the method chosen (Pearce, 2000). Therefore, it would clearly be an improvement if the three countries could perform their own empirical Stated Preference studies, rather than using values obtained elsewhere.
- Empirical studies on the valuation of health costs need to assess the impact of different risk contexts, i.e. are people sensitive to different levels of risk (sensitivity for *level* of risk) or does the willingness-to-pay differ for a reduction in health related risk from air pollution as opposed to traffic accident related risks (sensitivity for the *type* of risk) (Chanel et al., 2002). Recent studies in UK assessed the risk perception and willingness-to-pay for different traffic and non-traffic related risk situations whereby different relative values in peoples' perceptions were found (Jones-Lee et al. , 2000).
- In addition, the impact of different socio-demographic variables (e.g. age, income, education, cultural background, attitudes, etc.), of awareness and perception (e.g. knowledge about air pollution and health effects) and the effect of latency (time lag between exposure and health impact) must be further investigated (i.e., Cropper, 2000, Pearce, 2000 and Chanel et al. 2001).
- Also, for each study design it needs to be determined what exactly is being measured, e.g. whether it is the value of a "contemporary" life threatening risk at a defined moment in time (value of prevented statistical fatality) or the risk over a defined time span including the remaining life time, and if in peoples' perception, there occurs any weighting with regards to the quality of life over some period of time (Pearce, 2000). In this respect, recent literature indicates that it is not reliable to directly transform values of a prevented statistical fatality into single values of life years lost (Cropper, 2000).
- An important difference in WTP is also expected for the value of one's own risk as opposed to the risk to others. Very few studies have for example distinguished between survey questions valuing the respondent's own risk as a potential victim and questions valuing the risk of being a relative of a victim (Schwab-Christe and Soguel, 1995; Miller and Guria, 1991).
- In addition, if health improvements for the future are to be assessed (reduction in risk meaning increase in life time) in the long-term framework of a policy assessment, the appropriate choice of discount rates, annual growth rates and their impact on the

result must be studied in relation to intergenerational equity (Cropper, 2000; Pearce, 2000).
- Finally, if primary data collection is not possible, it needs to be determined under which conditions existing values may be transferred to the new location, e.g. by conducting meta-analytic studies, or by transferring cost functions (meta-equations) with introduction of a set of "local" determining variables. However, this raises the ethical question of "whether it is fair to adopt different values for the same health effect in different geographical contexts" … "since the determinants $X_1 \ldots X_n$ will unquestionably vary by location" (Pearce, 2000)

*Dealing with the problem of uncertainty in general:*
- With regards to uncertainty of results, further research needs to establish an adequate way of integrating the measurements of uncertainty that occur in the three scientific domains into one measurement of uncertainty (WHO, 2001b). The tri-national study only presents the upper and lower estimates based on a 95% confidence interval from epidemiological effect estimates. Given the uncertainties in the assessment of population exposure and the economic values, in this particular case no approach was yet elaborated to quantify the overall uncertainty, by modelling the distribution of combined impact probabilities, e.g. by using a Monte Carlo simulation approach.

Finally, there is also the question of how the results can be used for policy related decisions on local and community level. Based on the above described methodology, a number of cities used the same methodological framework for a local assessment of air pollution-related health impacts. A recent example of using the tri-national approach is an application in eight major Italian cities (WHO, 2001a). On the American continent, the reduction in air pollution and positive health effects resulting from Greenhouse Gas Mitigation strategies between 2000 and 2020 was forecast for the four cities Santiago de Chile, Mexico City, Sao Paolo and New York, using a similar method (Cifuentes, et al., 2001). These different applications underline the importance of working towards a convergence of methods and assumptions in the three scientific domains.

## 5. Conclusion

The present study of Austria, France and Switzerland on air pollution-related health impacts, whose results have recently been confirmed by a similar study of eight major Italian cities, and a study of selected metropolitan areas on the American continent, shows that the air pollution related health effects are far from negligible.

According to the proposals of the WHO Charter on Transport, Environment and Health, the promotion of common research on a European and international level in all three scientific domains is recommended, in order to improve the quality and comparability of the information. Several more or less co-ordinated international attempts are currently underway to address the substantial need for research in the domain of air pollution, epidemiology and economy.

From a political point of view, it is necessary to substantially reduce the (traffic related) air pollution exposure of the population in order to obtain a long term reduction in health effects and long term benefits from the population's improved health. In Europe, the authorities of different countries intend to achieve this goal with a mix of measures, namely the integration of health information into the impact assessment of infrastructure projects, technical improvements in vehicles and fuels, a consistent application of the polluter-pays principle by internalising the external costs of traffic related air pollution into transport pricing and taxation schemes and a number of further Travel Demand Management (TDM) measures.

.


## Acknowledgments

Special thanks go to the peer reviewers:
- Dr. C. Dora, WHO European Centre for Environment and Health, Rome Division, Italy;
- Dr. H. Eerens from the National Institute of Public Health and the Environment (RIVM), Bilthoven, The Netherlands;
- Dr. M. Krzyzanowski, WHO European Centre for Environment and Health, Bildhoven Division, The Netherlands;
- Prof. Dr. M. Jones-Lee, Centre for the analysis of safety policy and attitudes to risk, Department of Economics, University of Newcastle, UK;
- Dr. R. Dubourg, Centre for social and economic research on the global environment, University College London, UK.

## References


Beattie J. et al. (1997), Valuing Health and Safety Controls: A Literature Review, London: Health and Safety Executive, 1997

Chanel O., Faugere E., Geniaux G., Kast R., Luchini S. Scapecchi P. (2002) Perceptions et valorisations économiques des effets de la pollution atmosphérique: Résultats d'une enquête contextuelle. GREQAM-IDEP, Marseille. chanel@ehess.cnrs-mrs.fr

Chanel O., Scapecchi P., Vergnaud J.-C. (2001) Long-term health effects and economic valuation of public policies: an application to air pollution in France. Groupement de Recherche en Economie Quantitative d'Aix-Marseille GREQAM-IDEP, Marseille. chanel@ehess.cnrs-mrs.fr

Chestnut L., (1995), Human Health Benefits from Sulfate Reduction under Title IV of the 1990 Clean Air Act Amendments, prepared for the U.S. Environmental Protection Agency, Washington

Cifuentes L., Borja-Aburto V.H., Gouveia N., Thurston G., Davis D.L. (2001) Assessing Health Benefits of Urban Air Pollution Reduction associated with Climate Change Mitigation (2000-2020): Santiago de Chile, Sao Paolo, Mexico City, New York. Environmental Health Perspectives. Vol. 109, Supplement 3, June 2001

Cropper M.L. (2000) Outline paper – DG Environment Workshop on Mortality Valuation. Workshop on the Value of reducing the risk of ill-health or a fatal illness. Brussels 13th November 2000. http://europa.eu.int/comm/environment/enveco/others/maureencropper_paper.pdf

Department of Health, Ad-hoc Group on the Economic Appraisal of the Health Effects of Air Pollution, (1999), Economic Appraisal of the Health Effects of Air Pollution, The Stationery Office, London

European Commission (1995), European Commission, DG XII, Science, Research and Development, JOULE: Externalities of Fuel Cycles ExternE Project, Report Number 1, Summary

European Commission (1995), European Commission, DG XII, Science, Research and Development, JOULE: Externalities of Fuel Cycles ExternE Project, Report Number 2, Methodology, Part II: Economic Valuation

European Commission (1995), European Commission, DG XII, Science, Research and Development, JOULE: Externalities of Fuel Cycles ExternE Project, Report Number 3, Coal and Lignite Fuel Cycles

Filliger P, Puybonnieux-Texier V, Schneider J. (1999), PM10 Population Exposure – Technical Report on Air Pollution; Health Costs due to Road Traffic-related Air Pollution; An impact assessment project of Austria, France and Switzerland., Bern 1999 (http://www.eehc.dk/London99/traffic.htm)

Institute for Environmental Studies/ Norwegian Institute for Air Research/International Institute for Applied System Research (1997), Economic evaluation of quality targets for sulphur dioxide, nitrogen dioxide, fine and suspended particualte matter and lead

Jones-Lee M.W., Loomes G., Rowlatt P., Spackman M., Jones S. (1998) Valuation of Deaths from Air Pollution; Centre for the Analysis of Safety Policy and Attitudes to Risk, CASPAR/ National Economic Research Associates N/E/R/A, London 1998

Jones-Lee M.W., Beattie J., Carthy T., Chilton S., et al. (2000). Valuation of Benefits of Health and Safety Control. Final Report. Health & Safety Executive. UK Dept. of Health, London

Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. ,(1999), Air Pollution Attributable Cases – Technical Report on Epidemiology; Technical Report of the Health Costs due to Road Traffic-related Air Pollution – An impact assessment project of Austria, France and Switzerland, Bern 1999 (http://www.eehc.dk/London99/traffic.htm)

Künzli N., Kaiser R., Rapp R., Ackermann-Liebrich U. (1996) Monetarisierung der verkehrsbedingten externen Gesundheitskosten. Teilbericht Epidemiologie. Studie im Auftrag des Dienstes für Gesamtverkehrsfragen im Generalsekretariat des Eidgenössischen Verkehrs- und Energiedepartementes, Bern 1996. Bezugsquelle: Bundesamt für Raumentwicklung, Abteilung für Verkehrskoordination (GVF), http://www.admin.ch/gvf

Künzli N., Kaiser R., Medina S., Sommer H., Filliger P., Seethaler R., Chanel O., Studnicka F. et al. (2000) Public Health Impact of Outdoor and Traffic-related Air Pollution: A Tri-national European Assessment, In: Lancet, Sept. 2000, Vo. 356, pp 795-801

Maddison D., (1997), Valuing the morbidity effects of air pollution, Centre for Social and Economic Research on the Global Environment (CSERGE), University College London and University of East Anglia

Miller T., Guria J. (1991) The Value of Statistical Life in New Zealand. New Zealand Ministry of Transport. Wellington, NZ

Nilson M., Gullberg M., (1998), Externalities of Energy, Swedish Implementation of the ExternE Methodology, published by the Stockholm Environment Institute SEI

Ostro B., Chestnut L., (1997) Assessing the Health Benefits of Reducing Particulate Matter Air Pollution in the United States, Environ. Res. 76:94-106

Pearce D. (2000) Valuing Risks to Life and Health. Towards Consistent Transfer Estimates in the European Union and Accession States. Paper prepared for the European Commission (DGXI) Workshop on Valuing Mortality and Valuing Morbidity. Nov. 13th, 2000, Brussels. Revised version (December 2000) http://europa.eu.int/comm/environment/enveco/others/david_pearce_paper.pdf

Schwab Christe N.G., Soguel N. (1995) Le prix du chagrin et de la douleur: Une évaluation contingente appliquée aux accidents de la route, Editions EDES, Neuchâtel

Seethaler R., (1999), Health Costs due to Road Traffic-related Air Pollution – An impact assessment project of Austria, France and Switzerland, Synthesis Report, Berne 1999
http://www.eehc.dk/London99/traffic.htm

Sommer H. (2000) Externe Lärmkosten des Verkehrs, Vorstudie II: Hedonic Pricing Analyse, im Auftrag zu Handen des Dienstes für Gesamtverkehrsfragen, Eidg. Departement für Umwelt, Verkehr, Energie und Kommunikation, Bern 2000. To order at: Bundesamt für Raumentwicklung, Abteilung für Verkehrskoordination (GVF), http://www.admin.ch/gvf

Sommer H., Neuenschwander R. (1996) Monetarisierung der verkehrsbedingten externen Gesundheitskosten. Synthesebericht. Studie im Auftrag des Dienstes für Gesamtverkehrsfragen im Generalsekretariat des Eidgenössischen Verkehrs- und Energiedepartementes, Bern, 1996. To order at: Eidgenössische Drucksachen- und Materialzentrale EDMZ, Bern 3000, Nr. 801.562.d (Tel. 41 –(0)31 – 322 39 98, Fax 41 – (0)3 – 992 00 23)

Sommer H., Seethaler R., Chanel O., Herry M., Masson S., Vergnaud J. Ch., (1999), Economic Evaluation - Technical Report on Economy; Technical Report of Health Costs due to Road Traffic-related Air Pollution – An impact assessment project of Austria, France and Switzerland, Berne 1999
http://www.eehc.dk/London99/traffic.htm

Viscusi W.K. (1993), The Value of Risks to Life and Health, Journal of Economic Literature, Vol. 31, No. 4, pp.1912-1946

WHO (1999), Charter on Transport, Environment and Health, Third European Union Ministerial Conference on Transport, Environment and Health, London 1999, http://www.who.dk/London99/

WHO (2001a) Health Impact Assessment of Air Pollution in the Eight Major Italian Cities. European Centre for Environment and Health. Rome http://www.euro.who.int/document/E75492.pdf.
http://www.euro.who.int/eprise/main/who/progs/hms/MainActs/20011128_2

WHO (2001b) Quantification of the Health Effects of Exposure to Air Pollution. Report of a WHO Working Group. European Centre for Environment and Health. Rome