Economic Evaluation in the Project „Health Costs due to Road Traffic-Related Air Pollution“


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Report Information

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1 Introduction

1.1 Starting point

The three countries France, Austria and Switzerland have 1998/99 realised a project to investigate the health costs due to road traffic-related air pollution.

With a common methodological approach, it was aimed to obtain comparable results for the health costs due to road traffic-related air pollution in the three countries in 1996.

The results of these investigations have been published in one synthesis report and three partial reports. The country-specific results represented an input for the WHO Ministerial conference in June 1999 in London.

After the conference, the three countries together with Sweden, Malta, the Netherlands (as new interested parts) and WHO have decided to continue the cooperation within the area in order to contribute to the implementation of the WHO Charter on Transport, Environment and Health. The continued work should be broadened and deal with all the relevant health costs and be carried out as a series of workshops. The objective of the work is that the result will be used as an input to the WHO Ministerial Conference in Budapest summer 2004 and perhaps also make a basis for a WHO guideline.

1.2 Objective and Structure of this paper

The objective of this paper is to give an overview of the methodological approach and the main results of the tri-national study “Health Costs due to Road Traffic-related Air Pollution”.

In chapter 2, you find an overview of the common approach. This is followed by chapter 3 and for 4 in which the basic principles and most important results in the areas “air pollution” and “epidemiology” are being presented. In the main part of this paper (chapter 5), the concept of the monetary evaluation and the cost factors that has been used in the tri-national investigation is introduced. A detailed discussion of the results follows in chapter 6, and chapter 7 gives a short view over the current work in Switzerland.

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2 This paper is based on a contribution which has been made for the Expert Workshop on Assessing the Ancillary Benefits and Costs of Greenhouse Gas Mitigation Strategies, 27-29 March 2000, Washington DC.
2 The research concept: An overview

The monetary evaluation of the health costs is based on an interdisciplinary co-operation in the fields of air pollution, epidemiology and economy. Figure 1 presents an overview of the different tasks of the three domains.

- **Air pollution:** Evaluation of the (traffic related) exposure to particulate matter
  The starting point of the study is the determination of the pollution level in 1996 to which the population was exposed. The entire population of Austria, France and Switzerland is subdivided into categories of exposure to different classes of pollution levels from a superposition of the mapping of ambient concentration of particulate matter (average annual PM10) with the population distribution map. In addition, a scenario without road traffic-related emissions is calculated and the exposure under these theoretic conditions is estimated.

- **Epidemiology:** Evaluation of the exposure-response function between air pollution and health impacts
  The relationship between air pollution and health has to be assessed. Thereby it has to be shown, to which extent different levels of air pollution affect a population's morbidity and mortality. This evaluation is based on the latest scientific state of the art presented in the epidemiologic literature and comprehends the results of extensive cohort studies as well as time series studies.

- **Economics:** Evaluation of the traffic-related health impacts and monetary evaluation
  Using epidemiological data regarding the relation between air pollution and morbidity and premature mortality, the number of cases of morbidity and/or premature mortality attributed to air pollution is determined for each of the health outcomes separately, using specific exposure-response functions. The same operations are carried out for the theoretical situation in which there is no road traffic-related air pollution. The difference between the results of these two calculations corresponds to the cases of morbidity and premature mortality due to road traffic-related air pollution. The morbidity and mortality costs arising from road traffic-related air pollution are then evaluated for each health outcome separately by multiplication of the number of cases with the respective cost estimates (willingness-to-pay factors for the reduction of the different health risks).
Throughout the entire project, many assumptions and methodological decisions had to be made along the various calculation steps in the domain of air pollution, epidemiology and economics. On each level, the method of dealing with uncertainty had to be defined. The research group decided that the main calculation ought to apply an “at least” approach, thus consistently selecting methodological assumptions in a way to get a result which may be expected to be “at least” attributable to air pollution. Accordingly, the overall impact of air pollution is expected to be greater than the final estimates. To unambiguously communicate the uncertainty in the common methodological framework, the results will be reported as a range of impacts rather than as an exact point estimate.
3 Epidemiology - the air pollution attributable health effects

In the last 10-20 years, epidemiology has dealt extensively with the effect of outdoor air pollution on human health. A considerable number of case studies in different countries and under different exposure situations have confirmed that air pollution is one of various risk factors for morbidity and mortality.

In general, air pollution is a mixture of many substances (particulates, nitrogen oxides, sulphurs dioxides). Knowing that several indicators of exposure (e.g. NO2, CO, PM10, TSP etc.) are often highly correlated, it is not accurate to establish the health impact by a pollutant-by-pollutant assessment, because this would lead to a grossly overestimation of the health impact. The objective is therefore to cover as best as possible the complex mixture of air pollution with one key indicator. Based on various epidemiological studies, in the present study PM10 (particulate matter with an aerodynamic diameter of less than 10 µm) is considered to be a useful indicator for measuring the impact of several sources of outdoor air pollution on human health. The derivation of air pollution attributable cases has been described in a separate publication.\(^3\) Thus, the key features of the epidemiology-based assessment are only summarized.

For the assessment of the health costs, it was not possible to consider all health outcomes found to be associated with air pollution. Only those meeting the following three criteria were considered:

- there is epidemiological evidence that the selected health outcomes are linked to air pollution,
- the selected health outcomes are sufficiently different from each other so as to avoid double counting of the resulting health costs (separate ICD\(^4\) codes),
- the selected health outcomes can be expressed in financial terms.

According to these selection criteria, seven health outcomes were considered in this study (see Table 2).

\(^3\) Künzli N. et al. (2000), Public Health Impact of Outdoor and Traffic-related Air Pollution: A Tri-national European Assessment, in press.

\(^4\) ICD: International Classification of Diseases.
Table 2: Air pollution related health outcomes considered

<table>
<thead>
<tr>
<th>Health outcome</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mortality</td>
<td>Adults, ≥ 30 years of age</td>
</tr>
<tr>
<td>Respiratory hospital admissions</td>
<td>All ages</td>
</tr>
<tr>
<td>Cardiovascular hospital admissions</td>
<td>All ages</td>
</tr>
<tr>
<td>Acute bronchitis</td>
<td>Children, &lt; 15 years of age</td>
</tr>
<tr>
<td>Restricted activity days</td>
<td>Adults, ≥ 30 years of age</td>
</tr>
<tr>
<td>Asthmatics: asthma attacks</td>
<td>Children, &lt; 15 years of age;</td>
</tr>
<tr>
<td></td>
<td>Adults, ≥ 15 years of age</td>
</tr>
</tbody>
</table>

The relation between exposure to air pollution and the frequency of health outcome is presented in Figure 3 by graphical means. The number of mortality and morbidity cases due to air pollution can be determined if the profile of the curve (exposure-response function) and its position (health outcome frequency) are known. These two parameters were determined for each health outcome, separately.

![Figure 3: Relation between air pollution exposure and cases of disease](image)

The exposure-response function (quantitative variation of a health outcome per unit of pollutant load) was derived by a meta-analytical assessment of various (international) studies selected from the peer-reviewed epidemiological literature. The effect estimate (gradient) was calculated as the variance weighted average across the results of all studies included in the meta-analysis.

In this project, the impact of air pollution on mortality is based on the long-term effect. This approach is chosen because the impact of air pollution is a combination of acute short-term as well as cumulative long-term effects. For example, lifetime air pollution exposure may lead
to recurrent injury and, in the long term, cause chronic morbidity and, therefore, reduce life expectancy. In these cases, the occurrence of death may not be associated with the air pollution exposure on a particular day (short-term effect) but rather with the course of the chronic morbidity, leading to shortening in life.

Accordingly, for the purpose of impact assessment, it was decided not to use response functions from daily mortality time-series studies to estimate the excess annual mortality but the change in the long-term mortality rates associated with ambient air pollution.\(^5\)

Contrary to the exposure function, which is assumed to be the same for all countries, the health outcome frequency (frequency with which a health outcome appears in the population for a defined time span) may differ across countries. These differences may result from a different age structure or from other factors (i.e. drinking and eating habits, different health care systems in the three countries, etc.). Therefore national or European data were used whenever possible to establish the countries’ specific health outcome frequency.

For each health outcome included in the tri-national study, Table 4 presents the effect estimates in terms of relative risks (column 2) and separately for each country the health outcome frequency (column 3-5), and the attributable number of cases for 10 µg/m\(^3\) PM10 increment.

Reading example:
The relative risk of long-term mortality for a 10 µg/m\(^3\) PM10 increment is 1.043 (column 2); therefore the number of premature fatalities increases by 4.3% for every 10 µg/m\(^3\) PM10 increment. Column 5 shows the number of deaths (adults ≥ 30 years) per 1 million inhabitants in Switzerland (8'260). With an average PM10 concentration of 7.5 µg/m\(^3\) a baseline frequency of 7'794 deaths would be expected. This proportion depends on the age structure of the population ≥ 30 years and therefore is different for each country. The absolute number of fatalities (340 cases for Switzerland, column 8) per 10 µg/m\(^3\) PM10 increment and per 1 million inhabitants corresponds to the 4.3% increase in mortality (column 2) applied to the baseline frequency of 7'794 deaths.

### Table 4: Additional cases per 1 million inhabitants and 10 µg/m³ PM10 increment

<table>
<thead>
<tr>
<th>Effect estimate</th>
<th>Observed population frequency, ( P_e )</th>
<th>Fixed baseline increment per 10 µg/m³ PM10 and 1 million inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Long-term mortality (adults ≥ 30 years; excluding violent death)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Austria</td>
<td>France</td>
</tr>
<tr>
<td>Long-term mortality (adults ≥ 30 years; excluding violent death)</td>
<td>1.043 (1.026-1.061)</td>
<td>9'330</td>
</tr>
<tr>
<td><strong>Respiratory hospital admissions (all ages)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Austria</td>
<td>France</td>
</tr>
<tr>
<td>Respiratory hospital admissions (all ages)</td>
<td>1.0131 (1.001-1.025)</td>
<td>17'830</td>
</tr>
<tr>
<td><strong>Cardiovascular hospital admissions (all ages)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Austria</td>
<td>France</td>
</tr>
<tr>
<td>Cardiovascular hospital admissions (all ages)</td>
<td>1.0125 (1.007-1.019)</td>
<td>36'790</td>
</tr>
<tr>
<td><strong>Chronic bronchitis incidence (adults ≥ 25 years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Austria</td>
<td>France</td>
</tr>
<tr>
<td>Chronic bronchitis incidence (adults ≥ 25 years)</td>
<td>1.098 (1.009-1.194)</td>
<td>4'990</td>
</tr>
<tr>
<td><strong>Bronchitis (children &lt; 15 years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Austria</td>
<td>France</td>
</tr>
<tr>
<td>Bronchitis (children &lt; 15 years)</td>
<td>1.306 (1.135-1.502)</td>
<td>16'370</td>
</tr>
<tr>
<td><strong>Restricted activity days (adults ≥ 20 years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Austria</td>
<td>France</td>
</tr>
<tr>
<td>Restricted activity days (adults ≥ 20 years)</td>
<td>1.094 (1.079-1.109)</td>
<td>2'597'300</td>
</tr>
<tr>
<td><strong>Asthmatics: asthma attacks (children &lt; 15 years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Austria</td>
<td>France</td>
</tr>
<tr>
<td>Asthmatics: asthma attacks (children &lt; 15 years)</td>
<td>1.044 (1.027-1.062)</td>
<td>56'700</td>
</tr>
<tr>
<td><strong>Asthmatics: asthma attacks (adults ≥ 15 years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Austria</td>
<td>France</td>
</tr>
<tr>
<td>Asthmatics: asthma attacks (adults ≥ 15 years)</td>
<td>1.039 (1.019-1.059)</td>
<td>173'400</td>
</tr>
</tbody>
</table>

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a: Restricted activity days: total person-days per year
b: Asthma attacks: total person-days per year with asthma attacks

\( P_e \): Frequency as observed at the current level of air pollution

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Table printed with permission from Lancet, Künzli N. et al. (2000), Public Health Impact of Outdoor and Traffic-related Air Pollution: A Tri-national European Assessment, in press.
4 Air Pollution - the PM10 population exposure

In addition to the epidemiological data need, information on the population’s exposure to PM10 is a further key element for the assessment of air pollution-related health effects. Information about the sources and the spatial distribution of PM10 is still sparse in Austria, France and Switzerland as it is in many other European countries. Therefore, it was necessary to calculate the spatial distribution of PM10 by using empirical dispersion models or statistical methods. The general methodological framework for the air pollution assessment consisted of four main steps:

- acquisition and analysis of the available data on ambient concentration of particulate matter (Black Smoke BS, Total Suspended Particulate TSP and PM10) for model comparison or correlation analysis between different particle measurement methods
- PM10 mapping by spatial interpolation with statistical methods or empirical dispersion modelling
- estimation of the road traffic-related part of PM10 (based on emission inventories for primary particles and for the precursors of secondary particles)
- estimation of the population exposure from a superposition of the PM10 map on the population distribution map

The differences between the countries concerning the procedures for measuring ambient particulate matter and the availability of emission data led to an adaptation of the general framework to the individual country specific case.

In **Austria**, particulate matter is measured in agreement with national legislation as Total Suspended Particulate (TSP) at more than 110 sites, whereas PM10 measurements are not yet available. It was assumed that ambient air TSP levels can be attributed to the contribution of local sources and regional background concentrations. Both of them were modelled separately. The starting point for the modelling of local contributions was the availability of a spatially disaggregated emission inventory for nitrogen oxides (NOx). An empirical dispersion model was established for NOx whose results could be compared with an extended network of NOx monitors. The spatial distribution of NOx was converted into TSP concentrations, using source specific TSP/NOx conversion factors. The regional background TSP levels were estimated from measurements and superimposed on the contributions from local sources. These results were compared to measured TSP data. Finally, PM10 concentrations were derived from TSP values by applying source specific TSP/PM10 conversion factors. The model is able to provide an estimate of the traffic-related part of PM10 concentration.

The **French work** was based on the available Black Smoke (BS) data. A correlation analysis between BS and PM10 (TEOM method\(^7\)) was first carried out. It was found that at urban background sites, BS and PM10 (TEOM) are about equal. Following this, linear relationships

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\(^7\) TEOM: Tapered element oscillating microbalance. Method for measuring continuously particle concentration.
were sought between the BS data and land use categories in the areas surrounding the measurement sites. Multiple regression analysis was performed for three categories of sites: urban, suburban and rural. Based on these regressions and using the land use data set, a PM10 map was established. A correction factor for secondary particles was defined using the European scale EMEP\textsuperscript{8} model. This was necessary because BS and TEOM considerably underestimate the amount of secondary particles in PM10. The percentage of PM10 caused by road traffic was determined in each grid cell using results from the Swiss PM10 model.

The Swiss work was based on a provisional national PM10 emission inventory. It was first disaggregated to a km\textsuperscript{2} grid. Dispersion functions for primary PM10 emission were defined in an empirical dispersion model, which was used to calculate the concentration of primary PM10. The contribution of secondary particles was modelled by using simple relationships between precursor and particle concentration. The long-range transported fraction was taken from European scale models. The PM10 fractions were then summed to create the PM10 map. The traffic related part was modelled separately, using both the road-traffic related portion of PM10 emission and the respective portion of the precursor emission for secondary particles.

The determination of the regional PM10 background was critical to the PM10 mapping procedures. The estimates of all three countries are in line with measured and modelled data from EMEP. The large-scale transported fraction of PM10 is considerable. At rural sites, over 50\% of PM10 may originate from large-scale transport. Furthermore, the contribution of traffic to PM10 background concentration is substantial and it may vary in space.

The population exposure to total PM10 is presented in Figure 5. Around 50\% of the population live in areas with PM10 values between 20 and 30 \(\mu g/m^3\) (annual mean). About one third is living in areas with values below 20 \(\mu g/m^3\). The rest is exposed to PM10 concentrations above 30 \(\mu g/m^3\). The high concentrations are found exclusively in large agglomerations.

\textsuperscript{8} EMEP: Co-operative Programme for the Monitoring and Evaluation of Long-Range Air Pollutants in Europe.
Figure 5: Frequency distribution of total PM10 population exposure (with share attributable to road traffic)\(^9\)

![Frequency distribution of total PM10 population exposure (with share attributable to road traffic)](image)

Figure 6: Frequency distribution of PM10 population exposure without share attributable to road traffic\(^10\)

![Frequency distribution of PM10 population exposure without share attributable to road traffic](image)

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The population exposure without PM10 fraction attributable to road traffic is shown in Figure 6. Compared to total PM10, the frequency distribution changes considerably. Most people would live in areas with PM10 values less than 20 µg/m³. In France and Switzerland, less than 3% of the population would live in areas with PM10 greater than 20 µg/m³. In Austria, this portion is higher due to an increased non-traffic caused regional PM10 background. However, in all three countries, the reduction of the percent values in higher PM10 concentration classes is substantial and indicates that road traffic contributes considerably to these PM10 concentration classes.

Population weighted PM10 averages are summarised in Table 7. Interpreting the figures one has to be aware of the fact that PM10 due to road traffic varies considerably spatially. In city centres, the relative contribution of road traffic to total PM10 is higher than in rural areas. Typical values, derived from the Swiss model are: 40 - 60% in cities and < 30% in rural areas.

Table 7: Population weighted annual PM10 averages for the three countries (calculated from the original grid values of the PM10 maps)

<table>
<thead>
<tr>
<th>PM10 concentration in µg/m³ (annual mean)</th>
<th>Austria</th>
<th>France</th>
<th>Switzerland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total PM10</td>
<td>26.0</td>
<td>23.5</td>
<td>21.4</td>
</tr>
<tr>
<td>PM10 without fraction attributable to road traffic</td>
<td>18.0</td>
<td>14.6</td>
<td>14.0</td>
</tr>
<tr>
<td>PM10 due to road traffic</td>
<td>8.0</td>
<td>8.9</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Despite the different methods used, the results of the three countries are similar, especially concerning PM10 levels caused by road traffic. The differences in total PM10 can be explained by the fact that (a) the background concentration is higher in Central and Eastern Europe than in the Western parts of Europe and (b) for Switzerland, large areas at higher altitudes have significantly lower PM10 levels. Furthermore, the sulphate fraction of the background concentration may increase from Western to Eastern Europe, resulting in an increase of the non-traffic related PM10 fraction. However, further investigations including measurements of PM10 as well as PM10 components are needed to explore in detail the significance of the differences found.

5 Monetary Evaluation

5.1 Overview of the components of the health costs

In Figure 8 is illustrated which costs can arise in principle because of health impacts. The total social costs of the health impacts consist of the following components:

- **Treatment costs**: This includes the costs of a stationary treatment in a hospital (infrastructure, doctor, medicaments etc.) as well as the costs of an ambulant treatment (consultation, medicaments etc.). The treatment costs can be distinguished between individually borne (of the person concerned) and collectively borne (e.g. in form of an assumption of a deficit of the hospital).

- **Administrative costs of personal insurances**: The health impacts due to air pollution lead to additional expenditures for insurances: The administration between patient, hospital and health insurance has to be processed and additional or dropped annuities lead to administrative expenditures for the insurance system.

- **Loss of production**: The health impacts lead to the situation that persons are temporarily or permanently not capable of working. Here again can be distinguished between the individually borne or collectively (e.g. in form of a loss of savings) borne loss of production.

- **Costs of averting-behaviour**: These are costs, which arise by prevention activities (e.g. leisure time stay in areas of minor exposure, change of domicile etc.). Reliable estimations to these costs do not exist until now. In general, they are considered as of minor importance.

- **Intangible costs**: The intangible costs consist of the loss of well being, pain and suffering due to an illness of the concerned person. The intangible costs can be much higher as the
material costs (treatment costs, loss of production, prevention costs), especially in the case of death or chronic illness.

5.2 Concepts of monetary evaluation

a) Cost of Illness Approach (COI)

This approach takes into account only the material costs of mortality or morbidity. It is based on the determination of the damage for the entire society, without regarding the individual difference in valuing lower or higher risks of mortality or morbidity. The COI-approach considers the following (in Figure 8 yellow resp. grey marked) components:

- Gross loss of production: As already explained, persons with health impacts are temporarily or permanently not capable of working. The gross loss of production considers the entire salary of this person. The individual consumption of this person is included because it represents a (foregone) benefit, too.
- Costs of medical treatment
- Administrative costs of personal insurances

The problem of this approach is illustrated in Figure 8: The costs of prevention and especially the immaterial costs are perfectly neglected.

In his practical appliance, this approach is often completed by a workaround in order to consider as well the intangible costs (pain, suffering etc.). The compensation granted by the courts for death and bodily harm is taken as an indicator of intangible costs. In comparison with the calculation of intangible costs by using the willingness-to-pay approach (see below), the results are considerably lower.

b) Willingness to Pay Approach (WTP)

In the last few years, the willingness-to-pay approach (WTP) could establish as an alternative to the COI-approach. This approach measures the willingness to pay of the population for the reduction of the risk which arises by the exposure to air pollution and endangers health. By using sophisticated methods, people are asked how much they would be willing to pay for an improvement of the security resp. for a decrease of the health risk.

It can be assumed that in peoples answer the individually borne costs enter, too. This means that at least a part of the averting-behaviour costs as well as the intangible costs are part of the stated willingness to pay (compare Figure 8). An additional advantage of this approach is that the evaluation of a reduced health risk takes place by taking into account the individual preferences and wishes. For this reason, the willingness-to-pay approach satisfies, compared to the COI approach, a very important condition of economic welfare theory.
However, problems with this approach arise in reference to the following aspects:

- **Reliability of the answers**: Several authors criticised that the survey take place under hypothetical conditions and that the persons asked do not have to pay the quoted values. This can lead to the situation that, consciously or unconsciously, too high values are stated. Additional criticism raised e.g. concerning the interdependence of the willingness to pay from the values proposed as well as concerning the handling of extreme values. With increasingly sophisticated interview procedures and additional questions to control the statements, it is possible to meet several of these objections.

- **Considered components of costs in the answers**: As illustrated in Figure 8, it has to be assumed that the willingness to pay consists primarily of the individually borne costs. The answers include for sure the immaterial costs and the individually borne treatment costs as well as the loss of salary. Regarding the treatment costs, there exists the problem that the individually borne part of the treatment costs depends on the social insurance system and could be very low. If the payments for insurance premium (resp. a reduction of premium payment with a reduced risk of air pollution) are being considered while stating the willingness to pay is a priori not clear. If not, then the treatment costs are considerably underestimated. Similar considerations can be applied concerning the loss of production: If the loss of production is widely covered by insurance payments then it probably will not be considered while stating the willingness to pay.

In summary, there can be concluded that the amount of the costs considered while stating the willingness to pay heavily depends on the specific design of the (social-) insurance system and the effective question posed. Many examples in the literature do not indicate which components of costs are covered by the declared willingness to pay.

- **Interdependence between the willingness to pay and the income**: The willingness-to-pay approach depends on the level of income, which may pose ethical problems when applied to very different countries (OECD vs. less developed countries).

Altogether, the willingness-to-pay approach has essential advantages in comparison with the COI-approach:

- The main advantage of the willingness-to-pay approach lies in evaluating the individual preferences for risk reductions of morbidity and premature fatalities. It therefore meets the requirements of welfare economics, since it reflects the individual point of view.

- This approach enables to consider in a more or less reliable way the intangible costs, which are especially in the case of death very high. The negligence of these costs – as in the CIO-approach – would lead to a considerably underestimation of the effective health costs.
Based on these considerations, the WTP-approach was chosen as the common methodological concept in the tri-national project.\textsuperscript{12}

5.3 Evaluation of mortality

Generally, there exist two different concepts to evaluate mortality resp. the risk of mortality: The first is based on the value of a prevented fatality (VPF) and the second is based on the value of the lost life years (VLYL = Value of Life Year Lost). The VPF-approach measures the risk of a premature death by calculating a monetary value. The VLYL-approach on the other hand evaluates not the risk of mortality but measures the lost life years caused by death.

In the tri-national project, the VPF-concept was used as a starting point. Indeed, because of the available budget and time restrictions, it was not possible to conduct an own empirical inquiry. Therefore, empirical results of road accident related WTP were used as a starting point.

The most recent studies from the 1990’s indicate a range of WTP values for the prevention of a statistical fatality of 0.7 to 6.1 million EUR.\textsuperscript{13} One of the latest empirical study, conducted by Jones-Lee et al.\textsuperscript{14} provides a VPF of 1.42 million EUR (range: 0.7-2.3 million EUR).

Based on these most recent results and the experience of former studies a starting value of 1.4 million EUR was adopted for the value of preventing a statistical fatality. This choice was supported by the use of a similar starting value (1.2 million EUR) in a recent study on behalf of the UK Department for Environment, Transport and Regions (DETR) and the fact that it lies in the lower part of the range of the majority of recent empirical evaluations.\textsuperscript{15} This choice is in line with the "at least" approach prevailing throughout the entire project.

Road accident related fatal risk differs from air pollution related risk. The latter is largely involuntary and beyond the responsibility and control of those exposed to it. In addition, while taking the risk of a traffic accident, driving itself offers a direct personal benefit. On the other hand, air pollution related risk is less often connected to a direct personal benefit, although it is to some extent transport induced. Because of this different risk context, air pollution re-

\textsuperscript{12} According to the country specific needs, in addition to the WTP-approach an alternative partial assessment approach was conducted, based on the loss of production or consumption (see chapter 5.3).


\textsuperscript{15} For example, the ExternE-Project, a very extensive project on behalf of the European Community on the external costs of energy use, is based on a meta-analytical value of 2.6 million Euro with a range from 2.1 to 3.0 million Euro. See: ExternE (1995), Externalities of Energy, Vol. 2: Methodology.
lated risk aversion is likely to be higher than for fatal road accidents.\textsuperscript{16} The impact of the contextual difference between road accident and air pollution related risk on individual aversion is subject of several empirical studies and has produced factors in the range of 1.5 to 2. However, the empirical evidence is not considered to be sufficient and following the "at least" approach, the contextual adaptation of the WTP value is abandoned in the present study.

Based on the available epidemiological literature, a direct conclusion about the age structure of the air pollution related premature deaths was not yet possible. However, it was known that these fatalities are mostly related to respiratory and cardiovascular diseases and lung cancer. In Austria, France and Switzerland, the average age of these respiratory and cardiovascular fatalities lies between 75 and 85 years (see Figure 9).

**Figure 9:** Age structure of fatalities due to respiratory, cardiovascular diseases and lung cancer in Austria\textsuperscript{17}, France and Switzerland (1996)

![Age structure of fatalities](image)

Hence, the average age of the air pollution related fatalities is much higher than for victims of fatal road accidents (30-40 years of age).

Theoretical as well as empirical evidence indicates a decreasing WTP with increasing age, with reduced remaining life expectancy and with reduced quality of life. For the present study,\textsuperscript{16,17}

\textsuperscript{16} This view is adopted by a number of authors. See: Jones-Lee et al (1998), On the Contingent Valuation of Safety and the Safety of Contingent Valuation: Part 1 - Caveat Investigator and Department of Health (1999), Economic Appraisal of the Health Effects of Air Pollution, p. 63-66

\textsuperscript{17} Only respiratory and cardiovascular diseases without lung cancer.
the relationship adopted is provided by the research of Jones-Lee.\textsuperscript{18} Weighting the age structure of the fatalities due to respiratory and cardiovascular disease and lung cancer in all three countries by the age factor, an average adaptation factor of 61% is obtained for the present willingness-to-pay for a prevented fatality value.

Based on the preceding discussion we used a value of 0.9 Mio. EUR (=61\% \times 1.4 \text{ Mio. EUR}) for the value of preventing a statistical fatality. Hence, the cost reducing adjustment for age is maintained, meanwhile the cost increasing adjustment for the risk context is abandoned. This implies a very strict application of the “\textit{at least}” approach.

5.4 Evaluation of morbidity

Unfortunately, the literature on WTP based, air pollution related morbidity costs was very rare in Europe in 1999 and most available studies refer to the US context. Their application to Europe is not completely unproblematic, since a recent research, study provides lower results for a European country.\textsuperscript{19} The different socio-cultural background and the difference in health care and insurance systems ask for an application of country specific WTP results. In spite of this problem, the present study had to be based on existing values since the available resources did not allow for an empirical survey within this project.

Table 10 presents the WTP for avoiding different air pollution related health outcomes.

<table>
<thead>
<tr>
<th>Health indicator</th>
<th>WTP-Value (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Hospital Admission</td>
<td>7’870 per admission\textsuperscript{20}</td>
</tr>
<tr>
<td>Cardiovascular Hospital Admission</td>
<td>7’870 per admission\textsuperscript{20}</td>
</tr>
<tr>
<td>Chronic Bronchitis</td>
<td>209’000 per case\textsuperscript{21}</td>
</tr>
<tr>
<td>Bronchitis</td>
<td>131 per case\textsuperscript{22}</td>
</tr>
<tr>
<td>Restricted Activity Day</td>
<td>94 per day\textsuperscript{22}</td>
</tr>
<tr>
<td>Asthmatics: Asthma Attacks (person day)</td>
<td>31 per attack\textsuperscript{23}</td>
</tr>
</tbody>
</table>


\textsuperscript{21} Chestnut L.G. (1995), Human health benefits from sulfate reductions under Title IV of the 1990 clean air act amendments, p. 5-20, WTP for an average chronic bronchitis case.

\textsuperscript{22} Maddison D. (1997), Valuing the morbidity effects of air pollution, p. 8.
6 Results

6.1 Quantitative results of PM10 related health effects

From the epidemiological data (fixed base line increment per 10 µg/m³ PM10 per 1 million inhabitant) on the one hand and the average exposure level of the population on the other hand, the number of health outcomes can be determined.

These calculations may be done for the current exposure to particulate matter as well as for a hypothetical situation without road traffic-related air pollution. The difference between the two results corresponds to the number of morbidity and mortality cases attributable to road traffic-related air pollution.

In Table 11 for Austria, France and Switzerland, the health effects considered are presented for the average annual exposure to total air pollution and for the average annual exposure to road traffic-related air pollution. According to the epidemiological foundations, for each health outcome the respective age group is considered. Knowing the distribution of the different population groups across exposure classes (chapter 3) and the parameters of the exposure-response function (chapter 2), the absolute number of health outcomes may be established for each country with or without the road traffic-related share of air pollution.

It needs to be emphasized that the health effects are only considered from the exposure class of 5-10 µg/m³ PM10 onwards (average 7.5 µg/m³ PM10). This restriction reflects the fact that epidemiological studies have not yet included the exposure-response relationship below this level. In addition, it needs to be considered that there is a natural background concentration level, which is not man made. For Austria, France and Switzerland this natural baseline pollutant level is estimated to be <7.5 µg/m³ PM10. For the further assessment of air pollution measures, it is adequate to only consider the air pollution of human activities.

In Table 11, the negative effects of air pollution are divided into the number of health outcomes related to total air pollution and those related to the road traffic share only.

a) Mortality

In 1996, air pollution caused 5'600 cases of premature death in Austria, 31'700 cases in France and 3'300 cases in Switzerland. In Austria 2'400, in France 17'600 and in Switzerland 1'800 cases are attributable to road traffic-related air pollution.

According to the epidemiological foundations, the increase in premature mortality is only considered for adults ≥30 years of age and for the exposure class of 5-10 µg/m³ PM10 (class mean 7.5 µg/m³ ) onwards.

---

<table>
<thead>
<tr>
<th>Health outcome</th>
<th>Cases or days attributable to total air pollution</th>
<th>Cases or days attributable to road traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Long-term mortality (adults ≥ 30 years; excluding violent death)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>5'600 - 7'800</td>
<td>3'300 - 4'700</td>
</tr>
<tr>
<td>France</td>
<td>19'200 - 44'400</td>
<td>2'000 - 4'700</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1'500 - 3'400</td>
<td>10'700 - 24'700</td>
</tr>
<tr>
<td>2. Respiratory hospital admissions (all ages)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>3'400</td>
<td>1'300</td>
</tr>
<tr>
<td>France</td>
<td>1'400 - 2000</td>
<td>140 - 2'500</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1'600 - 2'800</td>
<td>800 - 1'600</td>
</tr>
<tr>
<td>3. Cardiovascular hospital admissions (all ages)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>6'700</td>
<td>3'000</td>
</tr>
<tr>
<td>France</td>
<td>10'400 - 29'400</td>
<td>1'500 - 4'400</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1'500 - 4'300</td>
<td>5'900 - 16'300</td>
</tr>
<tr>
<td>4. Chronic bronchitis incidence (adults ≥ 25 years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>6'200</td>
<td>4'200</td>
</tr>
<tr>
<td>France</td>
<td>3'300 - 73'100</td>
<td>370 - 8'400</td>
</tr>
<tr>
<td>Switzerland</td>
<td>240 - 5'300</td>
<td>1'800 - 40'700</td>
</tr>
<tr>
<td>5. Bronchitis (children &lt; 15 years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>48'000</td>
<td>45'000</td>
</tr>
<tr>
<td>France</td>
<td>198'500 - 813'600</td>
<td>20'000 - 82'000</td>
</tr>
<tr>
<td>Switzerland</td>
<td>9'000 - 37'000</td>
<td>110'000 - 433'000</td>
</tr>
<tr>
<td>6. Restricted activity days (adults ≥ 20 years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>3'100'000</td>
<td>2'800'000</td>
</tr>
<tr>
<td>France</td>
<td>20'700'000 - 28'500'000</td>
<td>2'400'000 - 3'200'000</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1'100'000 - 1'600'000</td>
<td>11'500'000 - 15'900'000</td>
</tr>
<tr>
<td>7. Asthmatics: asthma attacks (children &lt; 15 years, person days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>35'000</td>
<td>24'000</td>
</tr>
<tr>
<td>France</td>
<td>149'000 - 337'000</td>
<td>15'000 - 33'000</td>
</tr>
<tr>
<td>Switzerland</td>
<td>9'000 - 21'000</td>
<td>83'000 - 188'000</td>
</tr>
<tr>
<td>8. Asthmatics: asthma attacks (adults ≥ 15 years, person days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>94'000</td>
<td>63'000</td>
</tr>
<tr>
<td>France</td>
<td>281'000 - 879'000</td>
<td>30'000 - 95'000</td>
</tr>
<tr>
<td>Switzerland</td>
<td>20'000 - 62'000</td>
<td>155'000 - 489'000</td>
</tr>
</tbody>
</table>

Table 11: Additional cases of mortality and morbidity due to air pollution in Austria, France, and Switzerland.
b) Morbidity

Within the additional morbidity cases, the highest incidence in all three countries is registered for acute bronchitis in children younger than 15 years. Some 21'000 cases in Austria, some 250'000 cases in France and some 24'000 cases in Switzerland were attributable to road traffic-related air pollution in 1996.

The second highest frequency is obtained for the incidence of chronic bronchitis in adults. In 1996, the number attributable to road traffic-related air pollution amounts to ca 2'700 cases in Austria, 20'400 cases in France and 2'200 cases in Switzerland.

The additional cases of cardiovascular hospital admissions (all ages) due to road traffic-related air pollution amount to 2'900 cases in Austria, 11'000 cases in France and 1'600 cases in Switzerland. The smallest number of road traffic attributable cases is obtained for respiratory hospital admissions (all ages). In 1996, it amounts to ca 1'500 cases in Austria, 7'700 cases in France and 700 cases in Switzerland.

Concerning the additional days of air pollution related morbidity, a very large number of restricted activity days for adults (≥ 20 years) results in all three countries. In 1996, in Austria, 1.3 million days, in France 13.7 million days and in Switzerland 1.5 million days with restricted activity are attributed due to road-traffic-related air pollution.

In 1996, for Austria 15'000 asthma attacks in children (<15 years) and 40'000 asthma attacks in adults (≥ 15 years) are attributable to road traffic-related air pollution. France and Switzerland attributed 135'000 and 13'000 asthma attacks in children and 321'000 and 33'000 asthma attacks in adults to road traffic-related air pollution.

6.2 Health costs due to air pollution based on the willingness-to-pay approach

Based on the willingness-to-pay approach, in 1996 the total air pollution in Austria, France and Switzerland caused a high level of health costs. The total air pollution related health costs across the three countries amount to 49’700 million EUR (Table 12), of which 26’700 million EUR are attributable to road traffic-related air pollution.

In Austria (6’700 million EUR) and Switzerland (4’200 million EUR) the total air pollution related health costs reach a similar level. Due to the much larger population, the French costs amount to 38’800 million EUR.
In all three countries, road traffic is a main source of air pollution related health costs. The absolute level of the road traffic-related air pollution amounts to 8.9 µg/m³ PM10 in France, 8.0 µg/m³ in Austria and of 7.4 µg/m³ in Switzerland (as population weighted annual averages). It needs to be remembered that tailpipe exhaust is only responsible for part of the PM10 concentration. The considerable proportion of other emissions, such as tyre wear, other abrasion products and road dust re-suspension are independent of the share of diesel engines.

The lower relative proportion of traffic-related health costs in Austria may be caused by a higher background of PM10 in 1996, which may contain a high sulphate amount (especially in Eastern Austria).
Depending on the country, 72% to 75% of the health costs are related to mortality (see Figure 13). The differences are mainly due to country specific differences in the baseline frequencies of the health outcomes observed.

**Figure 13:** Breakdown of air pollution related costs by mortality and morbidity

Comparing the total air pollution related health costs per capita (see Figure 14) the results of the three countries stay within the same range, although the central estimates indicate differences between the three countries. The highest per capita costs are shown for Austria.

For the road traffic-related health costs, the per capita results differ much less between the three countries: The highest value is obtained in France with about 370 EUR per capita, followed by Austria with about 360 EUR per capita and Switzerland with about 310 EUR per capita.

These differences are mainly due to air pollution levels (average level of population weighted total PM10 exposure and the traffic-related share) and the epidemiological results (different national mortality and morbidity rates in general). However, the results of the three countries stay within the same range. Therefore, the differences in per capita costs mentioned above should not be over interpreted.
6.3 **Health costs due to air pollution based on cost of illness (COI)**

According to the country specific needs, in addition to the WTP-approach a partial assessment approach has been used to evaluate the health costs:

- The mortality related health costs are based on the production/consumption loss. The losses are determined on the potential years of life lost.
- The morbidity related health costs are based on the costs of illness, which consist of the production loss due to incapacity of work and the medical treatment costs.

The partial assessment approach is an extreme implementation of the “at least” approach in so far, as it does not include a major aspect of mortality and morbidity risk related costs, namely the intangible costs. In addition, for some health outcomes (chronic bronchitis, asthma attacks) only the medical treatment costs are included, as for the production loss related to these health outcomes, no data is presently available. In absence of empirical data, for the very great number of restricted activity days no costs of production loss and medical treatment could be established at all.
The per capita costs of the partial assessment approach are shown in Table 15.

Table 15: Air pollution related health costs per capita based on the partial assessment approach (1996)

<table>
<thead>
<tr>
<th></th>
<th>Austria</th>
<th>France</th>
<th>Switzerland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs per capita</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(EUR)</td>
<td>140</td>
<td>70</td>
<td>160</td>
</tr>
<tr>
<td>80 - 190</td>
<td>40 - 100</td>
<td>100 - 230</td>
<td></td>
</tr>
<tr>
<td>30 - 80</td>
<td>20 - 60</td>
<td>50 - 120</td>
<td></td>
</tr>
</tbody>
</table>

All the above mentioned restrictions for the assessment of health costs due to air pollution reduces the costs by a factor of 3.6 (in Switzerland) up to a factor of 9.1 (in France) compare to the willingness to pay based results.

The differences between the countries are mainly based on the country specific calculation methods. Different cost levels for the production or consumption loss approach have been used: 18'230 EUR per year of life lost in Austria, 12'600 in France and 34'800 in Switzerland. The use of the same valuation per year of life lost for the three countries would have suppressed most of the differences in relative ratios between WTP and partial assessment results.

6.4 Interpretation and sensitivity of the results

For the assessment of air pollution related health costs, different methodological approaches are available. For an integral view, considering the material and intangible costs, the willingness-to-pay approach for the monetary valuation of mortality and morbidity costs comes to the fore.

Based on this approach, the results may be interpreted as follows:

- In all three countries, road traffic is a main source of air pollution related health costs. The absolute level of the road traffic-related costs stay within the same range: 0.9%-2.7% of the GDP in France, 0.8%-2.5% in Austria and 0.6%-1.7% in Switzerland.

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25 The Swiss value contains an amount of 14'200 EUR per year of life lost as a low and insufficient proxy for the intangible costs. The proxy is based on compensation payments granted by courts.
• Compared to other road traffic-related negative impacts (noise, accidents, damage to buildings), the health costs are considerable. According to comparative studies in Austria and Switzerland, the health costs exceed the present estimations of accident costs.

• Based on the actual air pollution, a reduction in the average PM10 exposure of 10 µg/m³ would result in the long run in a annual cost reduction of 3'600 million EUR in Austria, 24'300 million EUR in France and 3'000 million EUR in Switzerland. However, it needs to be borne in mind that

  – the health costs (assessed by the willingness-to-pay approach) are mostly borne by individuals through welfare losses and intangible costs. Therefore, the cost savings due to a reduction of air pollution don’t result in a similar reduction of the health budget covered by the social insurance system.

  – the cost reduction has to be seen as a long-term effect and that the savings during transition years would be less.

The sensitivity of the overall results is influenced by all three partial steps (the assessment of exposure, the exposure-response relationship for mortality and morbidity, the monetary valuation of mortality and morbidity related risk). The impact of key assumptions and methodological decisions has been quantified in the health impact paper26, and discussed in more detail in our full reports.27 In general, for each sensitive assumption an "at least" approach was adopted. The real costs of (road traffic-related) air pollution are considered to be higher than the results of the present study, since

• various PM10 related health effects (e.g. infant mortality) were not considered due to the absence of available data;

• the additional effects of other pollutants (e.g. ozone) were not considered;

• for the monetary valuation, generally lower estimates of cost factors were chosen.

7 Outlook

In Switzerland is currently a project in progress, which aims to update the health costs due to traffic-related air pollution.

This project has been initiated in March 2003 by the Federal Office of Spatial Development and is based on the investigations of the tri-national study. It will be finished in spring 2004. This project is processed basically by the same research team who already made the Swiss part of the tri-national study.\(^{28}\) The project consists of the following parts:

- **Part I: Peoples exposure to air pollution**
  This part of the project aims to identify the total peoples exposure to PM10 in the year 2000 and in addition to which extent the road traffic resp. the rail traffic was responsible for.

- **Part II: Health impacts (Epidemiology)**
  This part of the project aims to
  - investigate the exposure-response functions between air pollution and health impacts
  - and, by using these functions, to calculate the number of mortality and morbidity cases which result from peoples exposure to air pollution in the year 2000.

- **Part III: Evaluation of the health costs (Economics)**
  In the last part of the project, the obtained health impacts have to be evaluated in monetary terms and the annual health costs due to air pollution have to be indicated.

In comparison with the tri-national project, there have been made the following modifications concerning the evaluation of health costs:

- The willingness-to-pay approach will be completed by an estimation of the treatment costs, which are individually borne (not paid by the patient himself, but covered by insurance payments or by an assumption of an deficit).

- Beside the investigation of the number of premature deaths, we also calculate the number of lost life years and evaluate both results.

- The used health costs per case will be updated. If we use foreign values, we will adapt them for Switzerland by using the purchasing power parity.

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\(^{28}\) Epidemiology: Institute for social and preventive medicine (Charlotte Braun-Fahrländer, Martin Röösli); Air pollution: Infras (Jürg Heldstab) / Meteotest (Thomas Kuenzle); Economy and project coordination: Ecoplan (Heini Sommer).
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