



Health Costs due to Road Traffic-related Air Pollution

An impact assessment project of Austria, France and Switzerland

Prepared for the WHO Ministerial Conference on Environment and Health
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Economic Evaluation Technical Report on Economy

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U V E K
E T E C
E T E C

This report is part of a series developed in preparations for the transport environment and health session of the WHO Ministerial Conference on Environment and Health, held in London in 1999. The series includes: The collaborative study on the health costs of air pollution from transport, with reports on the methods and findings for estimation of air pollution exposure (TEH05), attributable cases (TEH06), economic valuation of health events (TEH07), and synthesis report (TEH04). A short monograph (TEH02) and a book (TEH03) which review the environmental health impacts of transport and draw policy implications, prepared as substantiation for the decisions taken in London. The Charter on transport environment and health (TEH01), a political document stating the concerns, principles, strategies and plan of action of Member States from the WHO EURO Region to promote transport systems which are sustainable for health and the environment. Details on these documents can be obtained on the web: <http://www.who.dk>. The series is expected to continue with reports of a case study on the health impacts of mopeds and from follow-up activities decided in the Charter.

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Summaries

Summary of the Technical Report on Economy

Introduction

In preparation to the Transport, Environment and Health Session of **the WHO Ministerial Conference on Environment and Health**, to be held in London in June 1999, a tri-lateral project was carried out by Austria, France and Switzerland. The project assessed the health costs of road traffic related air pollution in the three countries using a common methodological framework.

From the French side, this tri-lateral research has been selected as part of the French co-ordinated research program on transports (PREDIT)⁽¹⁾ by both steering groups of PREDIT in charge of research co-ordination in the field of health effects of transport related pollution and externalities' monetarisation. This underlines the commitment of PREDIT towards international cooperation.

Context: In addition to its positive impact on the growth and prosperity of the national economy and its importance for satisfying our individual needs for mobility, road transport also has adverse effects: accidents, noise, air pollution, harm to health, crop failure, etc.

In the last 10 to 20 years an increasing awareness may be observed for these negative effects of transport. Congestion, air pollution and noise affect more and more people. Their impact on health and welfare, the damage to buildings and the natural environment are considerable, just like the material and intangible costs caused by them.

These costs are mainly **external** costs which means that they are not covered by the polluters (the motorists) but that they are imposed on everybody. External costs cause a problem to the economy, as they are not included in the market price which leads to wrong decisions and to a wasting of scarce and vital resources (clean air, silence, clean water, etc.). Motorists behave as if those costs did not exist because they do not have to pay them. Including the external costs, their trips would have produced higher total costs than the total benefit. As a consequence, many trips would be avoided if the driver had to take all the external costs into consideration.

In order to stop to the wasting of scarce resources, the government has to take action and put a price on clean air and other environmental „products“. As a result, negative impacts of road transport have to be paid for by the polluter. The usual terminology for this process is „internalisation of externalities“.

A condition for such an environmental and transport policy is a knowledge about the negative impacts of road traffic and their monetary quantification. With the present study, an important part of the external traffic-related costs, namely the **negative impacts of road traffic-related air pollution on human health**, is evaluated and quantified in monetary terms.

The main **objective** of the tri-lateral research project was to quantify the road traffic-related health costs due to air pollution.

Another objective was the choice of a common methodological framework and the evaluation of results that are comparable for the three countries. Of course, within the common methodological

1 The PREDIT is a joint research program developed and supported by following institutions: Ministry of Transports, Ministry of Research, Ministry of Industry, Ministry of Environment, ADEME French Agency for Environment and Energy Management, ANVAR French Agency for Research Valorisation.

framework, some specific features of each country (data availability, health system, etc.) must be considered.

The research project is based on an **interdisciplinary co-operation** in the fields of air pollution, epidemiology and economy. To give an overview of the overall project, short summaries of the technical reports on air pollution and epidemiology are included in this report.

This report presents the results of the economy part of the project. The **main tasks** were:

- **to quantify the impacts of traffic related air pollution** on human health (number and type of additional cases of morbidity, number of additional cases of premature death) by combining the exposure-response relationship with the distribution of exposure to PM₁₀ in each country
- **to assess these health effects in monetary terms** by using adequate methods.

Results

For the monetary valuation of the air pollution related health effects, **the willingness-to-pay** is used as the **main approach**. This method assesses the health costs based on the willingness-to-pay for a decrease in mortality and morbidity related risk. Thereby, the material costs (loss of production/consumption and treatment costs) as well as the intangible costs (pain, suffering, fear of disease and death, grief, etc.) are considered.

According to the countries' specific needs, an alternative partial assessment approach is conducted based on the loss of production or consumption. Because of its limitation to the material costs only, the results of this partial assessment approach are lower as in the case of the willingness-to-pay approach.

Based on the **willingness-to-pay** approach, in 1996 the total air pollution in Austria, France and Switzerland causes a high level of health costs. The **total air pollution related health costs** of all three countries amount to some **49'700 million EUR** (Table S-1), of which some **26'700 million EUR** are attributable to **road traffic-related air pollution**.

In Austria (6'690 million EUR) and Switzerland (4'170 million EUR) the **total air pollution** related health costs reach a similar level. Due to the much larger population, the French costs amount to some 38'860 million EUR.

Table S-1: Health costs due to road traffic-related air pollution in Austria, France and Switzerland based on the willingness-to-pay approach (1996)

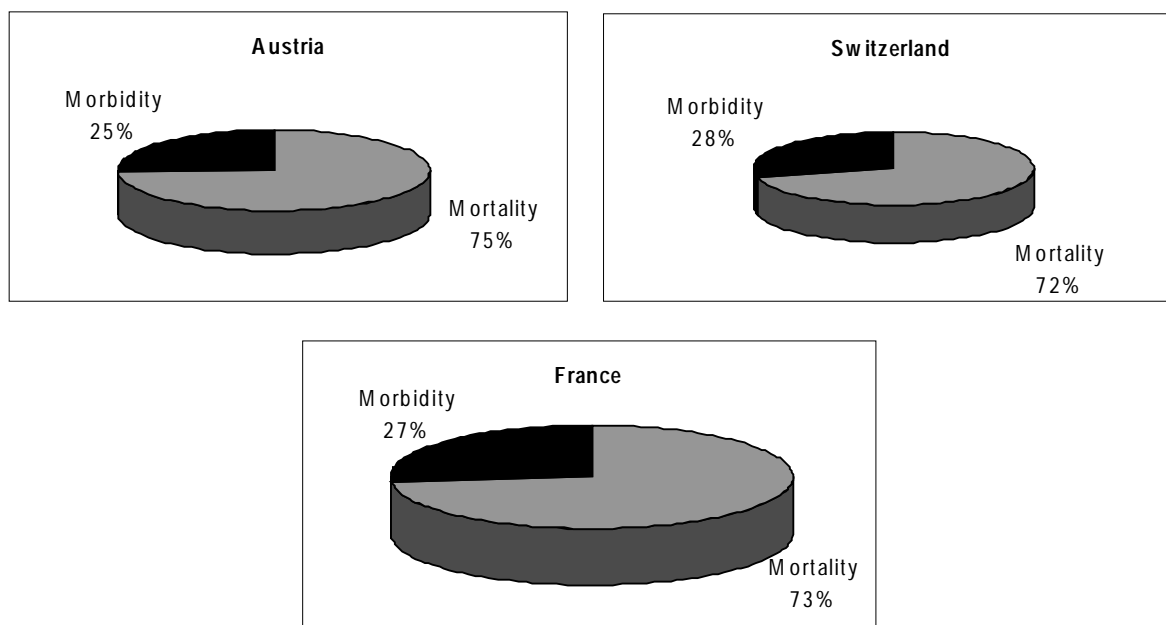
	Austria		France		Switzerland	
	Total costs with road traffic share	Costs attributable to road	Total costs with road traffic share	Costs attributable to road	Total costs with road traffic share	Costs attributable to road
Costs of mortality (million EUR)	5'019 3'033 - 7'031	2'170 1'311 - 3'041	28'523 17'282 - 39'932	15'866 9'613 - 22'212	2'983 1'787 - 4'186	1'586 950 - 2'225
Costs of morbidity (million EUR)	1'669 396 - 3'044	722 171 - 1'316	10'335 2'760 - 18'537	5'749 1'535 - 10'311	1'188 314 - 2'134	630 167 - 1'132
Total costs (million EUR)	6'687 3'429 - 10'075	2'892 1'483 - 4'357	38'858 20'042 - 58'469	21'615 11'148 - 32'523	4'170 2'101 - 6'319	2'216 1'117 - 3'357

	all three countries	
	Total costs with road traffic share	Costs attributable to road
Costs of mortality (million EUR)	36'524 22'102 - 51'149	19'622 11'875 - 27'477
Costs of morbidity (million EUR)	13'191 3'470 - 23'714	7'100 1'873 - 12'759
Total costs (million EUR)	49'715 25'572 - 74'863	26'723 13'748 - 40'236

The road traffic is in all three countries a main source of air pollution related health costs. The absolute level of the road traffic-related air pollution stay within the same range: $8.9 \mu\text{g}/\text{m}^3$ PM_{10} in France, $8.0 \mu\text{g}/\text{m}^3$ in Austria and of $7.4 \mu\text{g}/\text{m}^3$ in Switzerland (as population weighted averages). It needs to be remembered that tailpipe exhaust is only responsible for part of the PM_{10} concentration. The considerable proportion of other emissions, such as tyre wear, other abrasion products, road dust re-suspension are independent from the proportion of diesel engines. The lower relative proportion of traffic-related health costs in Austria may be caused by a higher background of PM_{10} in 1996 which may contain a high sulphate amount (especially in Eastern Austria).

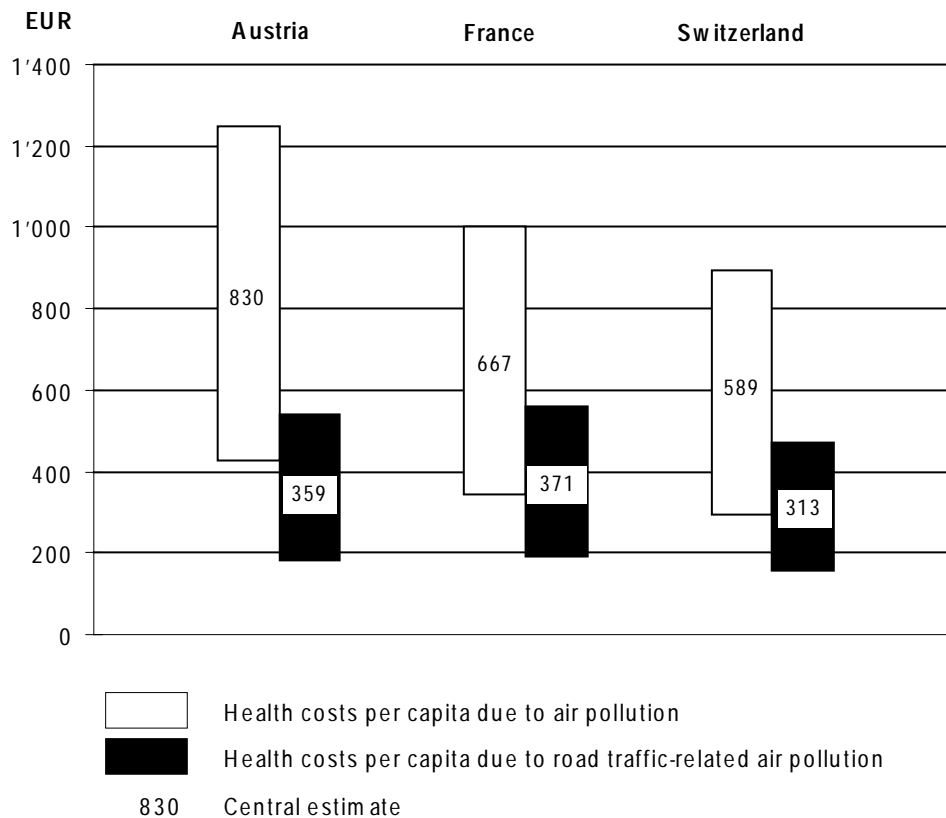
According to the country, 72% to 75% of the health costs are related to mortality (see Figure S-2). The differences are mainly due to country specific differences in the baseline frequencies of the health outcomes observed.

Figure S-2: Breakdown of air pollution related costs by mortality and morbidity



Comparing the **total air pollution related health costs per capita** (see Figure S-3) 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 registered for Austria (425 - 1'250 EUR). This amount is 41% higher than in Switzerland (297 - 892 EUR per capita). In France, the annual average costs per capita amount to 344 - 1'004 EUR.

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 based on 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 overinterpreted.

Figure S-3: Air pollution related health costs per capita (1996)

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). In general, for each sensitive assumption an "at least" approach was adopted. Therefore, the real costs of (road traffic-related) air pollution are considered to be higher than the results of the present study.

Recommendations

Considering these results, the following **main recommendations** can be drawn:

- The magnitude of assessed health costs indicates a need for action: not only making statements about the need for reducing air pollution but defining objectives and setting a concrete time schedule for their realisation is necessary.
- The polluter pays principle has to be applied to the domain of road traffic.
- Air pollution related health costs have to be included in cost-benefit analysis of road infrastructure projects and of policy measures and actions which are directed against a further increase in traffic flows.

In the economic domain, the following **further steps** should be developed:

- empirical surveys of the willingness-to-pay for a reduction in air pollution related mortality and morbidity,
- improvement of the long-term morbidity assessment,
- empirical studies of the age structure of the victims due to air pollution,
- evaluation of the cost of absence from work related to different health outcomes,
- development of policy measures and their implementation and periodic monitoring and readjustment of the policy measures,
- investigation of the time lag between exposure and health outcome on the one hand and the corresponding decrease in mortality and morbidity due to a exposure reduction, on the other hand.

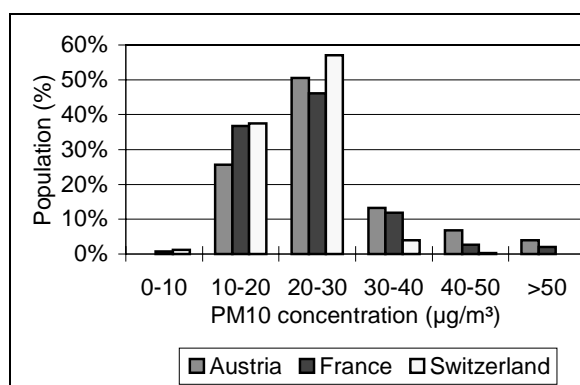
Short Summary of the Technical Report on Air Pollution⁽²⁾

In the framework of the preparation of the WHO Ministerial Conference on Environment and Health, Austria, France and Switzerland have co-operated in carrying out an impact assessment project on road-traffic related air pollution and its health costs. In this context, the main task of the air pollution part was to estimate the exposure of the population to the ambient concentration of the annual mean value of PM₁₀. Population exposure was calculated both for total PM₁₀ and for road-traffic related PM₁₀.

A general methodological framework was defined. This involved four main steps: (a) acquisition and analysis of data; (b) PM₁₀ mapping; (c) estimation of the road-traffic related fraction of PM₁₀; and (d) calculation of population exposure. The differences between the countries in the procedures for measuring airborne particles and in the availability of emission data led to an adaptation of the general methodological framework to the individual country specific case.

The modelled PM₁₀ concentration values derived for the three countries are generally in good agreement with measured values. For PM₁₀ mapping, the results show a tendency towards under-estimation. As main results, population weighted PM₁₀ averages and the frequency distribution of PM₁₀ population exposure are summarised in the following table and graph:

	PM ₁₀ concentration in µg/m ³		
	Austria	France	Switzerland
Total PM ₁₀	26.0	23.5	21.4
PM ₁₀ without fraction attributable to road traffic	18.0	14.6	14.0
PM ₁₀ due to road traffic	8.0	8.9	7.4



In city centres, the relative contribution of road traffic to total PM₁₀ is higher than in rural areas. Typical values are: 40 - 60 % in cities and < 30 % in rural areas. The large-scale transported fraction of PM₁₀ is considerable and the contribution of traffic to this PM₁₀ background is quite substantial.

Despite the different methods used, the results of the three countries are relatively similar, especially concerning PM₁₀ levels caused by road traffic. The differences between the countries may be caused by: (a) different background concentration, (b) different sulphate fraction in background PM₁₀, and (c) different proportion of areas at higher altitudes. However, further investigations are needed to explore in detail the significance of the differences found.

Several difficulties had to be overcome during the work on this study. As a consequence, recommendations have been worked out like (a) the establishment of national PM₁₀ networks using samplers that are compatible with the new European reference method, (b) the measurement of

2 Filliger P., Puybonnieux-Textier V., Schneider J. (1999), Health Costs due to Road Traffic-related Air Pollution, PM₁₀ Population Exposure.

other indicators of particulate matter such as PM_{2.5}, particle number, particle surface area and selected chemical PM₁₀ components, (c) the establishment of reliable emission inventories of PM₁₀ and smaller PM₁₀ fractions. Additionally, receptor studies should be launched.

Short Summary of the Technical Report on Epidemiology⁽³⁾

Austria, France and Switzerland have co-operated in carrying out an impact assessment project on road-traffic related health costs. Epidemiology provided the air pollution attributable cases. Moreover, it was a major aim to contribute to the development of a common methodological framework of international health impact assessment.

Effect estimates from epidemiologic studies are a key component for the assessment of air pollution impacts on health. If applicable, it was decided to consider both short- and long-term effects for the assessment. However, overlapping health measures had to be excluded to prevent from double counting the impact (monetary valuation). The selection of methodological assumptions was guided by a principle of 'at least', presumably resulting in an impact which is 'at least' attributable to air pollution. As one single indicator of urban air pollution, the assessment was limited to particulate matter of less than 10 µm in diameter (PM₁₀). A 'lowest assessed level' of 7.5 µg/m³ was applied to take into account that currently available epidemiologic studies have not included populations exposed to levels below 5-10 µg/m³ (mean 7.5 µg/m³). This report provides estimates for the impact of air pollution above the 'lowest assessed level'.

The following health outcomes were selected: total mortality based on cohort studies, respiratory hospital admissions, cardiovascular hospital admissions, chronic bronchitis in adults, bronchitis in the last 12 months in children, restricted activity days in adults, asthma attacks in children, and asthma attacks in adults.

The derivation of air pollution attributable cases was based on the attributable risk concept. For each health endpoint, epidemiologic exposure-response curves were derived from the available literature, using a meta-analytic approach to calculate variance weighted mean relative risks (RR). When significant heterogeneity was present, random effect estimates were calculated. The 95% percent confidence intervals of the exposure-response functions indicated the epidemiology-based range of uncertainty. National epidemiologic baseline data of incidence/prevalence were derived from available population based data. The number of cases and/or person days of outcome attributable to a 10 µg/m³ increment in PM₁₀ exposure were calculated (D10) applying the exposure-response functions and the 95% confidence intervals (D10_{low}, D10_{upp}) to the respective population baseline frequency. Differences in the national increments (D10) mostly stem from differences in the age structure and the health risk profile of the countries.

Uncertainties in the results are due to exposure assessment in the epidemiologic studies, health outcome frequency estimates, exposure-response estimates, and the impact assessment method. Further studies are needed to improve the quantification of chronic morbidity. Cohort studies on mortality should also assess years of life lost.

3 Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases.

There are major differences in the underlying methodological assumptions that may strongly influence the results. Thus, currently conducted impact assessment studies are often incompatible, and standardized methods are required.

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1 Introduction

1.1 Preamble

In preparation to the Transport, Environment and Health Session of **the WHO Ministerial Conference on Environment and Health**, to be held in London in June 1999, a tri-lateral project was carried out by Austria, France and Switzerland. The project assessed the health costs of road traffic related air pollution in the three countries using a common methodological framework.

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1.2 Context

In addition to its positive impact on the growth and prosperity of the national economy and its importance for satisfying our individual needs for mobility, road transport also has adverse effects: accidents, noise, air pollution, harm to health, crop failure, etc.

In the last 10 to 20 years an increasing awareness may be observed for these negative effects of transport. Congestion, air pollution and noise affect more and more people. Their impact on health and welfare, the damage to buildings and the natural environment are considerable, just like the material and intangible costs caused by them.

These costs are mainly **external** costs which means that they are not covered by the polluters (the motorists) but that they are imposed on everybody. External costs cause a problem to the economy, as they are not included in the market price which leads to wrong decisions and to a wasting of scarce and vital resources (clean air, silence, clean water, etc.). Motorists behave as if those costs did not exist because they do not have to pay them. Including the external costs, their trips would have produced higher total costs than the total benefit. As a consequence, many trips would be avoided if the driver had to take all the external costs into consideration.

In order to stop the wasting of scarce resources, the government has to take action and put a price on clean air and other environmental „products“. As a result, negative impacts of road transport have to be paid for by the polluter. The usual terminology for this process is „internalisation of externalities“.

A condition for such an environmental and transport policy is a knowledge about the negative impacts of road traffic and their monetary quantification.

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With the present study, an important part of the external traffic-related costs, namely the **negative impacts of road traffic-related air pollution on human health**, is evaluated and quantified in monetary terms.

1.3 Objective

In order to **quantify the road traffic-related health cost due to air pollution**, Austria, France and Switzerland have co-operated in a tri-lateral research project.

One objective is the choice of a common methodological framework and the evaluation of results that are comparable for the three countries. Of course, within the common methodological framework, some specific features of each country (data availability, health system, etc.) must be considered.

The results of this co-operation provide an input for the WHO Ministerial Conference in June 1999.⁽²⁾

The research project is based on an interdisciplinary co-operation in the fields of air pollution, epidemiology and economy. The tasks of the three domains may be summarised as follows (see Figure 1-1):

1 Air pollution: Evaluation of the (road-traffic related) exposure⁽³⁾

For the three countries Austria, France and Switzerland, the exposure of the residential population has to be assessed. The result has to present a fine register that describes to which level of concentration the number of persons living in each geographic unit are exposed. It must be considered that the emissions' source is not only road transport but other sources as well, such as industry and households.

2 Epidemiology: Evaluation of the exposure-response relationship between air pollution and health impacts⁽⁴⁾

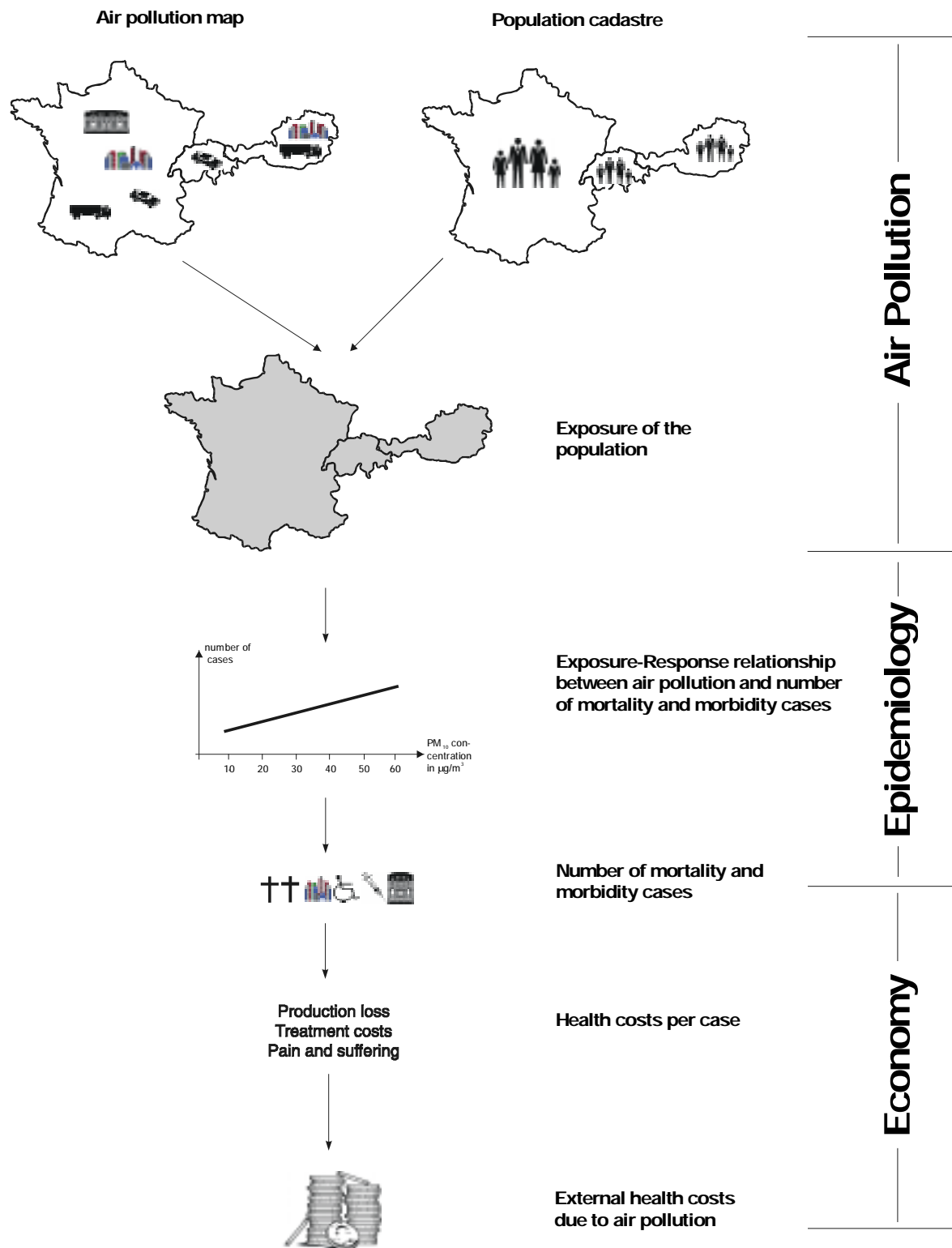
The relationship between air pollution and health has to be assessed. This step provides for each level of exposure the number of air pollution attributable cases of morbidity and mortality. This evaluation has to be based on the current epidemiologic evidence.

2 Third WHO-Ministerial Conference on Environment and Health, London, 16-18 June 1999.

3 Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases.

4 Filliger P., Puybonnieux-Texier V., Schneider J. (1999), Health Costs due to Road Traffic-related Air Pollution, PM₁₀ Population Exposure.

Figure 1-1: Study design



3 Economy: Evaluation of the road traffic-related health impacts and their monetarisation

By combining the exposure-response relationship with the distribution of exposure to PM₁₀ in each country, the impacts of traffic related air pollution on human health is to be quantified (number and type of additional cases of morbidity, number of additional cases of premature death). With adequate methods, these health effects finally have to be valued in monetary terms.

The present project is building on the earlier research in Switzerland.⁽⁵⁾ In the framework of this trilateral co-operation, several methodological questions were further discussed within the international and interdisciplinary group and have partly resulted in new approaches. Furthermore, the most recent scientific results have been adopted and in addition, several methodological calculation steps have been modified in order to make the common methodological framework also applicable for the evaluation of health costs in other countries.

1.4 Working Procedure

Working on the basis of a common methodological approach, the input data, the methodological choice for the single working steps and the findings were discussed, adjusted and adopted by the entire tri-lateral team.

The single working steps of each scientific domain (air pollution, epidemiology, economy) were prepared by three separate technical sub-groups consisting of the three countries' respective experts. For each scientific domain, the methodological procedure and findings are presented in separate technical reports⁽⁶⁾.

In all three domains, co-referees from the international scientific community were invited in order to critically advise and comment on the ongoing work.

1.5 The tasks of the economic part

The present report mainly concentrates on the **economic aspects** of the problem. The main task of this part is the **monetary valuation** of the (road traffic-related) health costs due to air pollution. In a first step the epidemiological bases are combined with the bases on air pollution. As a result, for every health indicator, it will be estimated to what extent these impacts increase due to air pollution.

5 ECOPLAN (1996), Monetarization of the external health costs attributable to transport; Künzli N. et al., Teilbericht Epidemiologie: Synthesebericht Monetarisierung der verkehrsbedingten Gesundheitskosten; Künzli N. et al (1997), Luftverschmutzung in der Schweiz - Quantifizierung gesundheitlicher Effekte unter Verwendung epidemiologischer Daten.

6 See Footnote 3 and 4.

Starting from this quantity (number of cases for each health measure), the next step consists of **a monetary valuation of these health impacts**. For every health measure the specific costs per case are determined. Of course, in this procedure various simplifying and sometimes critical assumptions have to be made.

In the present report, the assessment of these costs and the underlying assumptions will be discussed in detail.

1.6 The „at least“ approach in economic evaluation

For the overall project, which includes many assumptions and decisions in the field of air pollution, epidemiology and economy, it was decided to follow an „at least“ approach by selecting methodological assumptions in such a way as to get an impact or costs which may be expected to be at least attributable to (road traffic-related) air pollution.

In the field of economy, this approach was interpreted as follows:

The health costs related to air pollution are only assessed for those health outcomes which are suitable for monetary valuation and which may be clearly distinguished from each other. For other health outcomes such as emergency room visits, respiratory symptoms, eye irritation or a reduction of the lung function, a monetary valuation is abandoned.

For the assessment of economic costs, two different valuation methods are applied:

- The willingness-to-pay approach⁽⁷⁾ provides a realistic assessment of the real costs or losses in benefit that are resulting from air pollution related morbidity or premature mortality. Besides the material costs (production loss, medical costs), these estimations also cover the so-called intangible costs like pain, suffering, fear and a diminished pleasure or quality of life. In selecting the cost factors, values are chosen from existing empirical research that are in most cases comparatively low. Hence, it may be expected that the total effect of air pollution is greater than the presented estimates.
- The second approach does not include the intangible costs.⁽⁸⁾ The assessment is limited to the quantification of the production loss or consumption loss, according to observed market prices, and the medical costs. This approach estimates only a part of the real costs and therefore may be interpreted as an absolute lower boundary.

7 For a detailed presentation of this approach see chapter 3.1.2.

8 In the case of Switzerland, a monetary valuation of the intangible costs is not completely abandoned. However this part is explicitly identified and very low values are used.

1.7 Structure of the report

The present report is structured as follows:

- **Chapter 2** contains a summary of the epidemiological bases and the input data from the air pollution and exposure assessment that are used for the evaluation of the road traffic related mortality and morbidity. Starting from these basic results, for each country the number of cases of premature deaths and morbidity is calculated.
- In **Chapter 3** the costs of the air pollution related mortality are determined. The chapter contains an overview of different approaches for the valuation of the mortality risk. Based on this list, the approach chosen for this study is explained. Finally, the concrete calculation of the mortality costs for the three countries is presented.
- In **Chapter 4** the costs due to air pollution related morbidity are determined.
- In **Chapter 5** the results are summarised and their significance evaluated. Once again the main assumptions and the sensitivity of the results are discussed. A set of recommendations for the interpretation and implementation of these results is included.
- **Chapter 6** contains the open questions, and the remaining tasks for future research will be identified.

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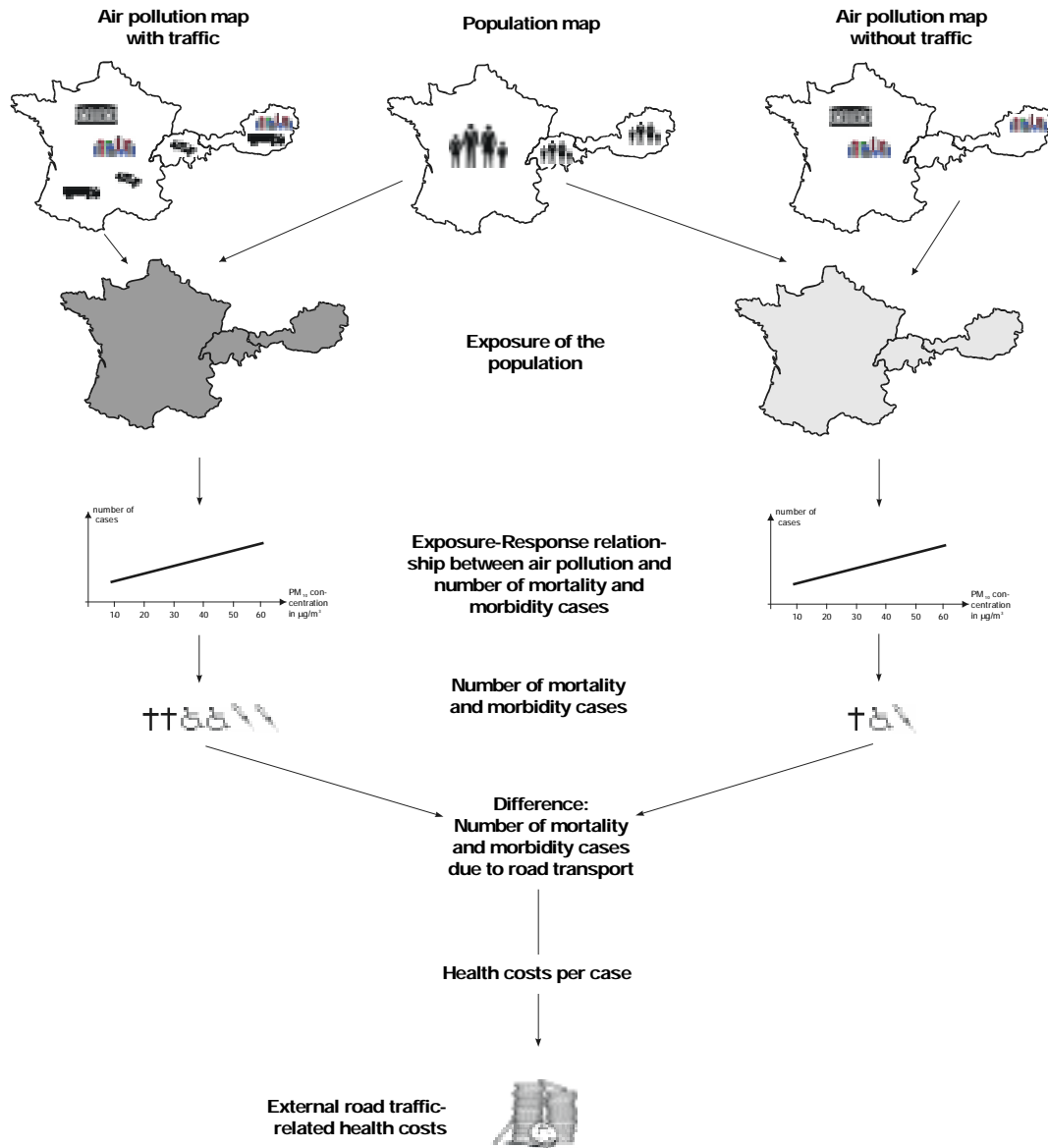
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2 Error! Switch argument not specified. **Health effects of air pollution**

2.1 **Methodological approach**

The number of mortality and morbidity cases due to air pollution is the base for the estimation of the health costs presented in the following chapters 3 and 4. In order to evaluate the number of cases, information on air pollution and epidemiology have to be combined. As shown in Figure 2-1, knowing the air pollution exposure of the population and the relationship between exposure and frequency of health outcomes, the number of mortality and morbidity cases due to air pollution may be evaluated.

Figure 2-1: Methodological approach for the evaluation of mortality and morbidity due to road traffic-related air pollution



These calculations may be done for today's exposure to pollutants 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.

2.2 Atmospheric pollutants considered

In general, air pollution consists in a mix of different pollutants. Most of the time, it is not possible to attribute the single health effects to one specific pollutant. Therefore, Epidemiology is based on measurements of „indicator pollutants“ that represent health relevant aspects of air pollution.

Given the available epidemiological data, „PM₁₀“ may be regarded an important and useful indicator for the health risk of air pollution. PM₁₀ consists of particulate matter with an aerodynamic diameter of 10 micrometers or less. **Thus, in this study PM₁₀ is also used as the main indicator for air pollution.**⁽¹⁾

The evaluation of the PM₁₀-exposure of the population is presented in the corresponding technical report.⁽²⁾ The country specific results are presented in the following table:

a) Austria

In 1996, the population of Austria is exposed to an average annual concentration of 26 µg/m³ PM₁₀ (including the share attributable to road traffic). However, without the emissions of the road traffic, we get an average annual concentration of about 18 µg/m³ PM₁₀. The difference is 8 µg/m³ PM₁₀. That means, the road traffic is generating about 31% of the total PM₁₀-concentration.

1 See Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases for a detailed justification to select PM₁₀ as a leading indicator for air pollution.

2 See Filliger P., Puybonnieux-Textier V., Schneider J. (1999), Health Costs due to Road Traffic-related Air Pollution, PM₁₀ Population Exposure.

Table 2-2: Average annual PM₁₀-exposure of the Austria population in 1996⁽³⁾

Pollution level (µg/m ³)	Mean of class	Population Exposure with share attributable to road traffic	Population Exposure without share attributable to road traffic
< 10	7.5	-	765'000
10-15	12.5	918'000	1'764'000
15-20	17.5	1'144'000	2'636'000
20-25	22.5	1'841'000	1'890'000
25-30	27.5	2'233'000	419'000
30-35	32.5	685'000	266'000
35-40	37.5	377'000	166'000
40-45	42.5	270'000	153'000
45-50	47.5	275'000	-
> 50	52.5	316'000	-
Total		8'059'000	8'059'000
Ø PM ₁₀ level		26.0*	18.0*

* Population-weighted average (calculated over the original grid values of the map)

b) France

In 1996, the population is exposed to an average annual concentration of 23.5 µg/m³ PM₁₀. The road traffic is producing about 8.9 µg/m³ or 37% of the total PM₁₀-concentration. Thus, other emissions outside road traffic are responsible of the average annual concentration of 14.6 µg/m³ PM₁₀.

3 Source: Filliger P., Puybonnieux-Textier V., Schneider J. (1999), Health Costs due to Road Traffic-related Air Pollution, PM₁₀ Population Exposure.

Table 2-3: Average annual PM₁₀-exposure of the French population in 1996⁽⁴⁾

Pollution level (µg/m ³)	Mean of class	Population Exposure with share attributable to road traffic	Population Exposure without share attributable to road traffic
0-5	2.5	130'619	210'393
5-10	7.5	306'262	1'925'200
10-15	12.5	3'009'512	30'289'282
15-20	17.5	18'342'500	24'351'795
20-25	22.5	19'396'900	1'102'375
25-30	27.5	7'456'342	306'230
30-35	32.5	4'544'100	72'796
35-40	37.5	2'368'213	-
40-45	42.5	953'333	-
45-50	47.5	615'277	-
50-55	52.5	523'101	-
55-60	57.5	232'879	-
60-65	62.5	160'871	-
> 65	67.5	218'162	-
Total		58'258'071	58'258'071
∅ PM ₁₀ level		23.5*	14.6*

* Population-weighted average (calculated over the original grid values of the map)

c) Switzerland

In 1996, the total population is exposed to an average annual concentration of 21.4 µg/m³ PM₁₀. Without the emissions of the road traffic, the average annual concentration of 14.0 µg/m³ PM₁₀ would remain. Thus, the road traffic is producing 7.4 µg/m³ or 35% of the total PM₁₀-concentration.

4 Source: Filliger P., Puybonnieux-Textier V., Schneider J. (1999), Health Costs due to Road Traffic-related Air Pollution, PM₁₀ Population Exposure.

Table 2-4: Average annual PM₁₀-exposure of the Swiss population in 1996⁽⁵⁾

Pollution level (µg/m ³)	Mean of class	Population Exposure with share attributable to road traffic	Population Exposure without share attributable to road traffic (%)
0-5	2.5	-	7'081
5-10	7.5	84'976	361'149
10-15	12.5	403'637	4'220'482
15-20	17.5	2'251'868	2'478'471
20-25	22.5	3'009'572	14'163
25-30	27.5	1'033'877	-
30-35	32.5	212'440	-
35-40	37.5	63'732	-
> 40	42.5	21'244	-
Total		7'081'346	7'081'346
Ø PM ₁₀ level		21.4*	14.0*

* Population-weighted average (calculated over the original grid values of the map)

2.3 Contribution of Epidemiology

There is no specific „air pollution disease”. Furthermore, air pollution is neither the only, nor the most important, cause for deteriorated health. Epidemiology is a science which simultaneously assess contributing causes of diseases in populations. In numerous epidemiological studies, scientific evidence has been gained on the negative effects of air pollution on human health.

In the epidemiological research, the harmful effect of air pollution on human health has been traced to a large number of different, partly overlapping, outcomes of health. In this project only a selection of such health outcomes could be integrated in the impact assessment. Each of the health outcomes had to fulfil the following criteria:

- A significant association between the health outcomes and air pollution had to be established.
- The health effect had to be well defined and delimited, in order to avoid double counting when estimating the corresponding costs.
- It must be possible to monetarize the health effect with the available methods.

Based on these selection criteria, the Epidemiology Group proposed a total of eight health outcomes. For each health outcome, the effect of air pollution has been derived from the available

5 Source: Filliger P., Puybonnieux-Textier V., Schneider J. (1999), Health Costs due to Road Traffic-related Air Pollution, PM₁₀ Population Exposure.

literature (meta-analytic average). These relative increases (or relative risk estimates, RR) are shown in Table 2-5.

Combining these effects (RR) with the national baseline frequency of the respective health outcomes yields the absolute numbers of health effects (number of cases per million inhabitants and per $10 \mu\text{g}/\text{m}^3 \text{PM}_{10}$). The differences in the country specific numbers may result from the different age structure (e.g. for biological reasons an older population has a higher mortality rate than a younger population) and from other factors (drinking and eating habits, smoking habits, different health care systems, etc.) which differ across countries.

The results in Table 2-5 may be interpreted as follows:

The relative risk of long-term mortality for a $10 \mu\text{g}/\text{m}^3 \text{PM}_{10}$ increment is 1.043 (column 2), therefore the number of premature fatalities increase by 4.3% for every $10 \mu\text{g}/\text{m}^3 \text{PM}_{10}$ increment. Column 5 shows the number of deaths (adults ≥ 30 years) per 1 million inhabitants in Switzerland (8'263) and the expected number of deaths {7'794}, if the PM_{10} concentration were on average at $7.5 \mu\text{g}/\text{m}^3$ (baseline frequency). This proportion depends on the age structure of the population ≥ 30 years and therefore is different for each country.

The fixed number of fatalities (337 cases for Switzerland, column 8) per $10 \mu\text{g}/\text{m}^3 \text{PM}_{10}$ increment and per 1 million inhabitants correspond to the 4.3% increase in mortality (column 2) applied to the baseline frequency of 7'794 deaths.

Table 2-5: Additional cases per million inhabitants and per 10 µg/m³ of pollutant concentration (of PM₁₀)⁽⁶⁾

	Effect estimate Relative Risk (± 95% Confidence Interval)	Observed population frequency, P _e {and expected baseline frequency, P ₀ at 7.5 µg/m ³ PM ₁₀ annual mean} Per 1 million inhabitants			Fixed baseline increment per 10 µg/m ³ PM ₁₀ and 1 million inhabitants cases (± 95% Confidence Interval)		
		Austria	France	Switzerland	Austria	France	Switzerland
Long-term mortality (adults ≥ 30 years)	1.043 (1.026-1.061)	9'326 {8'634}	8'391 {7'848}	8'263 {7'794}	374 (226-524)	340 (206-476)	337 (204-473)
Respiratory Hospital Admis- sions (all ages)	1.0131 (1.001-1.025)	17'826 {17'405}	11'550 {11'313}	10'300 {10'155}	228 (24-433)	148 (16-282)	133 (14-253)
Cardiovascular Hospital Ad- missions (all ages)	1.0125 (1.007-1.019)	36'790 {35'958}	17'270 {16'931}	24'640 {24'219}	449 (234-668)	212 (112-315)	303 (157-450)
Chronic Bronchitis Incidence (Adults ≥ 25 years)	1.098 (1.009-1.194)	4'986 {4'223}	4'661 {4'031}	5'013 {4'414}	413 (37-821)	394 (35-784)	431 (38-858)
Bronchitis (children < 15 years)	1.306 (1.135-1.502)	16'369 {10'457}	23'534 {15'806}	21'545 {15'125}	3'196 (1'409-5'774)	4'830 (2'129-8'728)	4'622 (2'037-8'352)
Restricted Activity Days (adults ≥ 20 years) ^a	1.094 (1.079-1.109)	2'597'294 {2'211'837}	3'221'240 {2'799'326}	3'373'040 {2'982'515}	208'355 (175'399-241'754)	263'696 (221'987-305'966)	280'976 (236'533-326'016)
Asthmatics: Asthma attacks (children < 15 years) ^b	1.044 (1.027-1.062)	56'670 {52'368}	62'789 {58'624}	57'483 {54'142}	2'325 (1'430-3'231)	2'603 (1'600-3'617)	2'404 (1'478-3'341)
Asthmatics: Asthma attacks (adults ≥ 15 years) ^b	1.039 (1.019-1.059)	173'439 {161'823}	169'491 {159'584}	172'914 {164'066}	6'279 (3'058-9'564)	6'192 (3'016-9'431)	6'366 (3'101-9'697)

a: Restricted activity days: total person-days per year

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

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

P₀: The calculated expected frequency at the reference level of 7.5 µg/m³ PM₁₀

6 Source: Kinzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases.

2.4 Results

2.4.1 Mortality

From the average exposure of the population on the one hand and the epidemiological bases (fixed baseline increment per $10 \mu\text{g}/\text{m}^3 \text{PM}_{10}$) on the other hand, the number of air pollution related premature deaths may be determined. For this estimation, the following conservative assumptions have been made:

- To be in line with the methods and populations of the two selected US studies for the effect estimate, the increase in mortality cases due to air pollution is only considered for age groups ≥ 30 years.⁽⁷⁾ This limitation is already considered in the results of Table 2-5 on the fixed baseline increment per $10 \mu\text{g}/\text{m}^3 \text{PM}_{10}$ and per 1 million inhabitants.
- The increase in mortality cases is only considered from the exposure class of $5\text{-}10 \mu\text{g}/\text{m}^3$ onwards (average $7.5 \mu\text{g}/\text{m}^3$). It is to emphasize that this can not be considered as a level of no-effect. So far, epidemiologic studies give no indication for a ‘no-effect threshold’ for PM_{10} , although some studies like those conducted in Switzerland include regions with rather low annual mean PM_{10} levels. However, studies did not include population living in regions with PM_{10} levels below $5\text{-}10 \mu\text{g}/\text{m}^3$. Therefore, we did not extrapolate the risk function down to zero. This is again in line with the „at least“ approach.⁽⁸⁾

a) Austria

The Table 2-6 shows the premature deaths due to air pollution in Austria 1996. Across the total population of about 8 million inhabitants, the average annual exposure (including the share attributable to road traffic) is about $26 \mu\text{g}/\text{m}^3 \text{PM}_{10}$. Without the emissions of the road traffic, the average annual concentration is about $18 \mu\text{g}/\text{m}^3 \text{PM}_{10}$. The difference (due to the traffic) is $8 \mu\text{g}/\text{m}^3 \text{PM}_{10}$.

Per million inhabitants and per $10 \mu\text{g}/\text{m}^3 \text{PM}_{10}$ the number of premature deaths is increased by 374 cases per year, which yields the following results:

7 The two cohort studies investigated the survival of persons aged ≥ 30 years in relation to the air pollution in different areas. See Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases, Chapter 6.8.1.

8 The selection of this level strongly influences the calculation of the additional cases due to the ‘total PM_{10} ’ air pollution. As an example, the number of premature deaths would be considerably higher if the lowest assessed level would not be considered.

In contrast, the calculation of the *absolute* number of additional cases attributable to road traffic is only marginally influenced by the selection of the lowest assessed level. The number of the traffic-related cases is derived by subtracting the number of non-traffic-related cases from the total number of cases. Since the lowest assessed level affects the total number of cases and the non-traffic-related cases by the same multiplicative factor, it will not change the difference, i.e., the absolute number of traffic-related cases. The lowest assessed level, however, modifies:

- the **population baseline frequency**, which would be lower without the lowest assessed level due to a higher attributable proportion, resulting also in a lower fixed baseline increment.
- the **proportion** of the traffic-related cases compared to the share that may be calculated using the PM_{10} concentration partition found in the air pollution report. Therefore, in this study absolute instead of relative numbers are used, whenever possible.

Table 2-6: Premature deaths due to air pollution in Austria 1996 (long term effects)

Pollution level ($\mu\text{g}/\text{m}^3$)	Mean of class	Population Exposure with share attributable to road traffic	Population Exposure without share attributable to road traffic
< 10	7.5	0	765'000
10-15	12.5	918'000	1'764'000
15-20	17.5	1'144'000	2'636'000
20-25	22.5	1'841'000	1'890'000
25-30	27.5	2'233'000	419'000
30-35	32.5	685'000	266'000
35-40	37.5	377'000	166'000
40-45	42.5	270'000	153'000
45-50	47.50	275'000	0
> 50	52.50	316'000	0
Total		8'059'000	8'059'000
∅ PM ₁₀ level		26.0*	18.0*

	Fixed baseline increment per Mio. inhabitants and $10 \mu\text{g}/\text{m}^3$	Additional cases due to air pollution		
		Total with road traffic share	Without road traffic share	Cases attributable to road traffic
Long-term mortality (adults ≥ 30 years)	374 226 - 524	5'576 3'370 - 7'813	3'165 1'912 - 4'434	2'411 1'457 - 3'378

* Population-weighted average (calculated over the original grid values of the map)

In Austria, the additional cases of premature (long-term) mortality due to air pollution are 3'370 - 7'813 (central estimate: 5'576).⁽⁹⁾ As it is impossible to directly observe or count these cases, we present the central estimates and the inherent range of uncertainty. The respective share in the situation without road traffic leads to 3'165 cases. That means, we have 2'411 cases due to road traffic related emissions. This is about 43% of all additional cases of premature mortality due to air pollution in Austria.⁽¹⁰⁾

9 It has to be mentioned that the average age of the victims due to air pollution is between 75 and 85 years. See Chapter 3.3.1.3 and Chapter 3.3.1.4. for a detailed discussion of the age structure and the reduced life expectancy.

10 This percentage is different from those in Chapter 2.2a) due to the fact that the increase in health effects is only considered from the exposure class of 5-10 $\mu\text{g}/\text{m}^3$ (average 7.5 $\mu\text{g}/\text{m}^3$) PM₁₀ onwards.

b) France

For the year 1996 France has about 58.3 million inhabitants. The average annual exposure (including the share attributable to road traffic) of the total population is about $23.5 \mu\text{g}/\text{m}^3$ PM_{10} . Without the emissions of the road traffic, the average annual concentration amounts to $14.6 \mu\text{g}/\text{m}^3$ PM_{10} . The difference (due to the traffic) is $8.9 \mu\text{g}/\text{m}^3$ PM_{10} .

Per million inhabitants and per $10 \mu\text{g}/\text{m}^3$ PM_{10} the number of premature deaths is increased by 340 cases per year, which yields the following results:

Table 2-7: Premature deaths due to air pollution in France 1996 (long term effects)

Pollution level ($\mu\text{g}/\text{m}^3$)	Mean of class	Population Exposure with share attributable to road traffic	Population Exposure without share attributable to road traffic
0-5	2.5	130'619	210'393
5-10	7.5	306'262	1'925'200
10-15	12.5	3'009'512	30'289'282
15-20	17.5	18'342'500	24'351'795
20-25	22.5	19'396'900	1'102'375
25-30	27.5	7'456'342	306'230
30-35	32.5	4'544'100	72'796
35-40	37.5	2'368'213	0
40-45	42.5	953'333	0
45-50	47.5	615'277	0
50-55	52.5	523'101	0
55-60	57.5	232'879	0
60-65	62.5	160'871	0
> 65	67.5	218'162	0
Total		58'258'071	58'258'071
Ø PM_{10} level		23.5*	14.6*

	Fixed baseline increment per Mio. inhabitants and $10 \mu\text{g}/\text{m}^3$	Additional cases due to air pollution		
		Total with road traffic share	Without road traffic share	Cases attributable to road traffic
Long-term mortality (adults ≥ 30 years)	340 206 - 476	31'692 19'202 - 44'369	14'063 8'521 - 19'689	17'629 10'681 - 24'680

* Population-weighted average (calculated over the original grid values of the map)

In France, air pollution causes some 31'692 cases of premature mortality in 1996. 17'629 cases are due to road traffic-related emissions. However, these results are approximations and can not be considered as exact figures.

c) Switzerland

In the year 1996 the residential population of Switzerland was 7.08 million inhabitants. On average, the population is exposed to 21.4 $\mu\text{g}/\text{m}^3$ PM_{10} per year. Without road traffic emissions, the annual average exposure would be reduced to 14.0 $\mu\text{g}/\text{m}^3$ PM_{10} .

Per million inhabitants and per 10 $\mu\text{g}/\text{m}^3$ PM_{10} the number of premature deaths is increased by 337 cases per year in the age group from 30 years onwards, which yields the following results:

Table 2-8: Premature deaths due to air pollution in Switzerland 1996 (long term effects)

Pollution level	Mean of class	Population Exposure with share attributable to road traffic	Population Exposure without share attributable to road traffic (%)
0-5	2.5	0	7'081
5-10	7.5	84'976	361'149
10-15	12.5	403'637	4'220'482
15-20	17.5	2'251'868	2'478'471
20-25	22.5	3'009'572	14'163
25-30	27.5	1'033'877	0
30-35	32.5	212'440	0
35-40	37.5	63'732	0
>40	42.5	21'244	0
Total		7'081'346	7'081'346
Ø PM_{10} level		21.4*	14.0*

	Fixed baseline increment per Mio. inhabitants and 10 $\mu\text{g}/\text{m}^3$)	Additional cases due to air pollution		
		Total with road traffic share	Without road traffic share	Cases attributable to road traffic
Long-term mortality (adults \geq 30 years)	337 202 - 473	3'314 1'986 - 4'651	1'552 930 - 2'179	1'762 1'056 - 2'472

* Population-weighted average (calculated over the original grid values of the map)

In Switzerland in the year 1996, air pollution caused 1'986 - 4'651 (central estimate: 3'314) cases of premature mortality. 1'762 (1'056 - 2'472) cases are due to road traffic-related emissions.

Comparing the figures with the number of annual fatal road-accidents, this number seems to be relatively high. However, for several reasons the difference between road accident related fatalities and air pollution related fatalities is less astonishing than at first sight:

- E.g. in Switzerland, in 1970 the number of 1'694 fatal road accidents was 2.5 times higher than today (616). The sudden and shocking impact of fatal road accidents - happening in a public space - may be one reason, why policy making focused primarily on this problem.
- Taking the non-fatal road accidents into account as well, the relation changes drastically. E.g. in Switzerland, in 1996 some 26'500 persons were injured in road accidents.

2.4.2 Morbidity

In the following Tables, the air pollution related health effects considered in this study are presented by country.

Again, the negative effects of air pollution are only considered above an exposure of $7.5 \mu\text{g}/\text{m}^3$ PM_{10} . In addition, it needs to be remembered that not all health effects of road traffic-related air pollution are presented in this table. The quantification of a number of different effects (e.g. the impact of air pollution on the prevalence of cancer) are not considered in this study. However, all the health effects listed below are based on epidemiological evidence concerning the exposure-response relationship between air pollution and the frequency of the health outcome in each country.

The following Table 2-9 shows the additional cases concerning the morbidity due to air pollution in Austria 1996 differentiated by the total number of cases with road traffic share, without the road traffic, and finally attributable to road traffic.

Concerning the cases attributable to road traffic, we obtain the highest figure in the case of bronchitis for children younger than 15 years with about 21'000 cases followed by cardiovascular hospital admissions (all ages) with 2'895 cases. Chronic bronchitis incidence accounts for 2'663 cases for adults older than 25 years. The smallest number of cases attributable to road traffic occurs for respiratory hospital admissions with about 1'500 cases for all ages.

Concerning the additional morbidity days due to air pollution, there are, for the restricted activity days of adults older than 20 years, about 1.3 million days in Austria 1996.

Table 2-9: Additional cases of morbidity due to air pollution in Austria 1996

	Fixed baseline increment (per Mio. inhabitants and 10 µg/m ³)	Additional cases / days due to air pollution		
		Total with road traffic share	Without road traffic share	Cases or days attributable to road traffic
PM ₁₀ level µg/m ³		26.0*	18.0*	8.0*
Respiratory Hospital Admissions (all ages)	228 24 - 433	3'399 358 - 6'456	1'929 203 - 3'664	1'470 155 - 2'792
Cardiovascular Hospital Admissions (all ages)	449 234 - 668	6'695 3'489 - 9'960	3'800 1'980 - 5'653	2'895 1'509 - 4'307
Chronic Bronchitis Incidence (Adults ≥ 25 years)	413 37 - 821	6'158 552 - 12'241	3'495 313 - 6'948	2'663 239 - 5'293
Bronchitis (children < 15 years)	3'196 1'409 - 5'774	47'652 21'008 - 86'090	27'046 11'923 - 48'862	20'606 9'085 - 37'228
Restricted Activity Days (adults ≥ 20 years)	208'355 175'399 - 241'754	3'106'544 2'615'175 - 3'604'519	1'763'174 1'484'288 - 2'045'808	1'343'371 1'130'886 - 1'558'711
Asthmatics: Asthma attacks (children < 15 years, person days)	2'325 1'430 - 3'231	34'665 21'321 - 48'174	19'675 12'101 - 27'342	14'990 9'220 - 20'832
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	6'279 3'058 - 9'564	93'619 45'594 - 142'598	53'135 25'878 - 80'934	40'484 19'716 - 61'664

* Population-weighted average (calculated over the original grid values of the map)

Table 2-10 shows the additional cases of morbidity due to air pollution in France. The number of restricted activity days (24.6 millions due to total air pollution, 13.7 million due to road traffic-related air pollution) and the number of acute and chronic bronchitis will be of particular interest for the monetary valuation.

Table 2-10: Additional cases of morbidity due to air pollution in France 1996

	Fixed baseline increment (per Mio. inhabitants and 10 µg/m ³)	Additional cases / days due to air pollution		
		Total with road traffic share	Without road traffic share	Cases or days attributable to road traffic
PM ₁₀ level µg/m ³		23.5*	14.6*	8.9*
Respiratory Hospital Admissions (all ages)	148 16 - 282	13'796 1'491 - 26'286	6'122 662 - 11'664	7'674 829 - 14'622
Cardiovascular Hospital Admissions (all ages)	212 112 - 315	19'761 10'440 - 29'362	8'769 4'633 - 13'029	10'992 5'807 - 16'333
Chronic Bronchitis Incidence (Adults ≥ 25 years)	394 35 - 784	36'726 3'262 - 73'079	16'297 1'448 - 32'429	20'429 1'814 - 40'650
Bronchitis (children < 15 years)	4'830 2'129 - 8'728	450'218 198'450 - 813'562	199'784 88'062 - 361'018	250'434 110'388 - 452'544
Restricted Activity Days (adults ≥ 20 years)	263'696 221'987 - 305'966	24'579'872 20'692'055 - 28'519'982	10'907'318 9'182'099 - 12'655'742	13'672'554 11'509'956 - 15'864'240
Asthmatics: Asthma attacks (children < 15 years, person days)	2'603 1'600 - 3'617	242'633 149'141 - 337'151	107'668 66'181 - 149'611	134'965 82'960 - 187'540
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	6'192 3'016 - 9'431	577'174 281'130 - 879'091	256'121 124'752 - 390'097	321'053 156'378 - 488'994

* Population-weighted average (calculated over the original grid values of the map)

Table 2-11 shows the additional cases of morbidity in Switzerland. As may be seen later from the monetary valuation, the cases with chronic bronchitis and the high number of restricted activity days will be of particular relevance for the overall result.

- In 1996, air pollution in Switzerland caused more than 4'200 additional cases of chronic bronchitis of which 2'200 cases are attributable to road traffic-related air pollution.
- Air pollution causes more than 2.7 million additional days with restricted activity of which nearly 1.5 million days (or some 53%) are attributable to road traffic.

Table 2-11: Additional cases of morbidity due to air pollution in Switzerland 1996

	Fixed baseline increment (per Mio. inhabitants and 10 µg/m ³)	Additional cases / days due to air pollution		
		Total with road traffic share	Without road traffic share	Cases or days attributable to road traffic
PM ₁₀ level µg/m ³		21.4*	14.0*	7.4*
Respiratory Hospital Admissions (all ages)	133 14 - 253	1'308 138 - 2'488	614 65 - 1'168	694 73 - 1'320
Cardiovascular Hospital Admissions (all ages)	303 157 - 450	2'979 1'544 - 4'425	1'399 725 - 2'077	1'580 819 - 2'348
Chronic Bronchitis Incidence (Adults ≥ 25 years)	431 38 - 858	4'238 374 - 8'436	1'990 175 - 3'961	2'248 199 - 4'475
Bronchitis (children < 15 years)	4'622 2'037 - 8'352	45'446 20'029 - 82'121	21'337 9'403 - 38'556	24'109 10'626 - 43'565
Restricted Activity Days (adults ≥ 20 years)	280'976 236'533 - 326'016	2'762'682 2'325'699 - 3'205'536	1'297'082 1'091'917 - 1'505'002	1'465'600 1'233'782 - 1'700'534
Asthmatics: Asthma attacks (children < 15 years, person days)	2'404 1'478 - 3'341	23'637 14'532 - 32'850	11'098 6'823 - 15'423	12'539 7'709 - 17'427
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	6'366 3'101 - 9'697	62'593 30'490 - 95'345	29'388 14'315 - 44'765	33'205 16'175 - 50'580

* Population-weighted average (calculated over the original grid values of the map)

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3 The monetary valuation of mortality

3.1 Short overview on the methodological approaches

Several approaches exist for the cost assessment in monetary terms of mortality due to air pollution or the benefit assessment of avoided negative impacts of air pollution.

Outside of the economic community the monetarization is criticised, since, according to common believe, the value of a human life cannot be expressed in monetary terms. In our opinion, this criticism is based on a misunderstanding: the economic science does not try to assess the value of a precise life.⁽¹⁾ It is the **benefit of a risk reduction** that is monetarized, if the number of fatalities could be reduced by improving the air quality (i.e. decreasing pollution).

For this assessment, the term "**value of preventing a statistical fatality**" (VPF) is often used in the economic theory. It reflects the fact that a decrease in risk is valued before the negative results have already taken place and not that a specific human life is valued after the impact of air pollution has provoked this person's death.

The monetary valuation of mortality in three different ways of assessment are to be considered:⁽²⁾

- **The gross production / consumption loss:** The costs of additional mortality cases are assessed according to the loss in income / production or the loss of consumption.
- **Willingness to pay (WTP) / Value of preventing a statistical fatality (VPF):** In this approach the willingness to pay for the avoidance of a statistical case of mortality or the "value of preventing a statistical fatality" is assessed.
- **Value of a life year (VOLY):** This approach assesses the value of the statistical number of gained or lost years of life. Most of the time, these values are derived from the value of preventing a statistical fatality (VPF).

In the following chapters, the main characteristics of the three approaches are presented and the advantages and disadvantages are discussed. Concerning the above presented categories, one needs to remember that amongst economists an intense discussion on the appropriate approach to monetarization has been held during the last years - a debate which is still going on.

1 We also believe that the loss or the diminution of life cannot be valued in monetary terms.

2 The comments in this chapter are partially based on Nera/Caspar (1998), Valuation of deaths from air pollution, p. 13-21.

3.1.1 Gross production / consumption loss

The gross production / consumption loss approaches assess the costs of a premature death by counting the discounted values of future production / consumption which the victims could have generated if they had not died prematurely.

This valuation concept is based on the loss that results from a premature death for the economy as a whole. It is a concept based on the general society, without regarding the individual difference in valuing lower or higher risks of mortality or fatal accidents.

Using the gross production / consumption as an indicator, these approaches are limited to the valuation of material aspects of life only. Overcoming this shortfall, this indicator is often combined with additional values for immaterial costs for pain, grief and suffering of the victims and their relatives.

The main advantage of this approach lies in its simple and transparent calculation concept. In the political discussion about the possible measures for a reduction in air pollution, this advantage may not be neglected. The relation to concrete, assessable production or consumption losses may result in a higher social acceptance for the non-economists than the evaluation approaches based on more sophisticated and complex approaches or utility concepts.

However, its main disadvantages are the following:

- When valuing an increase in security (e.g. in road traffic or as a consequence of lower air pollution levels), most people consider first of all their own fear/aversion or the fear/aversion of their relatives of a premature death per se. In doing so, the maintenance of a certain level of income / production or of a certain level of consumption does not play a major role. This fact is not reflected by both loss approaches, since they cover mainly the material consequences of a premature death. They assume that the value of a person is only represented by its production or consumption.
- In addition, the valuation of the production loss is based on the society as a whole and does not reflect the individual point of view. Therefore, it neglects a basic principle of the (welfare-) economic theory, according to which each valuation of positive or negative impacts has to be based on the variations in the utility of the concerned individuals.
- Finally, a discount rate must be chosen, and this choice will have major implications in the valuations, specially when the number of years of lost production/consumption is high.

3.1.2 Willingness-to-pay (WTP) / Value of preventing a statistical fatality (VPF)

The main advantage of the willingness-to-pay approach relies in its foundation on the individual viewpoint of the concerned population. This approach attempts to estimate the demand (the willingness-to-pay) for an improved environmental quality. Actually, it is measured by how much the concerned individuals are ready to pay in order to improve their own security or the one of other people. Adding the amounts of all concerned individuals results in a value that a group of concerned individuals attributes to the improvement in security or the reduction of environmental impacts.

The valuation of a reduced risk in mortality or the value of a "statistical" life saved (value of statistical life) is calculated by dividing the individual willingness-to-pay values for a risk reduction by the observed change in risk.

Simple example: It is assumed that a measure is able to reduce the risk of fatal road accidents in a year from 4 cases per 10'000 to 3 cases per 10'000. The individuals exposed to this risk are ready to pay for this risk reduction of 1 case per 10'000 an average amount of 100 EUR. In this case, the value of a statistical life amounts to 1 Million EUR (100 EUR/0.0001 risk reduction). Again it must be pointed out that the respondents are not asked about their willingness-to-pay for the avoidance of their death but about the willingness-to-pay for a change in risk.

As mentioned, the main advantages of the willingness-to-pay approach consists of a valuation of the VPF that considers the individual preferences and wishes of the concerned individuals. It therefore meets the requirements of welfare economics.

The following objections to the willingness-to-pay approach may be raised:

- The willingness-to-pay approach depends on the level of income: individuals with a high income are able to spend more money on their security than people with a low income. This income related valuation of the value of preventing a statistical fatality may be ethically problematic, specially when it applies to very different countries (eg. OECD and less developed countries).
- According to the organisation of the social insurance system, it may be that the material impacts of the improved security (e.g. the avoidance of production loss) are not taken into account in the individual willingness-to-pay, e.g. if the income loss is totally remunerated by the social insurance system, the material aspects of lower health risks are partly or totally neglected in the willingness-to-pay estimates, even though the social security system and the society as a whole are affected by the premature deaths.
- For the individuals it is difficult to be sufficiently aware of the levels of risk at stake, their consequences on health. It is also difficult for individuals to be familiar with small variations of risk. This may imply large discrepancies between individual valuations.

But the main difficulty of the WTP approach consists of obtaining reliable and correct empirical estimations. A multitude of empirical assessments conducted so far for the value of statistical life have provided a very large range. It also appears that, according to the questions and the starting values, a direct interview with the individual persons (the so called contingent valuation method CVM) may lead to unrealistic and biased results.

Reservations also exist concerning indirect methods (revealed preference-method) based upon information available on markets where goods are exchanged. Such markets may be markets for avertive expenditures (airbag, security belts, ABS, smoke detectors), the housing market or the labour market. For example, the meaning of salary differences between normal and risky jobs depends on the degree of information available to the workers about the real risk situation of their job. In addition, governmental or unionist influences may lead to a situation where the risk differences are provoking very high differences in salaries or none at all.

Nevertheless, recent researches provide promising results. The chosen approach is also based on a contingent valuation method, where the direct comparison between money and risk of mortality is replaced by a sequence of chained interviews.⁽³⁾

3.1.3 Value of a life year (VOLY)

Most of the VPF values are based on the willingness-to-pay for the reduction in risk of fatal road accidents. The victims of road accidents typically have an average age of 30-40 years. The remaining average life expectancy for this age group is 35 to 45 years.

On the contrary, the victims of air pollution have a much higher average age of about 70-80 years. The remaining life expectancy in this age group is about 10 to 15 years.

The promoters of the VOLY approach raise the objection that a direct use of VPF values from road accidents for the valuation of mortality due to air pollution is not adequate, especially because of the differences of life expectancy in these two situations (the number of lost life years is not the same).

Concerning the different life expectancy, they propose a similar concept as in the gross production loss approach.

Thus, a constant value is attributed to each future life year lost due to a premature death. Often, this value is chosen in a way that the discounted sum for the remaining life years equals the total VPF. The VOLY is therefore derived from existing estimations of VPF. Some studies on VOLY are also based on a direct survey of the willingness-to-pay for the prolongation of life for one year.

At a first view, the VOLY approach seems to provide some essential advantages:

Like the VPF approach, it also relies on the welfare economic concept of willingness-to-pay. In addition, the monetary valuation of the mortality risk is explicitly differentiated according to the age structure of the affected population. This procedure implies that the willingness-to-pay of an individual to reduce the mortality risk can be subdivided in constant, future values of annual utility, which cannot be enjoyed if death occurs prematurely.

It might be possible that the willingness-to-pay of individuals of more than 70 years or 80 years does decrease, e.g. due to a smaller number of relatives. A very low willingness-to-pay is also possible, when a person suffering from a heavy illness is standing shortly before death.

The empirical evidence and the following considerations indicate that in the majority of cases, the willingness-to pay for a mortality risk reduction cannot simply be derived from the remaining life expectancy, but that it is determined by a large number of other factors. In particular, the following factors are relevant:

- „Emotional and personal costs to those who would be bereaved. These might be expected to peak in middle age, when there are most likely to be young and/or old dependants.
- The will to life, and an associated belief in the sanctity of life and the right to protection by society from certain hazards.

3 See also the explanations in chapter 3.3.1.1.

- Concern about not achieving specific aspirations, typically over the next few months or years, but sometimes extending for longer periods - such as seeing one's children or grandchildren grow up."⁽⁴⁾

It is therefore not surprising that the linear decrease of VPF with raising age, implicitly adopted in the VOLY approach, cannot be confirmed by the empirical findings. Based on present studies it may be assumed that the willingness-to-pay reaches a slight peak in the middle age group (30-45 years).⁽⁵⁾

3.2 Assessment approach chosen in the present study

The **main assessment approach** of the present study is based on the concept of **WTP/VPF** according to the previous presentation in chapter 3.1.2. Estimations from the domain of road accidents are used as a starting point for the assessment of the mortality risk due to traffic-related air pollution. As shown in chapter 3.3 below, these values have to be adapted to the special context of air pollution. The choice of the WTP/VPF approach as a core method in the present study is based on **the welfare-theoretical foundation** of this concept.

The WTP/VPF concept starts implicitly from a **victim's scenario**. The impact of air pollution on the mortality risk is estimated from the cases of premature death (that is of real but anonymous cases). It is assumed that there are susceptible subgroups that experience health impairment and premature mortality due to air pollution.

On the other hand the **"whole population's scenario"** assumes that air pollution has a similar impact for all members of the population, which is in the single case a very small reduction in life expectancy. There, it is assumed that air pollution constitutes a worsening risk factor for the whole population and not only for a specific subgroup.

In the victim's scenario the total person-time lost due to air pollution is contributed by those susceptible to air pollution injury. In the whole population scenario the same total person-time lost due to air pollution is considered as a shortening in life experienced by everybody. Therefore, in the victim's scenario, the „average victim“ has lost a long period of life due to air pollution whereas in the whole population scenario everybody lost a short period of time.

Conceptually, the interpretation of the epidemiological findings favour the victim's scenario. The disposition for certain diseases is not randomly distributed, but shows significant differences instead. E.g. the epidemiological findings show that the impact of air pollution on respiratory mortality is higher than on total mortality, or that the increase in hospital admissions also depends on the disease. Thus, according to susceptibility status, effect estimates may be different. Under the whole population scenario effect estimates are assumed to be identical for the whole population.

In theory there are arguments in favour for both scenarios. The discussion on the more realistic scenario is still in progress.

4 Quoted from: Nera/Caspar (1998), Valuation of deaths from air pollution, p.18.

5 This assessment is based on Nera/Caspar (1998), Valuation of deaths from air pollution, p.18. For the empirical evidence compare e.g. Jones-Lee M. (1989), The Economics of Safety and Physical Risk, Jones-Lee M. et al (1993), The Value of Preventing Non-Fatal Road Injuries: Findings of a Willingness-to-Pay National Sample Survey.

As **partial assessment values**, additional calculations are conducted in the individual countries. In order to respond to the specific needs of the different participating countries, these partial assessment values are established according to different methodological concepts.

- For **Austria and Switzerland** the partial assessment costs for the air pollution related mortality costs are established according to an enlarged version of the **gross production loss approach** (see chapter 3.4.1). The gross production loss approach is chosen in order to compare the health costs due to road traffic-related air pollution with the costs of road accidents, already established with the same approach in these countries.
- In **France** an alternative estimation of the mortality costs is established with the **net loss of consumption approach**, which is a variant of the gross production loss approach. Furthermore, these calculations will be based on the whole population approach.

Figure 3-1 presents an overall view of the chosen methodological approaches of this study.

Figure 3-1: Methodological approaches chosen for the cost assessment

	partial assessment approach			main approach
Valuation Methodology	gross production loss	extended gross production loss	net consumption approach	willingness to pay
Epidemiological Impact-Scenario	victims scenario		whole population scenario	victims scenario
Assessment concept used by following countries	A	CH	F	all

3.3 The mortality costs based on the willingness-to-pay / Value of preventing a statistical fatality approach

In this chapter the willingness-to-pay approach is applied for the assessment of the air pollution related mortality. As already mentioned, the WTP approach is based on the economic welfare theory and corresponds to its principles: Costs and benefits of a measure have to be assessed according to the individual preference of the affected population.

The willingness-to-pay approach for a reduction of the mortality risk contains implicitly an estimation for a „statistical life saved“ or the value of preventing a statistical fatality (VPF). Again one needs to remember that it is not a valuation for a specific victim, but that the gain in utility due to a lower mortality risk is estimated in monetary values.

3.3.1 Value of preventing a statistical fatality

In the economic literature there is a multitude of empirical studies on the value of preventing a statistical fatality. Most of the time, these studies contain a willingness-to-pay approach for the risk reduction for fatal road accidents, an estimation of salary differences due to different risks on the job or the persons' willingness to spend money for their own security (e.g. airbag, fire alarm systems, etc.).

Unfortunately, so far there is no study on the willingness-to-pay for a reduction in mortality risk related to air pollution.⁽⁶⁾ Under the available budget and time constraint, conducting an empirical

6 A study is currently under development in France, but its results will not be available before January 2000 (see Gre-gam (1999), Economic and socio-anthropologic approach of air pollution).

study in this domain was not possible within the present study. It is therefore necessary to base the assessment of air pollution related mortality risks on WTP-values from other studies and to adapt these values for the air pollution impacts. Thus, the following procedure was adopted:

- Choice of a base value for the value of preventing a statistical fatality related to fatal road accidents
- Adjustment of this value to
 - the different perception and acceptance of air pollution related risks
 - the structure of the age distribution and the life expectancy of the victims
 - possibly the different life qualities of the victims.

3.3.1.1 Basic value for preventing a statistical fatality

A good overview of the recent empirical studies on the value of preventing a statistical fatality is presented, for example, in Viscusi (1993) and Beattie (1998).⁽⁷⁾ An actual overview on different studies from the 90's shows that the chosen values of preventing a statistical fatality lie with a few exceptions between 0.7 and 6.1 million EUR. Two of the most recent European studies on the assessment of external costs of transport related to air pollution are based on a value of 3.1 million EUR.⁽⁸⁾

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 EUR with a range from 2.1 to 3.0 million EUR.⁽⁹⁾

In an actual project of the UK Department of Health for the year 1996 the assessment of air pollution is based on a VPF of 1.2 million EUR (0.8 million £).⁽¹⁰⁾

The latest empirical study conducted by Jones-Lee et al. provide a VPF of 1.42 million EUR with a range of 0.7 to 2.3 million EUR.⁽¹¹⁾ These evaluations are based on a sophisticated survey design which tries to avoid the willingness-to-pay of the respondents depending on the questions' order or on prescribed amounts. In addition, it was shown that most of the respondents find it difficult to estimate the monetary value for very small changes in risk. Instead of a direct survey (money versus a reduction in mortality risk), a "chained" approach is chosen in this study.⁽¹²⁾

7 Viscusi W.K. (1993), *The Value of Risks to Life and Health*; Beattie J. et al (1998), *Valuing Health and Safety Controls: A Literature Review*. An overview on selected studies is also presented in annex A.

8 See Institute of Environmental Studie, 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 particulate matter and lead*; ZEW / ISI (1997), *External Quality Evaluation*.

9 See ExternE (1995), *Externalities of Energie, Vol 2: Methodology*.

10 Department of Health (1999), *Economic Appraisal of the Health Effects of Air Pollution*, p. 65.

11 Jones-Lee M. et al (1998), *On the Contingent Valuation of Safety and the Safety of Contingent Valuation: Part 2 - The CV/SG „Chained“ Approach*.

12 First, the willingness-to-pay for a sure recovery after a road accident is examined. Then, the respondents are faced with a situation of being injured and being asked to chose between two different medical treatments. One treatment immediately leads to a total recovery but includes a remaining risk $x (>0)$ that the treatment fails and immediate death occurs. The other treatment requires hospitalisation with a "normal" time span of recovering. There is also a risk y of a failure with fatal consequences but the risk is smaller than in the previous case ($x > y$).

Starting from these newest results and the experience of former studies **a basic value of 1.4 million EUR** is adopted for the further monetarization of the value of preventing a statistical fatality (**VPF**). This choice has been made for the following reasons:

- The results from M. Jones-Lee et al. have a high scientific quality.
- A similar starting value (1.2 million of EUR) is also used in the study on behalf of the UK Department for Environment, Transport and Regions (DETR).
- The proposed value for VPF of 1.4 million EUR is in the lower part of the range of the majority of empirical evaluations. Thus, it is a rather conservative estimate of the real costs („at least-approach“).

3.3.1.2 Adjustment for different perception and acceptance of risks

Different research projects have shown that the willingness-to-pay for a reduction in risk depends on the type of risk examined. The following factors are of major importance:

- voluntariness
- control
- responsibility
- direct personal benefit while taking the risk

In general, the studies show that for voluntarily incurred risk and risks relying to a large extent on someone's own responsibility and control (e.g. mountain climbing), the acceptance is higher than for involuntary risks that are beyond someone's control (e.g. risks of an accident of a nuclear power plant, risks from air pollution or risks of sudden infant death syndrome⁽¹³⁾).

In comparison with the road traffic accidents for which the basic value is used, the air pollution related mortality risk is

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

Because of this different scenario, most likely the aversion against air pollution related risk is considerably higher than the aversion against the risk of fatal road accidents.⁽¹⁴⁾ Accordingly, the willingness-to-pay for a reduction in air pollution related risk is higher.

13 Compare e.g. Mendeloff J., Kaplan R.M. (1990), Are Twenty-fold Differences in „Lifesaving“ Costs Justified?: A Psychometric Study of the Relative Value Placed on Preventing Deaths from Programme Addressing Different Hazards; McDaniels T.L. et al (1992), Risk Perception and the Value of life; Jones-Lee M., Loomes G. (1995), Scale and Context Effects in the Valuation of Transport Safety.

14 This view is adopted by a number of authors, compare e.g. 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.

How big this aversion factor really is may not be determined definitely at this moment. Empirical studies show that according to the type of risk the willingness-to-pay varies by a factor of 3.⁽¹⁵⁾ A study by Jones-Lee shows that the respondents estimate an avoided fatal incidence in the London Subway 1.5 times higher than an avoided fatal road accident.⁽¹⁶⁾

In a recent study on behalf of the UK Department of Environment, Transport and the Regions (DETR), the basic value for road accident related risk has increased by a factor of 2 depending on the risk scenario.

To summarise, following the empirical evidence, willingness-to-pay values for a reduction of air pollution related risk are considered to be higher than the risk of fatal road accidents. The aversion factor might be in a range of 1.5 to 2, but cannot be definitely determined yet.

Altogether the empirical evidence is regarded to be too small to quantify the different risk-acceptance by an exact number. Therefore, **in accordance with the „at least-approach“ the present study explicitly renounces on further adjustments of this baseline value** and adopts 1.4 million EUR for the value of preventing a statistical fatality (VPF).

3.3.1.3 Adjustment for advanced Age

Based on the available epidemiological literature, a direct conclusion about the age structure of the air pollution related premature deaths is not yet possible. It is, however, known that these fatalities are mostly related to respiratory and cardiovascular disease and lung cancer.⁽¹⁷⁾ In Austria, France and Switzerland, the average age of these respiratory and cardiovascular fatalities is between 75 and 85 years (see also Fig. 3-2).⁽¹⁸⁾ Thus, the average age of the air pollution related fatalities is much higher than for victims of fatal road accidents (30-40 years of age).

Figure 3-2: Age structure of fatalities due to respiratory, cardiovascular diseases and lung cancer in Austria⁽¹⁹⁾, France and Switzerland (1996)

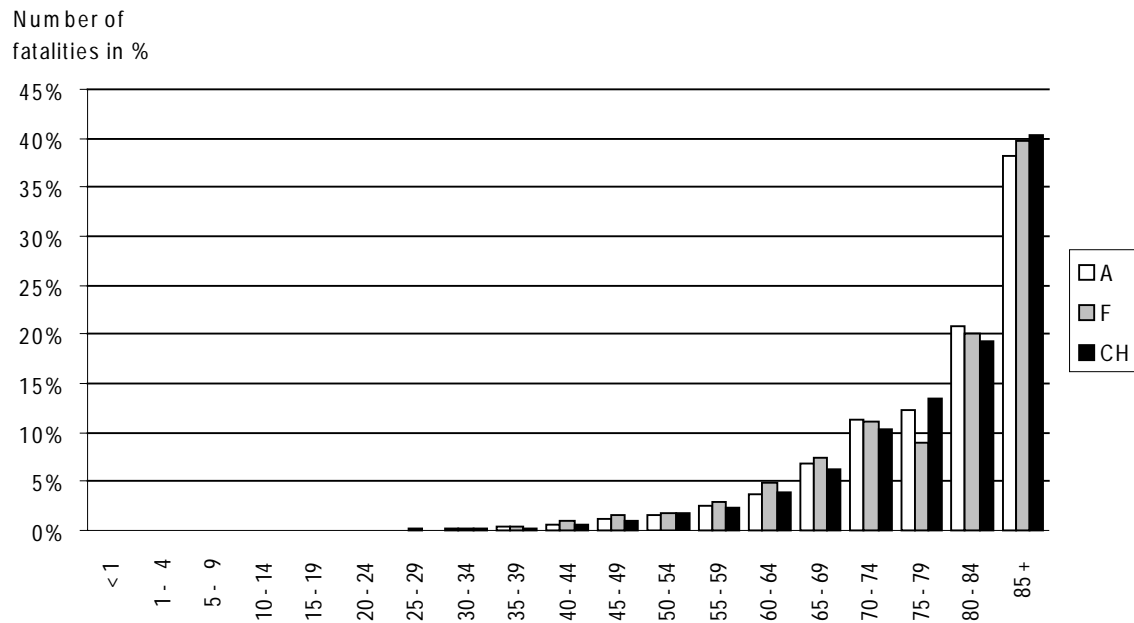
15 Mendeloff J., Kaplan R.M. (1990), Are Twenty-fold Differences in „Lifesaving“ Costs Justified?: A Psychometric Study of the Relative Value Placed on Preventing Deaths from Programm eAddressing Different Hazards

16 Jones-Lee M., Loomes G. (1995), Scale and Context Effects in the Valuation of Transport Safety.

17 See Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases.

18 Austria: 79.8 years; France: 78.9 years; Switzerland: 80.2 years.

19 Only respiratory and cardiovascular diseases without lung cancer.

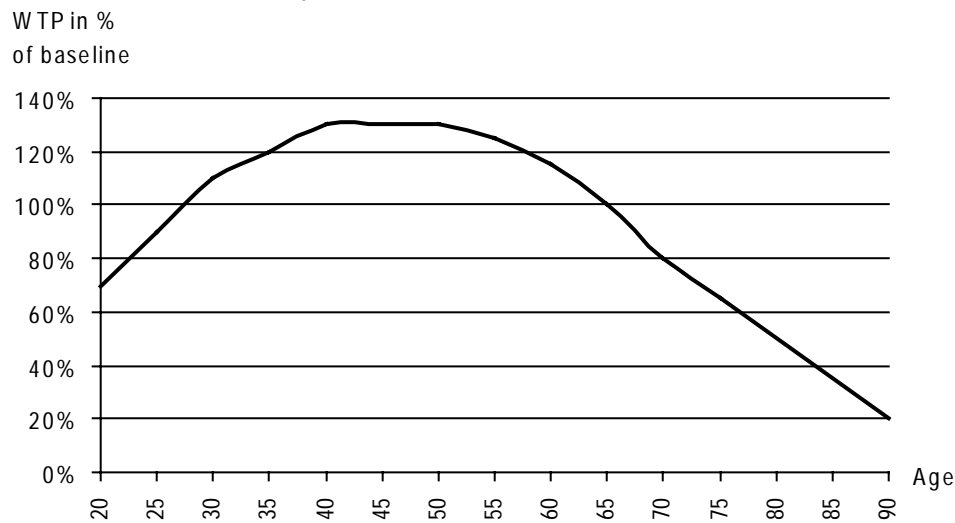


There are theoretical reasons as well as empirical evidence that WTP for risk reduction of mortality is decreasing with increasing age, with reduced remaining life expectancy and with reduced quality of life.

Several studies by Jones-Lee show a reversed U-shaped relationship between the age and the willingness-to-pay, whose curvature may vary slightly between the different studies.

For the present study, the relationship adopted is provided by the latest research of Jones-Lee and is presented in Figure 3-3.

Figure 3-3: The relationship between the age and the willingness-to-pay for a mortality risk reduction⁽²⁰⁾



Weighting the age structure of the fatalities due to respiratory and cardiovascular disease and lung cancer in all three countries (Figure 3-2) by the curve above, an adaptation factor of 61% is obtained.

Due to these results, reducing the average VPF to 61% of the initial value seems to be adequate. On the other hand, two main objections may be raised against this procedure:

- From an ethical point of view it may be questioned to adopt a valuation system varying by age and therefore implicitly favouring the saving of younger peoples' lives compared to older peoples' lives.
- From a methodological point of view it could also be criticised that the age related correction factor causes a considerable reduction of the health costs. On the other hand the risk context - as presented in the above chapter - is not used as an adjustment factor for an increase of VPF, although several empirical studies confirm its impact.

In order to face these difficulties and in order to show that these decisions cannot be made without subjective perception and estimation - partly because of insufficient empirical evidence - two approaches are applied for the further calculations:

□ **VPF: 0.9 million EUR (=61% x 1.4 million EUR)**

With this procedure a very strict application of the "at least-approach" is favoured. The cost reducing adjustment for age is maintained, meanwhile the cost increasing adjustment for the type of risk is abandoned, since there is less empirical evidence available.

□ **VPF: 1.4 million EUR**

In this assessment VPF adjustment for age and risk contexts are not taken into account. This approach is based on the opinion that as well as for age as for risk context there are reasons for

20 Source: Department of Health (1999), Economic Appraisal of the Health Effects of Air Pollution, p. 67 and direct information of M. Jones-Lee (1998).

an adjustment, although in different directions. But the empirical results are not yet sufficient for a definitive quantification of these adjustments.⁽²¹⁾

3.3.1.4 Adjustment for reduced Life Expectancy

The question is, whether in addition to the higher average age of air pollution related premature deaths, an additional adjustment factor has to be applied, as the victims remaining potential life expectancy based on their reduced health status is considerably lower than the average remaining life expectancy of those in good health status in the corresponding age group.

Even if it might be the case that the health status of air pollution related premature deaths is very low in the years before death, this is not a reason for reducing VPF when evaluating the long term mortality costs of air pollution.

In general, epidemiologic studies do not allow to identify the 'victims' on an individual level. The cohort mortality studies show that the air pollution exposure experience reduces life expectancy. This may be due to a complex combination of both, short-term and long-term effects. It can be assumed that if air pollution would have been lower, the average life expectancy would be longer. Therefore, without air pollution, these victims also would have an equal WTP for health risk avoidance as their corresponding age group.

3.3.1.5 Adjustment for lower Quality of Life

The quality of life of victims due to air pollution may be lower due to the advanced disease than the life quality of their corresponding age group. According to theoretical considerations and empirical evidence it may also be assumed that the WTP for a risk reduction is lower at a very bad health status (due to the increased suffering at this stage) than at a normal health status.

Nevertheless, a reduction in WTP for the evaluation of long term effects and costs of air pollution should not be adopted. Again, it may be assumed that the victims would - without an exposure to long term air pollution - benefit from a similar health status and a similar quality of life than the average of their corresponding age group. Furthermore, age adjustment of WTP may implicitly include changes in quality of life.

21 An other possible interpretation of this approach could be, that both contrary effects are regarded as more or less equal in its importance. According to the empirical studies this isn't impossible.

3.3.1.6 Summary: VPF for the air pollution related mortality

The starting point for the assessment is the basic value of 1.4 million EUR. It has been established in the latest research that is conducted on behalf of the UK Department of Environment, Transport and the Regions. The basic value represents an average value of preventing a statistical fatality (VPF) in the context of road traffic accidents.

In comparison to the road traffic accidents, the assessment of air pollution related victims has to observe two special circumstances:

- Air pollution related risk is to a large extent involuntary and is beyond the control and responsibility of the victims. Also, incurring the risk is less often combined with a direct personal benefit. These factors indicate a lower risk acceptance inducing in general a higher willingness-to-pay.
- On average, the victims have a considerably higher age (75-85 years) than the victims of fatal road accidents (35-45 years). Based on empirical evidence, it must be further assumed that the willingness-to-pay is decreasing at an advanced age.

The choice of VPF is taking these two opposite effects into account as follows:

- The "**at least-approach**" only adjusts for age and does not consider the higher risk aversion. The VPF for air pollution related mortality is established at 61% of the basic value and therefore amounts to **0.9 million EUR**.
- The starting point of the second calculation variant is the intention to basically adjust for both effects. But since for the risk context adjustment reliable empirical results still are missing and an asymmetrical treatment should be avoided, an explicit adjustment for both effects is abandoned. The VPF therefore remains at **1.4 million EUR**.

A further adaptation of these values based on the shortened life expectancy of the victims compared to their corresponding age group or based on their weaker health status is not taken into account. Most likely, the health status of the victims may be very low a few years before death and accordingly, the life expectancy is shortened. But in a long term perspective - that is the foundation of this study - according to the epidemiological evidence, the poor health status is a consequence of air pollution, ultimately leading to premature death.

3.3.2 Costs of air pollution related mortality

Based on the established VPF, the costs of air pollution related mortality may be derived from the number of cases (chapter 2.4.1). The following Tables present the results of the three countries:

Table 3-4: Costs of air pollution related mortality according to the willingness-to-pay approach in Austria 1996

	Austria	
	Total with road traffic share	Cases attributable to road share
Number of deaths due to air pollution (long term mortality, adults \geq 30 years)	5'576 3'370 - 7'813	2'411 1'457 - 3'378
Costs of mortality		
at least (only adjustment for age without adjustment for risk)	5'019 mill. EUR 3'033 - 7'031	2'170 mill. EUR 1'311 - 3'041
without adjustment for age and risk	7'807 mill. EUR 4'717 - 10'938	3'376 mill. EUR 2'040 - 4'730

The Table 3-4 shows that in Austria the 2'411 death cases due to air pollution attributable to road share cause about 2'200 million EUR. These are 43% of the costs due to the total air pollution. This calculation applies a VPF of 0,9 million EUR and takes into account the adjustment for age without adjustment for risk only.

However, without adjustment both for age and risk one gets a VPF for air pollution related mortality at 1.4 million EUR. The respective costs of air pollution attributable to the road share would then amount to nearly 3'400 million EUR, that are (also) 43% of the costs due to the total air pollution as in the case of a VPF of 0.9 million EUR.

Table 3-5: Costs of air pollution related mortality according to the willingness-to-pay approach in France 1996

	France	
	Total with road traffic share	Cases attributable to road share
Number of deaths due to air pollution (long term mortality, adults \geq 30 years)	31'692 19'202 - 44'369	17'629 10'681 - 24'680
Costs of mortality		
at least (only adjustment for age without adjustment for risk)	28'523 mill. EUR 17'282 - 39'932	15'866 mill. EUR 9'613 - 22'212
without adjustment for age and risk	44'369 mill. EUR 26'883 - 62'117	24'681 mill. EUR 14'953 - 34'552

In France the valuation of air pollution related mortality with a VPF of 0.9 million EUR reach at least 28'523 million EUR, about 15'866 million EUR of which are road traffic induced.

With a VPF for air pollution related mortality at 1.4 rather than 0.9 million EUR, the valuations would be 44'369 million EUR, as shown in Table 3-5. In this case, some 24'681 million EUR would be induced by road traffic.

In Switzerland (see Table 3-6) the costs of air pollution related mortality with a VPF of 0.9 million EUR reach nearly 3'000 million EUR, about 1'600 million EUR of which are road traffic induced. There are several reasons to establish a VPF for air pollution related mortality at 1.4 rather than 0.9 million EUR. In this case, the costs would amount to 4'640 million EUR, as shown in Table 3-6. In this case, some 2'500 million EUR would be induced by road traffic related air pollution.

Table 3-6: Costs of air pollution related mortality according to the willingness-to-pay approach in Switzerland 1996

	Switzerland	
	Total with road traffic share	Cases attributable to road share
Number of deaths due to air pollution (long term mortality, adults ≥ 30 years)	3'314 1'986 - 4'651	1'762 1'056 - 2'472
Costs of mortality		
at least (only adjustment for age without adjustment for risk)	2'983 mill. EUR 1'787 - 4'186	1'586 mill. EUR 950 - 2'225
without adjustment for age and risk	4'640 mill. EUR 2'780 - 6'511	2'467 mill. EUR 1'478 - 3'461

3.4 Partial assessment of the Costs of Mortality

3.4.1 Costs by the gross production loss approach

The main advantages and disadvantages of the gross production loss approach have been analysed in Chapter 3.1. Hence we concentrate on a short description of the main points:

- The gross production loss approach assesses the costs of a premature death by counting the discounted values of future income or production output which the victims could have obtained if they had not died prematurely.
- The gross production approach is limited on the material aspects of the follow-up costs due to air pollution. It does not reflect the costs of fear, pain and suffering of the victims or their relatives with this approach.
- In this project Austria and Switzerland apply the gross production loss approach as a partial assessment for the air pollution related mortality. The approach is chosen to allow a comparison with the health costs due to road traffic-related air pollution with the costs of road accidents, already assessed with the same approach in these countries.⁽²²⁾ In the case of Switzerland the approach is extended by combining the gross production with additional values for immaterial costs for pain, grief and suffering of the victims and their relatives.

²² See for Switzerland: ECOPLAN (1993), Soziale und externe Kosten von Verkehrsunfällen in der Schweiz: Aktualisierung für das Jahr 1993.

The main methodological points of its application are the following:

- Use of gross output: Unlike the net output (without proper consumption) the gross output does not only reflect the difference between production and consumption but also takes into account the total production value of the production of a human being throughout his or her life. The fact that consumption itself also constitutes a benefit for every individual argues in favour of using gross output. People who fall ill or die due to air pollution lose not only their production capacity but also part or all of their consumption potential and the resulting benefits.
- The indicator for the production loss is national labour income. The national labour income is divided by the whole population (without any differentiation for unemployed, retired or handicapped people) in order to get the per capita loss of production. This calculation concept is based on the assumption that the national wage income is the product of labour division within the society as a whole. Thus, the total labour income (wages) measured on the market is taken to be the result of a production by all persons, regardless of whether the individual contributes directly to the production result as an employee or indirectly as a housewife, home worker or volunteer or through undeclared work.

The main advantage of this assumption is that it is not necessary to make a distinction - which in any case would be quite problematic from an ethical point of view - between, for example young employed people and retired persons, or between paid and unpaid (household) work.

- For fatalities, production losses are determined based on the potential years of life lost. Since in such cases production loss must be calculated over a period of many years, it is necessary to apply a real growth rate of production and a rate of discount.⁽²³⁾ For the purpose of this calculation it is assumed that the real growth rate of production corresponds to the rate of discount (2%).

23 When an individual dies or becomes disabled, the loss of time (for work or any other activity) covers many years. A present value can be attributed to the future costs by converting the loss to a present worth. Doing so, two aspects have to be considered:

- First, the loss of production per capita and per year doesn't remain constant in the future. Due to the economic growth the loss per capita and per year is increasing. The increase depends on the assumed real growth rate.
- Secondly, it matters to individuals and society whether a cost (or a loss) is born immediately or at a later date. Normally, the weight attributed to future losses is less than the one of the actual loss. The difference depends on the assumed discount rate (time preference rate). The higher this rate is, the lower is the value given to future costs (or losses).

The values of the growth rate and the discount rate depend on the specific situations. An international review of the calculation of the economic costs of road accidents in 13 European countries showed that the growth rates used vary between 0% (Austria, Luxembourg and Spain) and 2.4% (Finland). On the other hand, the discount rates applied vary between 0% (Austria, Germany and Switzerland) and 10% (France and Spain) (see COST 313 (1994), Socio-economic costs of road accidents, p. 32.)

3.4.1.1 Mortality costs in Austria based on the gross production loss approach

In Austria 1996, the costs of mortality due to air pollution estimated by the gross output approach are in total (including the road traffic share) 1'000 million EUR, while the costs attributable to the road share are about 400 million EUR.

Table 3-7: Costs of air pollution related mortality according to the extended gross production loss approach in Austria 1996

	Austria	
	Total with road traffic share	Cases attributable to road share
Number of deaths due to air pollution (long term mortality, adults \geq 30 years)	5'576 3'370 - 7'813	2'411 1'457 - 3'378
Costs of mortality	987 mill. EUR 597 - 1'383	427 mill. EUR 258 - 598

3.4.1.2 Mortality costs in Switzerland based on the extended gross production loss approach

In 1996 the national labour income in Switzerland amounts to 145.9 thousand millions EUR which is an average labour income of 20'600 EUR per capita and year. The average age of the victims (\geq 30 years) due to respiratory and cardiovascular diseases and lung cancer is 80.2 years. The corresponding life expectancy of this age class is 9.5 years. Average production loss of a fatality thus amounts to 195'700 EUR.

For the Swiss results, in addition to the production loss, the intangible costs such as pain, grief and suffering are added. The intangible costs are evaluated on the bases of reparation legally determined for fatal accidents. In the specific case of Switzerland, this amount is roughly 134'800 EUR per death. The reparation payments are used as a proxy, since there are no WTP-studies available in Switzerland for the evaluation of intangible costs.

On the basis of these data, it is possible to calculate the mortality costs by the **extended** gross production loss approach.

Table 3-8: Costs of air pollution related mortality according to the extended gross production loss approach in Switzerland 1996

	Switzerland	
	Total with road traffic share	Cases attributable to road share
Number of deaths due to air pollution (long term mortality, adults \geq 30 years)	3'314 1'986 - 4'651	1'762 1'056 - 2'472
Costs of mortality	1'095 mill. EUR 656 - 1'537	582 mill. EUR 349 - 817
gross loss of production	649 mill. EUR 389 - 910	345 mill. EUR 207 - 484
immaterial costs (grief, pain)*	447 mill. EUR 268 - 627	238 mill. EUR 142 - 333

* Based on compensation payments, which have been fixed by Swiss courts in cases of killing and physical injury

In Switzerland 1996, the costs of mortality due to air pollution estimated by the extended gross production loss approach amount to 656-1'537 million EUR. The costs attributable to the road traffic share are about 349-817 million EUR (central estimate: 582 million EUR).

As already mentioned the costs estimated by the extended gross production loss approach represents a partial assessment of the real mortality costs due to air pollution.

3.4.2 Costs by the final consumption loss approach for France

As an alternative to the valuation of mortality with the WTP approach, we present hereafter an approach based upon a whole population scenario - instead of the victim scenario - and consumption losses - instead of production losses.

3.4.2.1 The whole population scenario

In order to calculate the number of years lost, the whole population scenario is chosen. The purpose is to compute directly the reduction of life expectancy due to air pollution exposure.

The calculation proceeds as follow.

In Step 1, we compute the life expectancy corresponding to the mortality rates observed.

$$\begin{aligned}
 Q_e(t) &= Q_e^{WAc}(t) + Q_e^{Ac}(t) \\
 S_e(t+1) &= S_e(t) \times [1 - Q_e(t)] \\
 LE_e &= \sum_t \left[(S_e(t+1) - S_e(t)) \times (t + \frac{1}{2}) \right]
 \end{aligned}$$

where

- $Q_e(t)$, $Q_e^{WAc}(t)$ and $Q_e^{Ac}(t)$ stand respectively for
 - + the observed death rate at age t for all causes,
 - + the observed death rate at age t for all causes except violence and accidents,
 - + the observed death rate at age t for violence and accidents,
- $S_e(t)$ is the observed survival rate at age t,
- LE_e is the life expectancy for the current level of pollution.

For the life expectancy calculation, we suppose that people dying between age t and age t+1 have survived $t + \frac{1}{2}$ years on average.

In step 2, we compute the life expectancies for the hypothetical situations with reduced air pollution. Air pollution affects the death rates for all causes except accident. Then

$$\begin{aligned}
 Q_0^{WAc}(t) &= \frac{Q_e^{WAc}(t)}{1 + [(RR-1)(E-B)/10]} \text{ and } Q_0(t) = Q_0^{WAc}(t) + Q_e^{Ac}(t) \\
 Q_{WRT}^{WAc}(t) &= \frac{Q_e^{WAc}(t)}{1 + [(RR-1)(E-E_{WRT})/10]} \text{ and } Q_{WRT}(t) = Q_{WRT}^{WAc}(t) + Q_e^{Ac}(t)
 \end{aligned}$$

where

- B is the baseline exposure level of $7.5 \mu\text{g}/\text{m}^3$
- E is the observed population average exposure level
- E_{WRT} is the estimated population average exposure level without road traffic air pollution,
- $Q_0^{WAc}(t)$ and $Q_{WRT}^{WAc}(t)$ stand respectively for
 - + the death rate at age t for all causes except violent and accidental deaths with air pollution reduced to the baseline level,
 - + the death rate at age t for all causes except violent and accidental deaths without road traffic air pollution

Then we deduce the corresponding survival rates and life expectancies.

Because of main differences in death rates between male and female, we choose to compute life expectancies for each gender separately. The results are given in Table 3-9.

Table 3-9: Lost life expectancies due to air pollution exposure

	Male	Female
Average exposure level	23,5 $\mu\text{g}/\text{m}^3$ 14,6 $\mu\text{g}/\text{m}^3$	
E		
E_{WRT}		
Life expectancies		
LE_e	73,634 years	81,678 years
LE_0	74,280 years	82,225 years
	74,030 - 74,537	82,014 - 82,442
LE_{WRT}	73,999 years	81,988 years
	73,857 - 74,148	81,867 - 82,114
Lost life expectancies per inhabitant due to :		
Total air pollution	0,646 year	0,547 year
	0,396 - 0,903	0,336 - 0,764
Road traffic air pollution	0,365 year	0,310 year
	0,223 - 0,514	0,189 - 0,436

* 1994 mortality data

3.4.2.2 The mortality costs based on the final consumption approach

Choosing a valorisation of human life based upon the household final consumption per inhabitant within the whole population scenario is motivated by the following reasons.

- Consumption seems to be a reliable approximation of the utility of life at least in its tangible part. Indeed, most of everyday acts require expenses (dwelling, food, travels, health care, leisure ...) in order to fill fundamental needs, directly or not (e.g. through the parents for young children). Death obviously gives a term to all of this.
- It also constitutes a convenient way to avoid a direct valuation of human life, which is always source of ethical and conceptual disagreements. Nevertheless this approach restricts itself to the material aspects and does not value fear, pain and suffering of the victims or their relatives.
- The choice of a discount rate and its implications are essential in the loss of production approach but are de facto avoided by using a whole population scenario.

The French final household consumption amounts to 730 thousands millions EUR in 1996 so that the final consumption per year and per inhabitant amounts to 12'583 EUR.

3.4.2.3 Results for France

According to Table 3-10, an average PM_{10} exposure level of $23.5 \mu\text{g}/\text{m}^3$ hasten death - compared to a baseline level of exposure of $7.5 \mu\text{g}/\text{m}^3$ - by 0.646 year for male, and 0.547 year for female. These figures are respectively 0.365 and 0.310 for the share due to road traffic related air pollution. Hence, these results must be applied to the number of deaths observed each year in order to obtain annual costs.

Table 3-10: Costs of air pollution related mortality according to the loss of consumption approach in France 1996

	Male	Female
Deaths all causes*	270'749	249'216
Years lost due to air pollution exposure	174'904 years 107'217 - 244'486	136'321 years 83'737 - 190'401
Total annual costs	3'916 million EUR 2'403 - 5'472	
Years lost due to road traffic air pollution exposure	98'823 years 60'377 - 139'165	77'257 years 47'102 - 108'658
Total annual costs	2'216 million EUR 1'352 - 3'118	

* 1994

In France the costs of air pollution related mortality valued by the loss of consumption approach reach 3'916 million EUR, from which 2'216 million EUR are road traffic induced.⁽²⁴⁾

24 On the whole, we find that 311'225 years are lost due to air pollution. According to the victim scenario, 31'692 premature deaths are due to air pollution. That means that 311'225 years correspond formally to a victim scenario with an average of 10 years lost per victim, a result quite close to the Swiss and Austria ones. Based upon the same epidemiologic relations, it is not very surprising for the two scenarios - victim and whole population - to give close results.

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4 Error! Switch argument not specified.TheError! Switch argument not specified.e costs of morbidity

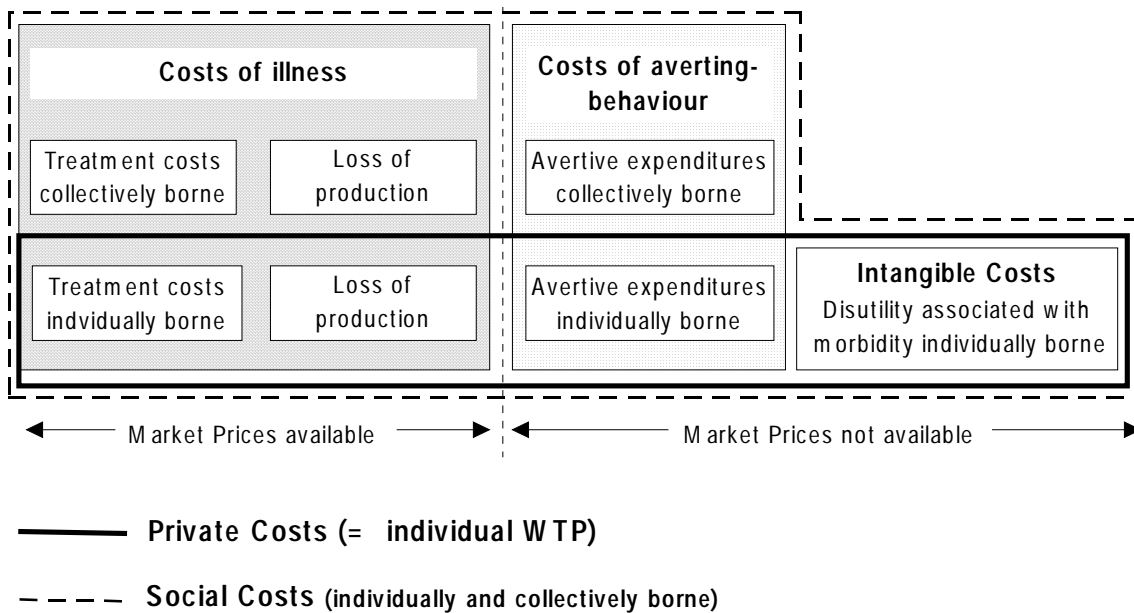
4.1 Overview of the valuation methods

As shown in Figure 4-1, the morbidity costs may be subdivided into different categories:

- **Costs of illness (COI)** contain the loss of production due to a possible incapacity to work and the medical treatment costs. These costs determine the "material part" of the health costs. They also may be assessed on the basis of real market prices (loss of earnings, costs for medications, costs per day in hospital, etc.).
- **Costs of averting-behaviour** are those costs which result from a different behaviour due to air pollution. They consist of, for example, the abstention from practising outdoor sport activities during a summer day with a high ozone concentration, the installation of air filters or a different choice of residential location due to air pollution (e.g. moving out of inner cities). The more costs (or measures) are taken in order to avoid a high air pollution concentration, the smaller will likely be the number of air pollution related morbidity cases resulting. According to the extent of the measures taken so far, neglecting the costs of averting behaviour may result in a considerable under estimation of the morbidity costs. But for the assessment of these costs market prices are mostly non-existent.⁽¹⁾
- A third essential part of the morbidity costs are the so called **intangible costs**. They reflect the individual loss of utility and consist of the pain, grief and suffering due to an illness. According to the experience of several authors, the wish not to get ill is mainly determined by these inconveniences (losses in utility).⁽²⁾

1 Using indirect approaches, a part of these costs may theoretically still be assessed, e.g. the amount of time that cannot be spent outdoors because of air pollution could be monetarized on the basis of a salary level. Also the costs of a change in residential location could be estimated on the basis of the costs for moving. The problem with these calculations lies in the absence of figures for the forced change in residential location or the number of forced indoor hours.

2 Compare e.g. Maddison D. (1997), Valuing the morbidity effects of air pollution, p. 9.

Figure 4-1: Overview of the costs of morbidity

The **private costs** of morbidity consist of the sum of all individually borne costs. But as presented in Figure 4-1, not all the cost consequences of morbidity are considered. According to the different institutional forms of the health care systems and the social security systems, part of the costs is covered by the whole society and is not borne individually.

Thus, the assessment of the real economic costs of morbidity has to establish the **social costs** that consist of the individually borne as well as the collectively borne costs.

The empirical estimation of the morbidity costs may be conducted on the basis of a damage cost approach or a willingness-to-pay approach. Both approaches have advantages and disadvantages:

- The **damage cost approach** evaluates the damage costs due to a disease by market prices. This approach is specially suitable for the assessment of production loss and medical treatment costs (the so called costs of illness COI). Hereby, it does not matter if the costs are individually borne or if they are covered by the whole society in the form of an insurance payment. Nevertheless, this approach is not suitable for the assessment of costs of averting behaviour, since the extent of behavioural changes is mostly unknown and in most cases no market prices are available for the estimation of these costs. This approach is completely inapplicable for the assessment of pain, grief and suffering as there don't exist any market prices for these cost factors.
- The **willingness-to-pay** approach focuses on the individually borne costs (private costs). Based on individual utility gains resulting from a lower air pollution concentration and less days of illness, the willingness-to-pay is surveyed for a reduction in air pollution related risk. This willingness-to-pay reflects all cost factors which are borne by the individual:
 - the change in days of illness with absence from work, multiplied by the individually borne loss of earnings
 - the change in need for treatment, multiplied by the individually borne treatment costs

- the change in averting-behaviour, multiplied by the individually borne averting-behaviour-costs and
- the change in grief, pain and suffering expressed in monetary values.

The advantage of the willingness-to-pay approach lies in the integration of intangible costs which cannot be evaluated directly with the damage cost approach. These intangible costs may be considerably higher than the material costs of a disease (production loss, treatment costs).

The main disadvantage of the willingness-to-pay approach lies in its limitation to the individually borne costs. As earlier presented in Figure 4-1, the individual costs only represent part of the total social costs of morbidity. Specifically, the costs of illness are underestimated by the individual willingness-to-pay approach, since a considerable part of the cost of illness is, according to the health system, covered by collective means (social insurance contributions). The exact extent is determined by the institutional structure and will be different for each country.

In summary, the experience shows that neither with the damage cost approach nor with the willingness-to-pay approach the social costs of morbidity are completely assessed. Therefore the question arises whether it is not possible to combine these two approaches.

An interesting solution would consist of evaluating the total individually and socially borne costs of illness with the damage cost approach and to use the individual willingness-to-pay for the intangible costs. However, Figure 4-1 indicates that such a combination might lead to double counting and to an over-estimation of the morbidity costs, if the willingness-to-pay also contains the individually borne costs of illness.

The ideal solution of this problem consists of subdividing the willingness-to-pay into its single components (intangible costs, costs of treatment, costs of production loss, costs of behavioural changes) and assess the willingness-to-pay for the intangible costs separately. This procedure would allow us to combine the costs of illness with an estimate of the willingness-to-pay for intangible costs.

So far, present surveys on willingness-to-pay for the risk reduction of morbidity do not allow for such a differentiated subdivision. In the available research reviewed in our project for selected diseases the general willingness-to-pay is assessed on the basis of symptom descriptions and eventually some additional indicators on the disease related restrictions. An exact delimitation of all the different cost factors has not been identified or is not explicitly presented in the published results.

Based on this situation, **the following procedure is chosen for the assessment of the morbidity costs:**

- As a **partial assessment** the morbidity costs are estimated using the Costs of illness (COI) only. It is clear that the intangible costs are not taken into account with this procedure which leads to a considerable under-estimation of the real morbidity costs.
- Using **the willingness-to-pay approach**, a better approximation to the real social costs of morbidity is aimed for. In this approach the privately borne costs are included. Specifically the disease related troubles (limited mobility, pain, grief and suffering) may be evaluated which are the principal reason for avoiding getting sick.

However, it also needs to be taken into account that this approach does not yet include all the costs, since the willingness-to-pay only covers the individually borne costs.

In order to avoid possible double counting, any form of combination of the two calculation methods is abandoned.

4.2 Costs of morbidity according to the willingness-to-pay approach

4.2.1 WTP-Values for the avoidance of morbidity due to air pollution

The assessment of morbidity costs according to the willingness-to-pay approach has to be based on specific WTP-values for the considered health outcomes:⁽³⁾

- Respiratory Hospital Admission
- Cardiovascular Hospital Admission
- Chronic Bronchitis
- Bronchitis
- Restricted Activity Days
- Asthmatics: Asthma attacks

However, it shows that there are only very few European WTP-studies for air pollution related health outcomes. Most of the existing studies refer to a USA context. Their application to a European context may not be appreciated definitely. First results of a Norwegian study⁽⁴⁾ suggest that the WTP for a risk reduction in morbidity is lower in Norway than in the USA. As mentioned earlier, the individual willingness-to-pay also depends on the extent to which the victims have to pay their different costs (e.g. medical treatment costs, loss of wages) themselves or to which extent these costs are covered by insurance. As the health care and insurance systems differ considerably from one country to another, as a basic rule country specific WTP-values should be applied.

In spite of these difficulties, the following calculations had to be based on existing values, since it was not possible to conduct specific empirical surveys within the framework of this project. Furthermore, unrelated to the above mentioned country specific differences, the comparability of morbidity WTP-values from different studies causes a very difficult problem. In contrast to mortality that presents one single, well defined health outcome, morbidity can be assessed at very different stages. Maddison (1977) has solved this problem in his evaluation by combining different WTP-studies from USA and Norway with a "health-status-index".

In the literature on "health-status-index", the reduction in wellbeing due to morbidity is assessed by a scale from 0 to 10, based on various symptoms and their effect on social activities, physical activities and mobility. Based on these values, the WTP-results could be estimated as a function of

3 For a detailed description of the symptoms see: Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases.

4 Navrud S. (1998), Valuing Health Impacts from Air Pollution in Europe - New Empirical Evidence on Morbidity.

the health-status-index and the duration of disease. This statistical relationship was then used to estimate WTP-values for those health outcomes that are related to air pollution.

In Table 4-2 the results are presented for bronchitis, restricted activity and asthma attacks. For the WTP values of the other two health outcomes (hospital admission and chronic bronchitis), results from two other studies have been used, since they were not treated in the Maddison study.

Table 4-2: WTP for the avoidance of health states due to air pollution

Health indicator	WTP-Value (EUR)
Respiratory Hospital Admission	7870 per admission ⁽⁵⁾
Cardiovascular Hospital Admission	7870 per admission ⁽⁵⁾
Chronic Bronchitis	209000 per case ⁽⁶⁾
Bronchitis	131 per case ⁽⁷⁾
Restricted Activity Day	94 per day ⁽⁷⁾
Asthmatics: Asthma attacks (person day)	31 per attack ⁽⁷⁾

5 Based on ExternE (1995), Externalities of Energy, Volume 2, Methodology, Part II: Economic Valuation, p. 519, adjusted for inflation according to Nilsson M., Gullberg M. (1998), Externalities of Energy, Swedish Implementation of the ExternE Methodology.

6 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.

7 Maddison D. (1997), Valuing the morbidity effects of air pollution, p. 8.

The WTP values of Table 4-2 are relatively low which corresponds again to the "at-least" approach.⁽⁸⁾

It needs to be considered that the WTP for the avoidance of chronic bronchitis deals with a long-term disease that is often accompanied by a very severe reduction of well-being and may under certain circumstances lead to death.

4.2.2 Results for Austria, France and Switzerland

The following tables summarise the results for Austria, France and Switzerland separately.

Table 4-3: Costs of air pollution related morbidity according to willingness-to-pay approach in Austria 1996

	Morbidity attributable to air pollution with road traffic share		Morbidity attributable to road traffic	
	Cases or days	Costs (mill. EUR)	Cases or days	Costs (mill. EUR)
Respiratory Hospital Admissions (all ages)	3'399 358 - 6'456	26.8 2.8 - 50.8	1'470 155 - 2'792	11.6 1.2 - 22.0
Cardiovascular Hospital Admissions (all ages)	6'695 3'489 - 9'960	52.7 27.5 - 78.4	2'895 1'509 - 4'307	22.8 11.9 - 33.9
Chronic Bronchitis Incidence (Adults ≥ 25 years)	6'158 552 - 12'241	1'287.0 115.3 - 2'558.4	2'663 239 - 5'293	556.5 49.9 - 1'106.3
Bronchitis (children < 15 years)	47'652 21'008 - 86'090	6.2 2.8 - 11.3	20'606 9'085 - 37'228	2.7 1.2 - 4.9
Restricted Activity Days (adults ≥ 20 years)	3'106'544 2'615'175 - 3'604'519	292.0 245.8 - 338.8	1'343'371 1'130'886 - 1'558'711	126.3 106.3 - 146.5
Asthmatics: Asthma attacks (children < 15 years, pers. days)	34'665 21'321 - 48'174	1.1 0.7 - 1.5	14'990 9'220 - 20'832	0.5 0.3 - 0.6
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	93'619 45'594 - 142'598	2.9 1.4 - 4.4	40'484 19'716 - 61'664	1.3 0.6 - 1.9
Total costs of morbidity in million EUR		1'668.6 396.2 - 3'043.6		721.6 171.3 - 1'316.1

Using the WTP approach, the costs of morbidity in Austria attributable to the road traffic share of air pollution vary strongly for the different morbidity categories: concerning the cases, from over than 550 million EUR for the chronic bronchitis (incidence) of adults older than 24 years to 2.7

8 In other studies, the estimation of morbidity costs has been done partly with considerable higher WTP-values. See e.g. Pearce D. (1996), Health effects of ozone and nitrogen oxides in an integrated assessment of air pollution; Ostro B., Chestnut L. (1997), Assessing the Health Benefits of Reducing Particulate Matter Air Pollution in the United States.

million EUR for bronchitis of children younger than 15 years; concerning the categories in days, from about 126 million EUR for the restricted activity days of adults older than 19 years to 0.5 million EUR for asthma attacks of children younger than 15 years.

Table 4-4: Costs of air pollution related morbidity according to willingness-to-pay approach in France 1996

	Morbidity attributable to air pollution with road traffic share		Morbidity attributable to road traffic	
	Cases or days	Costs (mill. EUR)	Cases or days	Costs (mill. EUR)
Respiratory Hospital Admissions (all ages)	13'796 1'491 - 26'286	108.6 11.7 - 206.9	7'674 829 - 14'622	60.4 6.5 - 115.1
Cardiovascular Hospital Admissions (all ages)	19'761 10'440 - 29'362	155.5 82.2 - 231.1	10'992 5'807 - 16'333	86.5 45.7 - 128.5
Chronic Bronchitis Incidence (Adults ≥ 25 years)	36'726 3'262 - 73'079	7'675.7 681.8 - 15'273.5	20'429 1'814 - 40'650	4'269.7 379.1 - 8'495.9
Bronchitis (children < 15 years)	450'218 198'450 - 813'562	59.0 26.0 - 106.6	250'434 110'388 - 452'544	32.8 14.5 - 59.3
Restricted Activity Days (adults ≥ 20 years)	24'579'872 20'692'055 - 28'519'982	2'310.5 1'945.1 - 2'680.9	13'672'554 11'509'956 - 15'864'240	1'285.2 1'081.9 - 1'491.2
Asthmatics: Asthma attacks (children < 15 years, pers. days)	242'633 149'141 - 337'151	7.5 4.6 - 10.5	134'965 82'960 - 187'540	4.2 2.6 - 5.8
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	577'174 281'130 - 879'091	17.9 8.7 - 27.3	321'053 156'378 - 488'994	10.0 4.8 - 15.2
Total costs of morbidity in million EUR		10'334.7 2'760.0 - 18'536.6		5'748.7 1'535.2 - 10'311.0

The monetary valuation of air pollution related morbidity lies between 2'800 and 18'500 million EUR (central value 10'335). The share due to road traffic amounts to 1'500-10'300 million EUR (central estimate 5'749). The major category is chronic bronchitis - 74% of the total value - and Restricted Activity Days - 22%. The remaining categories only represent 4% of the total valuation.

Table 4-5: Costs of air pollution related morbidity according to willingness-to-pay approach in Switzerland 1996

	Morbidity attributable to air pollution with road traffic share		Morbidity attributable to road traffic	
	Cases or days	Costs (mill. EUR)	Cases or days	Costs (mill. EUR)
Respiratory Hospital Admissions (all ages)	1'308 138 - 2'488	10.3 1.1 - 19.6	694 73 - 1'320	5.5 0.6 - 10.4
Cardiovascular Hospital Admissions (all ages)	2'979 1'544 - 4'425	23.4 12.2 - 34.8	1'580 819 - 2'348	12.4 6.4 - 18.5
Chronic Bronchitis Incidence (Adults ≥ 25 years)	4'238 374 - 8'436	885.7 78.2 - 1'763.1	2'248 199 - 4'475	469.8 41.6 - 935.3
Bronchitis (children < 15 years)	45'446 20'029 - 82'121	6.0 2.6 - 10.8	24'109 10'626 - 43'565	3.2 1.4 - 5.7
Restricted Activity Days (adults ≥ 20 years)	2'762'682 2'325'699 - 3'205'536	259.7 218.6 - 301.3	1'465'600 1'233'782 - 1'700'534	137.8 116.0 - 159.9
Asthmatics: Asthma attacks (children < 15 years, pers. days)	23'637 14'532 - 32'850	0.7 0.5 - 1.0	12'539 7'709 - 17'427	0.4 0.2 - 0.5
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	62'593 30'490 - 95'345	1.9 0.9 - 3.0	33'205 16'175 - 50'580	1.0 0.5 - 1.6
Total costs of morbidity in million EUR		1'187.8 314.0 - 2'133.6		630.1 166.7 - 1'131.8

In Switzerland, according to the WTP-approach, the air pollution related costs of morbidity amount to some 314 to 2'134 million EUR (central estimate: 1'188 million EUR). The share due to road traffic-related air pollution amounts to 167 - 1'132 million EUR (central estimate: 630 million EUR). The highest costs are registered with chronic bronchitis and with restricted activity days.

Compared to the mortality costs (see Table 3-6), the morbidity costs are to a factor 4 lower. Nevertheless, they have to be regarded as considerable costs.

4.3 Costs of illness (COI) as partial assessment

4.3.1 Methodology and data bases

As Figure 4-1 shows, in this approach, the morbidity costs are estimated according to market prices for medical treatment and for the loss of production. The other cost components (costs of averting behaviour, intangible costs) are neglected, since there is no directly observable market price available for their assessment.

Clearly, this approach leads to a considerable underestimation of the real costs. For the different health outcomes, the calculation methods and the applied cost factors may be presented as follows:

□ Respiratory and cardiovascular hospital admission

The medical treatment costs were calculated based on the average duration of a hospital admission and the average daily cost.

For the loss of production it needs to be considered that the patient after a hospital admission cannot directly return to work thereafter. It is assumed that the time for recovering lasts at least as long as the stay in hospital itself.

The per capita production loss is estimated based on the total labour income divided by the total population. It is assumed that the national labour income is the result of a division of labour among all members of society - young and old persons, people with and without a job, etc. A differentiation of the production loss according to the socio-economic status of a person (working, jobless, retired, homework, etc.) is not necessary⁽⁹⁾.

Respiratory Hospital Admission	Austria	France	Switzerland
Average duration in hospital	9.8 days	8.9 days	11.1 days
Hospital costs per day	452 EUR	408 EUR	600 EUR ⁽¹⁰⁾
Average gross production loss per day	50 EUR	55 EUR	56.5 EUR

Cardiovascular Hospital Admission	Austria	France	Switzerland
Average duration in hospital	17.5 days	8.1 days	13.6 days
Hospital costs per day	452 EUR	477 EUR	600 EUR ⁽¹¹⁾
Average gross production loss per day	50 EUR	55 EUR	56.5 EUR

9 See also chapter 3.4.1.

10 Public subsidies included.

11 Public subsidies included.

□ **Chronic Bronchitis**

For the assessment of medical costs, a special Swiss evaluation of the medical treatment costs was used, in which, based on a decision tree model (decision-making flow chart) for patients with chronic bronchitis, different treatment variations and their costs were evaluated.⁽¹²⁾

According to this assessment, the treatment costs per patient and year amount to an average of 220 EUR. Since this assessment deals with a chronic disease, the yearly costs have to be aggregated for the total duration of the disease. About the average duration, no definite evidence is available. As a cautious assumption an average of 15 years is presumed.

Concerning the production loss, a cost assessment is not considered, although it has to be considered that this disease is, according to its development, accompanied by a partial or total disability for work during shorter or longer time periods. However, for a quantification of the resulting production loss, data availability is not sufficient.

Chronic Bronchitis	Austria	France	Switzerland
Costs per case and year ⁽¹³⁾	220 EUR	220 EUR	220 EUR
Average disease duration per case (assumption)	15 years	15 years	15 years

□ **Bronchitis**

For Switzerland, the treatment costs are assessed based on the medication use (medication turn over) and amount to 32.8 EUR per case.

Similar to the chronic bronchitis, for the assessment of the production loss, data on the corresponding disability for work are lacking.

Bronchitis	Austria	France	Switzerland
Costs per case	24.8 EUR	39 EUR	32.8 EUR

□ **Restricted activity days**

In the epidemiological literature, a homogeneous definition for restricted activity days is missing. It may cover days laid off with disability from work but also days where the respiratory symptoms only lead to a small change in the activity behaviour. In addition, it is not known to which extent the victims call for medical assistance of a doctor or consume medication.

Based on these difficulties in differentiation, an estimation of treatment costs and production loss costs had to be abandoned.

12 IMIB (1996), Monetarisierung der verkehrsbedingten externen Gesundheitskosten: Behandlungskosten.

13 The Swiss value is used because it is based on a cautious specific study.

□ Asthma Attacks

The assessment of treatment costs is also based on the above mentioned special evaluation for Switzerland. The treatment costs are calculated on the base of the daily dose of bronchodilators. Per day, these costs amount to an average of 0.3 EUR for Austria and 0.55 EUR for France and Switzerland.

Once again, the estimation of the production loss had to be abandoned, since it is not known how often and to what extent asthma attacks lead to a disability to work.

Asthma Attacks	Austria	France	Switzerland
Costs of medication use per day	0.3 EUR	0.55 EUR ⁽¹⁴⁾	0.55 EUR

4.3.2 Results for Austria, France and Switzerland

Using the gross output approach, the costs of morbidity in **Austria** attributable to the road traffic share of air pollution vary also for the different morbidity categories (see Table 4-6): concerning the cases, from 28 million EUR for cardiovascular hospital admissions (all ages) to 0.5 million EUR for bronchitis of children older than 15 years.

In **France**, the air pollution related morbidity costs for 1996 amount to 75 - 534 million EUR, with a central estimate of 297. The two largest categories are chronic bronchitis (121 million EUR) and cardiovascular hospital admissions (94 million EUR). The share due to road traffic is about 55%, that means 42 - 297 million EUR with a central estimate of 165. Nevertheless, it must be kept in mind that these costs only represent acute morbidity - except for chronic bronchitis - and that chronic morbidity costs may be considered as several times higher than acute.

14 Based on the Swiss value.

Table 4-6: Costs of illness due to air pollution in Austria 1996

Austria	Morbidity attributable to air pollution with road traffic share				Morbidity attributable to road traffic			
	cases or days	loss of production (mill. EUR)	treatment costs (mill. EUR)	costs of illness (mill. EUR)	cases or days	loss of production (mill. EUR)	treatment costs (mill. EUR)	costs of illness (mill. EUR)
Respiratory Hospital Admissions (all ages)	3'399 358 - 6'456	3.3 0.4 - 6.3	15.1 1.6 - 28.6	18.4 1.9 - 34.9	1'470 155 - 2'792	1.4 0.2 - 2.7	6.5 0.7 - 12.4	8.0 0.8 - 15.1
Cardiovascular Hospital Admissions (all ages)	6'695 3'489 - 9'960	11.7 6.1 - 17.4	53.0 27.6 - 78.8	64.7 33.7 - 96.2	2'895 1'509 - 4'307	5.1 2.6 - 7.5	22.9 11.9 - 34.1	28.0 14.6 - 41.6
Chronic Bronchitis Incidence (Adults ≥25 years)	6'158 552 - 12'241	-	20.3 1.8 - 40.4	20.3 1.8 - 40.4	2'663 239 - 5'293	-	8.8 0.8 - 17.5	8.8 0.8 - 17.5
Bronchitis (children < 15 years)	47'652 21'008 - 86'090	-	1.2 0.5 - 2.1	1.2 0.5 - 2.1	20'606 9'085 - 37'228	-	0.5 0.2 - 0.9	0.5 0.2 - 0.9
Restricted Activity Days (adults ≥20 years)	3'106'544 2'615'175 - 3'604'519	-	-	-	1'343'371 1'130'886 - 1'558'711	-	-	-
Asthmatics: Asthma attacks (children < 15 years, pers. days)	34'665 21'321 - 48'174	-	0.01 0.01 - 0.01	0.01 0.01 - 0.01	14'990 9'220 - 20'832	-	0.004 0.003 - 0.006	0.004 0.003 - 0.006
Asthmatics: Asthma attacks (adults ≥15 years, person days)	93'619 45'594 - 142'598	-	0.03 0.01 - 0.04	0.03 0.01 - 0.04	40'484 19'716 - 61'664	-	0.01 0.01 - 0.02	0.01 0.01 - 0.02
Total costs of illness in million EUR				104.6 38.0 - 173.7				45.2 16.4 - 75.1

Table 4-7: Costs of illness due to air pollution in France 1996

France	Morbidity attributable to air pollution with road traffic share				Morbidity attributable to road traffic			
	cases or days	loss of production (mill. EUR)	treatment costs (mill. EUR)	costs of illness (mill. EUR)	cases or days	loss of production (mill. EUR)	treatment costs (mill. EUR)	costs of illness (mill. EUR)
Respiratory Hospital Admissions (all ages)	13'796 1'491 - 26'286	13.5 1.5 - 25.7	50.1 5.4 - 95.4	63.6 6.9 - 121.2	7'674 829 - 14'622	7.5 0.8 - 14.3	27.9 3.0 - 53.1	35.4 3.8 - 67.4
Cardiovascular Hospital Admissions (all ages)	19'761 10'440 - 29'362	17.6 9.3 - 26.2	76.4 40.3 - 113.4	94.0 49.6 - 139.6	10'992 5'807 - 16'333	9.8 5.2 - 14.6	42.5 22.4 - 63.1	52.3 27.6 - 77.7
Chronic Bronchitis Incidence (Adults ≥25 years)	36'726 3'262 - 73'079	-	121.2 10.8 - 241.2	121.2 10.8 - 241.2	20'429 1'814 - 40'650	-	67.4 6.0 - 134.1	67.4 6.0 - 134.1
Bronchitis (children < 15 years)	450'218 198'450 - 813'562	-	17.6 7.7 - 31.7	17.6 7.7 - 31.7	250'434 110'388 - 452'544	-	9.8 4.3 - 17.6	9.8 4.3 - 17.6
Restricted Activity Days (adults ≥20 years)	24'579'872 20'692'055 - 28'519'982	-	-	-	13'672'554 11'509'956 - 15'864'240	-	-	-
Asthmatics: Asthma attacks (children < 15 years, pers. days)	242'633 149'141 - 337'151	-	0.13 0.08 - 0.19	0.13 0.08 - 0.19	134'965 82'960 - 187'540	-	0.07 0.05 - 0.10	0.07 0.05 - 0.10
Asthmatics: Asthma attacks (adults ≥15 years, person days)	577'174 281'130 - 879'091	-	0.32 0.15 - 0.48	0.32 0.15 - 0.48	321'053 156'378 - 488'994	-	0.18 0.09 - 0.27	0.18 0.09 - 0.27
Total costs of illness in million EUR				296.8 75.3 - 534.3				165.1 41.9 - 297.2

Table 4-8: Costs of illness due to air pollution in Switzerland 1996

Switzerland	Morbidity attributable to air pollution with road traffic share				Morbidity attributable to road traffic			
	cases or days	loss of production (mill. EUR)	treatment costs (mill. EUR)	costs of illness (mill. EUR)	cases or days	loss of production (mill. EUR)	treatment costs (mill. EUR)	costs of illness (mill. EUR)
Respiratory Hospital Admissions (all ages)	1'308 138 - 2'488	1.6 0.2 - 3.1	8.7 0.9 - 16.6	10.4 1.1 - 19.7	694 73 - 1'320	0.9 0.1 - 1.7	4.6 0.5 - 8.8	5.5 0.6 - 10.4
Cardiovascular Hospital Admissions (all ages)	2'979 1'544 - 4'425	4.6 2.4 - 6.8	24.3 12.6 - 36.1	28.9 15.0 - 42.9	1'580 819 - 2'348	2.4 1.3 - 3.6	12.9 6.7 - 19.2	15.3 7.9 - 22.8
Chronic Bronchitis Incidence (Adults ≥25 years)	4'238 374 - 8'436	-	14.0 1.2 - 27.8	14.0 1.2 - 27.8	2'248 199 - 4'475	-	7.4 0.7 - 14.8	7.4 0.7 - 14.8
Bronchitis (children < 15 years)	45'446 20'029 - 82'121	-	1.5 0.7 - 2.7	1.5 0.7 - 2.7	24'109 10'626 - 43'565	-	0.8 0.3 - 1.4	0.8 0.3 - 1.4
Restricted Activity Days (adults ≥20 years)	2'762'682 2'325'699 - 3'205'536	-	-	-	1'465'600 1'233'782 - 1'700'534	-	-	-
Asthmatics: Asthma attacks (children < 15 years, pers. days)	23'637 14'532 - 32'850	-	0.01 0.01 - 0.02	0.01 0.01 - 0.02	12'539 7'709 - 17'427	-	0.01 0.00 - 0.01	0.01 0.00 - 0.01
Asthmatics: Asthma attacks (adults ≥15 years, person days)	62'593 30'490 - 95'345	-	0.03 0.02 - 0.05	0.03 0.02 - 0.05	33'205 16'175 - 50'580	-	0.02 0.01 - 0.03	0.02 0.01 - 0.03
Total costs of illness in million EUR			54.8 18.0 - 93.2				29.0 9.5 - 49.4	

In Switzerland the air pollution related morbidity costs for the year 1996 amount to 18 - 93 million EUR (central estimate: 55 million EUR). Some 53%, or 9.5 to 49 million EUR are attributable to the road-traffic related air pollution.

The cardiovascular hospital admissions are responsible for most of the costs (29 million EUR). The treatment costs of chronic bronchitis are responsible for about 14 million EUR. A similar amount of about 10 million EUR results from respiratory hospital admissions.

As mentioned above, it needs to be pointed out that the absence of data prevented the assessment of the production loss for various health outcomes.

In contrast to the WTP approach, the costs of illness do not contain intangible costs (pain, grief and suffering). However, the wish not to fall ill is, as mentioned in chapter 4 already, to a large extent determined by these intangible costs. Comparing Table 4-5 and 4-8, this applies specially for the chronic bronchitis and the restricted activity days.

- The mere treatment costs are relatively low for the chronic bronchitis. However, this disease may induce considerable restrictions according to the state of its development. This fact leads to a great willingness-to-pay for its avoidance.
- As mentioned above, for the restricted activity days the material costs (production loss, medical treatment costs) may only be assessed under great difficulties. Due to missing data bases, a quantification had to be abandoned. However, investigation of the willingness-to-pay indicates that restricted activity days cause considerable troubles. Even if the WTP-value per day is not very high, a large number of restricted activity days leads to a high total amount.

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5 Final results, interpretation and uncertainties

This chapter contains a summarised presentation of the air pollution related health costs (chapter 5.1). In chapter 5.2 an interpretation of the results is presented. Chapter 5.3 discusses the validity of the results and presents an overview of all the sensitive assumptions. The final chapter 5.4 contains recommendations about the implementation of these results.

5.1 Final results

The results are presented in two different parts. The first chapter contains the air pollution related health costs based on the willingness-to-pay approach which is the main common methodological framework used for the monetary valuation. The second chapter presents the country specific estimation of a partial assessment approach of road traffic-related health costs.

5.1.1 Air pollution related health costs based on the willingness-to-pay approach

The costs of air pollution related mortality and morbidity may be subdivided into so-called material and intangible costs. The material costs consists primarily of a reduced capacity (which leads to production or consumption losses) and of costs for ambulant and/or stationary treatment. In addition to material consequences, morbidity and mortality may induce fear, pain, suffering, diminished pleasure and loss in life quality. In many cases, the so-called intangible costs may be significantly higher than the mere material costs.

In 1996 the (road traffic-related) air pollution induced in Austria, France and Switzerland a high level of health costs. The country specific estimations are presented in Table 5-1.

The **total air pollution related health costs** of the three countries together amount to some **49'700 million EUR**, of which some **26'700 million EUR** are attributable to **road traffic-related air pollution**.

In Austria (6'690 million EUR) and Switzerland (4'170 million EUR), the **total air pollution** related health costs reach a similar level. Due to much larger population, the French costs amount to 38'860 million EUR.

The **road traffic-related part** of the health costs amount in Austria to 2'890 million EUR, in Switzerland to 2'220 million EUR and in France to 21'600 million EUR.

In France, in the absence of their own values, the road traffic-related part of PM₁₀ concentration had to be established based on Swiss figures. In Switzerland, compared to France there is a considerably lower proportion of diesel engines in use. Therefore applying Swiss values to a French context must be considered as an „at least“ approach for the French results. However, 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, road dust re-suspension are independent from the proportion 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).

Table 5-1: Road traffic-related health costs in Austria, France and Switzerland based on the willingness-to-pay approach ⁽¹⁾ (1996)

	Austria		France		Switzerland	
	Total costs with road traffic share	Costs attributable to road	Total costs with road traffic share	Costs attributable to road	Total costs with road traffic share	Costs attributable to road
Costs of mortality (million EUR)	5'019 3'033 - 7'031	2'170 1'311 - 3'041	28'523 17'282 - 39'932	15'866 9'613 - 22'212	2'983 1'787 - 4'186	1'586 950 - 2'225
Costs of morbidity (million EUR)	1'669 396 - 3'044	722 171 - 1'316	10'335 2'760 - 18'537	5'749 1'535 - 10'311	1'188 314 - 2'134	630 167 - 1'132
Total costs (million EUR)	6'687 3'429 - 10'075	2'892 1'483 - 4'357	38'858 20'042 - 58'469	21'615 11'148 - 32'523	4'170 2'101 - 6'319	2'216 1'117 - 3'357

	all three countries	
	Total costs with road traffic share	Costs attributable to road
Costs of mortality (million EUR)	36'524 22'102 - 51'149	19'622 11'875 - 27'477
Costs of morbidity (million EUR)	13'191 3'470 - 23'714	7'100 1'873 - 12'759
Total costs (million EUR)	49'715 25'572 - 74'863	26'723 13'748 - 40'236

The assessment of the costs is based on the so-called **willingness-to-pay approach**. The main characteristic of this approach consists in assessing both the material costs as well as the intangible costs. In summary, the surveyed populations are asked how much they value a reduction in air pollution related mortality and morbidity risk. In this sense, the willingness-to-pay for an increase in security or a decrease in material and intangible damage (costs) is assessed.

1 The resulting costs are based on a value of preventing fatality of 0.9 Million EUR. Under the assumption of a higher VPF of 1.4 million EUR (see chapter 3.3.1.6) the total costs (including morbidity) are 40% to 46% higher according to the country.

This integral consideration of material and intangible costs based on the WTP approach leads to a realistic estimation of the real costs or losses in utility that the air pollution related victims have to suffer.

Figure 5-2 presents the distribution of health costs between mortality and morbidity. **Predominant are the mortality costs**, amounting to 72% - 75% according to the country.

Being based on the same methodology, as for the economic valuation procedure as well as for the epidemiological exposure-response function, the similarity of results between the countries is not astonishing. The small differences are mainly due to the country specific differences in the base-line frequencies of the health outcomes observed.

Figure 5-2: Breakdown of air pollution related costs by mortality and morbidity

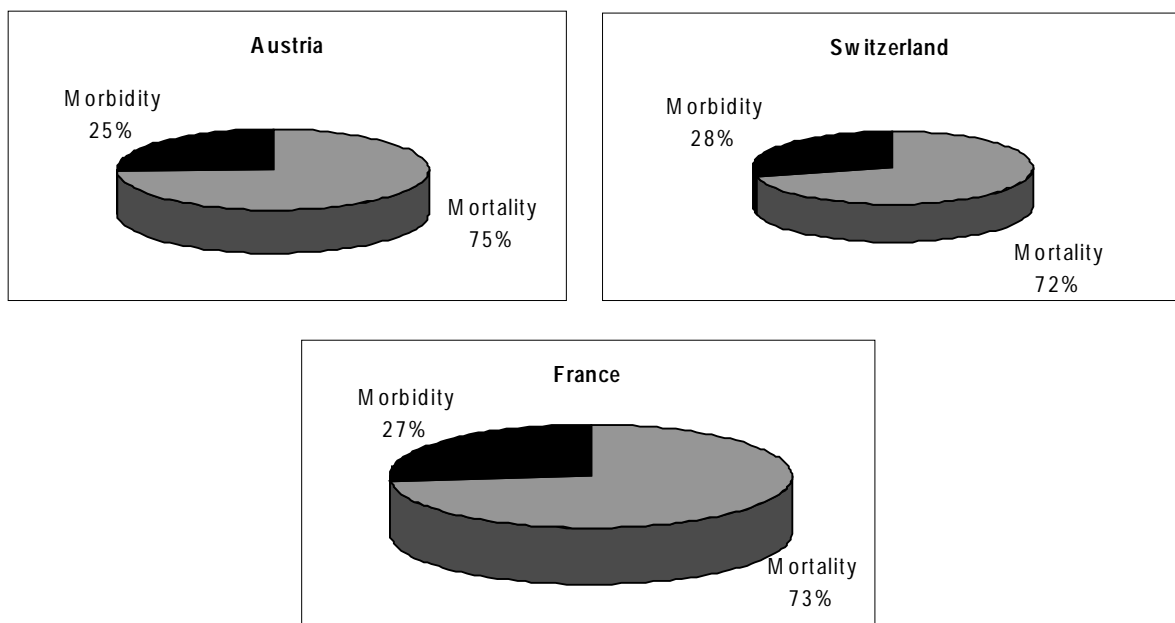
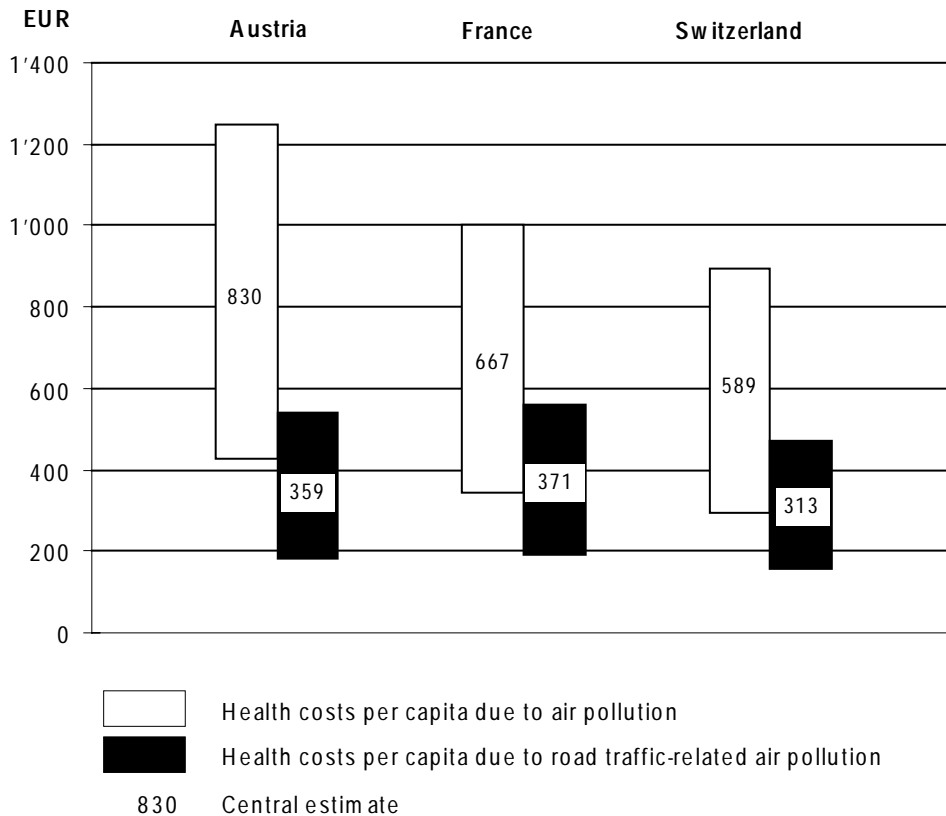


Figure 5-3 presents the air pollution related health costs per capita and allows a relative comparison between the three countries.

Figure 5-3: Air pollution related health costs per capita (1996)



Comparing the **total air pollution related costs per capita** 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 registered for Austria (425 - 1'250 EUR). This amount is 41% higher than in Switzerland (297 - 892 EUR per capita). In France, the annual average costs per capita amount to 344 - 1'004 EUR.

In all three countries, the monetary valuation of morbidity and mortality is based on the same economic methods. Therefore, the national differences result from epidemiological and air pollution related specificity:

- In fact, the highest population weighted annual PM_{10} exposure was estimated for Austria ($26.0 \mu\text{g}/\text{m}^3$) compared to the other countries (France: $23.5 \mu\text{g}/\text{m}^3$; Switzerland: $21.4 \mu\text{g}/\text{m}^3$).
- In addition, the incremental cases of premature mortality per each increase of $10 \mu\text{g}/\text{m}^3$ PM_{10} and per million inhabitants is somewhat higher in Austria (374 cases) compared to France (340 cases) and Switzerland (337 cases).

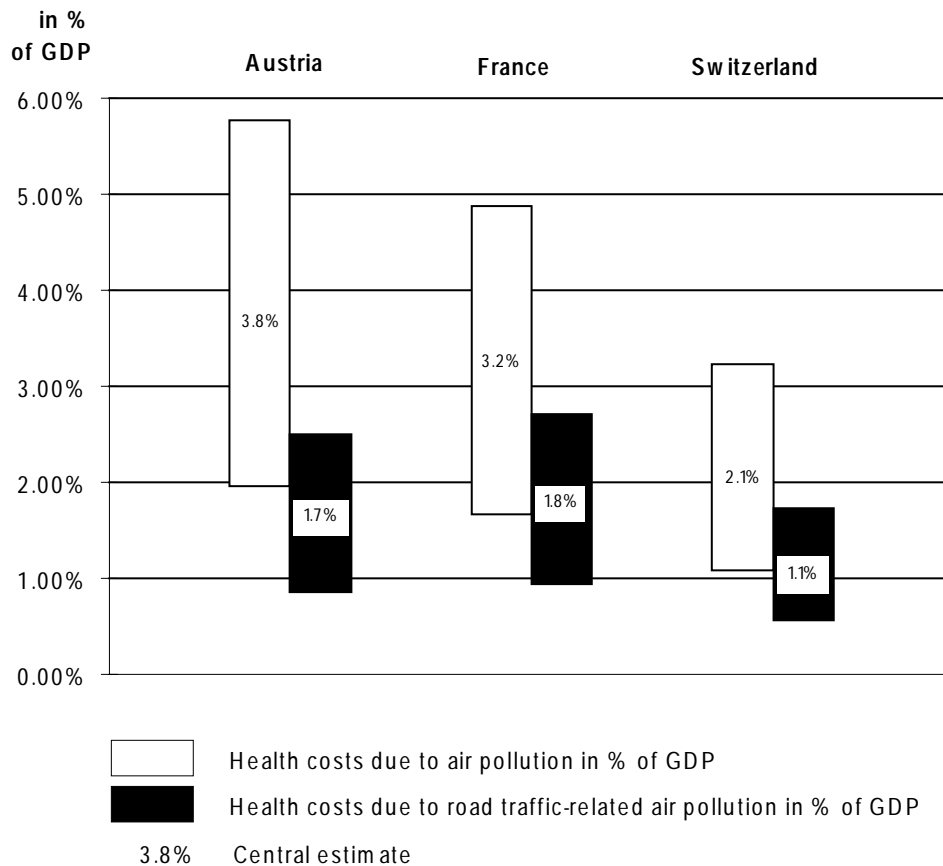
Both effects together lead to a higher level of air pollution related health costs.

Within the **road traffic-related health costs**, the difference in per capita costs between the three countries is lower. French values (191 - 588 EUR) are 19% higher than the Swiss (158 - 474 EUR) values and only 3% higher than the Austrian values (184 - 541 EUR). The relatively modest differences are due to the absolute level of the road traffic-related air pollution. The estimations

provide a mean road traffic-related concentration of $8.9 \mu\text{g}/\text{m}^3$ $\text{PM}_{10}^{(2)}$ in France, of $8.0 \mu\text{g}/\text{m}^3$ PM_{10} in Austria and of $7.4 \mu\text{g}/\text{m}^3$ PM_{10} in Switzerland.

Figure 5-4 compares the air pollution related health costs to the **gross domestic product (GDP)**.

Figure 5-4: Air pollution related health costs in percent (%) of GDP



In general, the results are quite similar to the comparison of per capita costs. The order of the countries results remains unchanged. In Austria the **total air pollution related health costs** amount to 2.0% - 5.8% of GDP, in France to 1.7% - 4.9% and in Switzerland to 1.1% - 3.2%.⁽³⁾

The **road traffic-related health costs** amount to 1.1% of GDP for Austria, 1.8% for France and 1.1% for Switzerland, whereas the **population weighted average** (across all three countries) amounts to **1.7%**.

2 As already mentioned, in absence of data the assessment of road traffic-related PM_{10} share in France had to be based on a Swiss repartition.

3 The comparison of the health costs due to air pollution (and costs of other negative impacts of the traffic like noise and accidents) with the gross domestic product (GDP) is often used in the economic literature. It allows to compare the situation between various countries and it gives an indication for the relevance of the costs. Of course one has to bear in mind, that health costs based on a willingness-to-pay approach includes cost components (pain, suffering, fear of disease and death), which are not considered in the gross domestic product.

5.1.2 Partial assessment approach: the air pollution related health costs based on gross production / consumption loss approach

According to the country specific needs, in addition to the WTP-approach a **partial assessment approach** has been used to evaluate the health costs. In Austria and France, the calculations of this partial assessment do not include any intangible cost components (such as pain, suffering, etc.). In Switzerland, the mortality cost estimate does include the intangible costs, but based on a much lower cost level than in the previous WTP assessment.

The partial assessment reduces the costs by a factor of 3.6 (in Switzerland) up to a factor of 9.1 (in France) compared to the willingness-to-pay based results. In Austria, the partial assessment results are six times lower than the WTP-values.

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.⁽⁴⁾ 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. Using the Swiss value in every country for example, leads to a ratio of 3 in Austria, 3.5 in France and still 3.6 in Switzerland

Slight differences in medical treatment costs between countries also play a part in these differences.

It is evident that the partial assessment of the air pollution related health costs is much lower than the results based on the WTP approach. Whereas the WTP-approach explicitly integrates the intangible costs, the latter are not taken into account in the partial assessment estimates at all (or are considered at a very low level in the case of Switzerland). Moreover, the willingness-to-pay approach values the Restricted Activity Days - which represent 20% of the total health costs - whereas the partial assessment method does not. Valuing those by the average gross production loss per day would more than triple the costs of morbidity based on the production loss approach.

Thus, these points have to be taken into account for the interpretation of the results.

4 See section 3.4. Austria uses a gross production loss approach and values a year of life lost at 20'600 EUR per year with a loss of life expectancy of 9.5 years, Switzerland adds to this value intangible costs estimated at 134'800 per life, that means 14'200 per year of life lost, hence leading to a total of 34'800 EUR. France uses the loss of consumption approach with a value of 12'600 EUR per year of life lost.

Table 5-5: Partial assessment of road traffic-related health costs (in 1996) based on the gross production / consumption loss approach

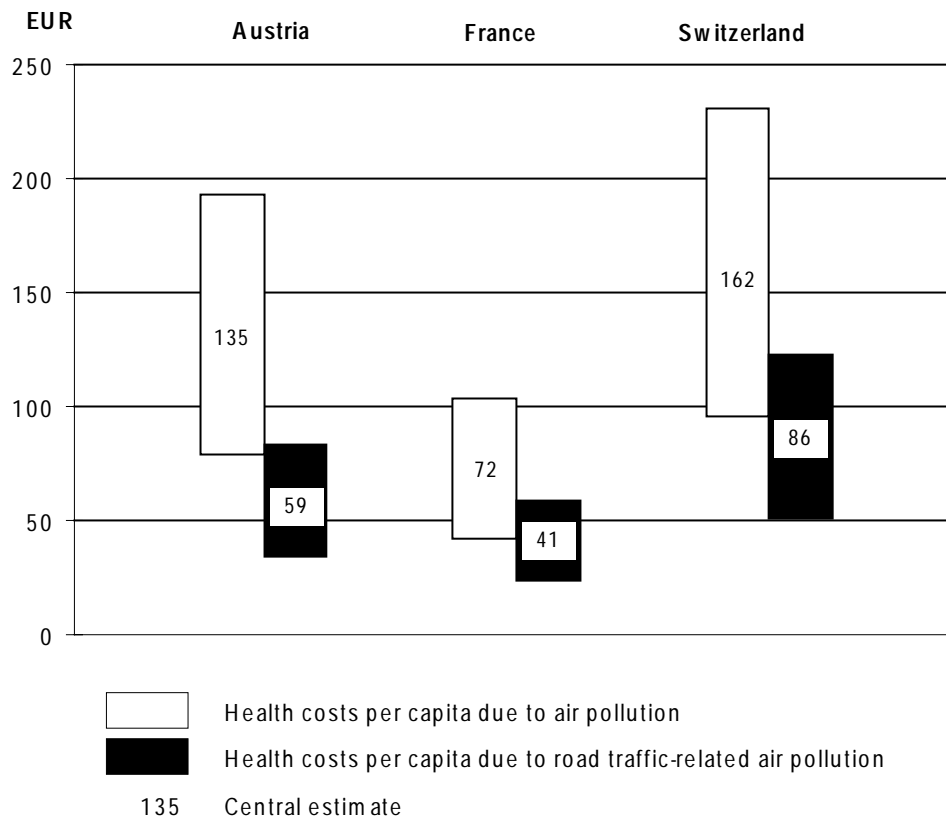
	Austria		France		Switzerland	
	Total costs with road traffic share	Costs attributable to road traffic	Total costs with road traffic share	Costs attributable to road traffic	Total costs with road traffic share*	Costs attributable to road traffic*
Costs of mortality (million EUR)	987 597 - 1'383	427 258 - 598	3'916 2'403 - 5'472	2'216 1'352 - 3'118	1'095 656 - 1'537	582 349 - 817
Costs of morbidity (million EUR)	105 38 - 174	45 16 - 75	297 75 - 534	165 42 - 297	55 18 - 93	29 10 - 49
Total costs (million EUR)	1'092 635 - 1'557	472 274 - 673	4'213 2'478 - 6'006	2'381 1'394 - 3'415	1'150 674 - 1'631	611 359 - 867

	Total	
	Total costs with road traffic share	Costs attributable to road traffic
Costs of mortality (million EUR)	5'999 3'656 - 8'393	3'225 1'959 - 4'533
Costs of morbidity (million EUR)	456 131 - 801	239 68 - 422
Total costs (million EUR)	6'455 3'787 - 9'194	3'465 2'027 - 4'955

* Including immaterial costs of mortality based on compensation payments granted by courts

Figure 5-7 also presents the per capita costs of the partial assessment for each country.

Figure 5-6: Partial assessment of air pollution related health costs per capita (1996), based on the gross production / consumption loss approach



From the above figure it follows that the partial assessments of (traffic-related) health costs in Austria and Switzerland are similar. Due to the methodological approach chosen in France, the partial assessment for this country is significantly lower.⁽⁵⁾

5 As mentioned above the differences between the countries are mainly based on the country specific calculation methods. See page 63 and Chapter 3.4 for description of these methods.

5.2 Interpretation of 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 1996, the health costs related to the total air pollution amount to 1.1%-3.2% (Switzerland), 1.7%-4.8% (France) and 1.9-5.5% (Austria) of the gross domestic product GDP. This is a magnitude which has to be considered as important. In comparison, the average growth in GDP during the last six years was in all three countries sometimes significantly below this level.⁽⁶⁾
- The road traffic is in all three countries 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.
- 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. 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 (see the following boxed discussion).

6 Average real growth rate of GDP between 1990-1996: Austria: 1.9%, France: 1.1%, Switzerland: -0.1%).

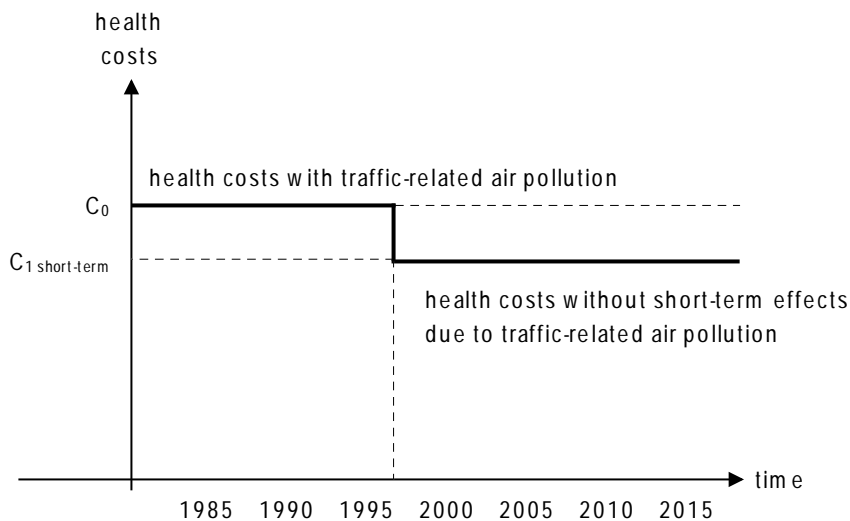
Digression: Reducing air pollution and the development of health costs in the short and long-term

Health effects due to air pollution occur with a certain time lag after emission of the pollutants. The delay is different for short-term effects and long term effects, and implies different interpretations of the cost due to (road traffic-related) air pollution.

Concerning short-term (or acute) effects, one can reasonably consider that a decrease in the level of air pollution (for our purpose, the suppression of the traffic related air pollution) immediately results in a decrease in the levels of the associated health variables and hence in health costs.

Figure 5-8 thus represents the level of short term health effects with and without traffic-related air pollution. The annual health costs saved, after the year of reduction (1996 in this example), are $C_0 - C_{1 \text{ short-term}}$.

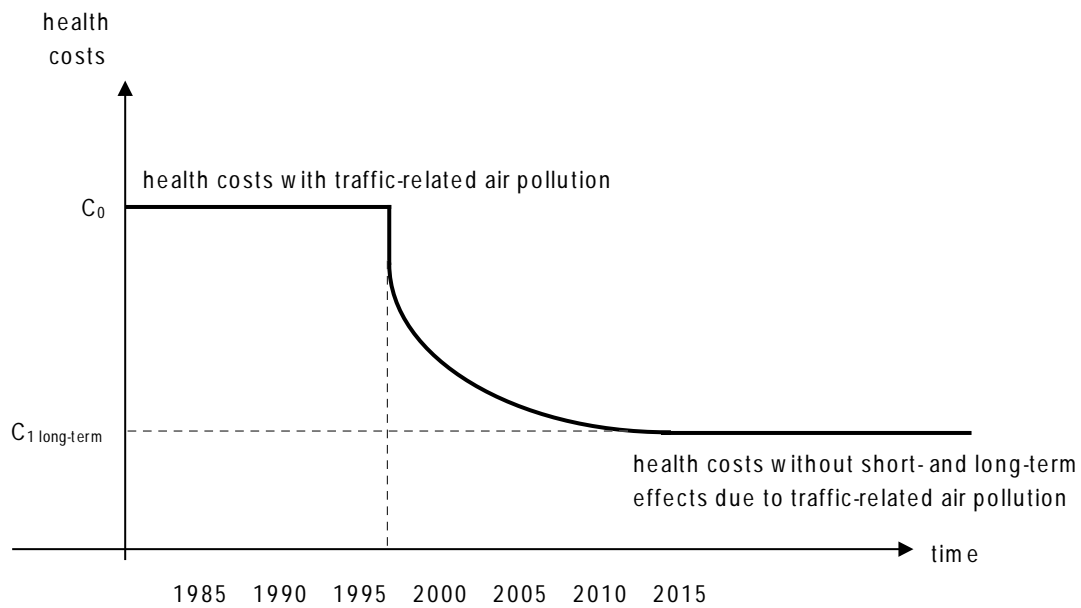
Figure 5-7: Evolution of short-term health costs after a reduction in 1996



Concerning long-term or chronic effects, a current reduction will fully produce its effects only several years later, due to the fact that the exposure is cumulative : health costs in year t_0 do not only depend on the emission of (and exposure to) pollutants in t_0 but are also determined by the pollution levels in the previous years $t_{-1}, t_{-2}, \dots, t_{-n}$.

If the traffic-related component of air pollution is suppressed in 1996, health costs would adjust to the level $C_{1 \text{ long-term}}$ after a certain number of years, when the entire population will have been exposed to this new level (as shown in figure 5-9). Thus, the annual health costs saved, after the year of reduction, are less than $C_0 - C_{1 \text{ long-term}}$, but a fraction of $C_0 - C_{1 \text{ long-term}}$ increasing with time up to $C_0 - C_{1 \text{ long-term}}$.

Figure 5-8: Illustrative representation of the evolution of short- and long-term health costs after a reduction in 1996



The required time window of exposure to induce long-term effects is not yet known. Therefore the time lag to fully profit from air pollution reduction can not be determined. Hence, it is not possible to compute the exact health costs in the transitional phase (1996 until annual health costs reached the level $C_{1 \text{ long-term}}$).

In the framework of this study it was therefore necessary to restrict the evaluation of the health costs to the long-term costs (or savings) due to an increase (or a reduction) in air pollution.

5.3 The validity and sensitivity of the results

The presentation of the range of the results indicates that the results rely necessarily on a set of assumptions and decisions that include a certain degree of uncertainty. As already mentioned in the introduction, critical assumptions were always based on the "at least" approach. Hence, the health costs presented must be interpreted as minimal costs. The real costs of transport-related air pollution are most probably significantly higher.

The road traffic-related health costs are dominated by the mortality costs and amount to 72 - 75% of the total costs (see Figure 5-2).

The sensitivity of the total results depends firstly of the cases of premature mortality and their costs. The following aspects have a special influence on the magnitude of these costs:

- the exposure of the population and the road traffic-related part of pollution
- the exposure-response function used for the assessment of air pollution related effects on health outcomes
- the applied cost factors for the monetary valuation of mortality risk.

a) PM₁₀ exposure of the population and the share attributable to road traffic⁽⁷⁾

The differences between the countries in the procedures for measuring airborne particles and in the availability of emission data made it impossible to define a single uniform method for calculating population exposure. There was an obvious need for adaptation of the general methodological framework to the individual case. The three countries were obliged to select different procedures depending on the available data.

The quality of the country specific models is checked by comparing modelled with measured values. This comparison shows that the quality is within the range that could be expected from the experience with dispersion and statistical models. The results of the PM₁₀ mapping show a tendency towards underestimation. This is in line with the selected „at-least“ approach of the overall project.

Many assumptions and estimations had to be done to calculate the PM₁₀ population exposure. The air pollution team judges the results of all three countries concerning the total PM₁₀ exposure as well as the road traffic share as the „best available estimate“ that could be obtained on the basis of the now available measurements and emission data. The differences of PM₁₀ population exposure between the countries are small and within the uncertainty range of the models.

b) Exposure-Response relationship to calculate the number of premature deaths due to air pollution⁽⁸⁾

The exposure-response function for mortality is based on two large prospective cohort studies from the US. Cohort studies are chosen for health impact assessment because they capture the total impact of pollution on „time to death“. The cohort studies report substantially larger effect estimates than indicated by daily time-series studies. This is explained by the fact that the cohort studies include premature death due to chronic morbidity enhanced by air pollution. The evidence of the cohort studies, however, is increased by the large number of international time-series studies showing consistent effects of short-term exposure on daily mortality, including data from France and Switzerland. Under consideration of design and quality of the US cohort studies, it was decided that they can be applied for this health impact project. Additional research on the impact of long-term exposure to air pollution is needed, particularly in Europe.

As to the application of these values to Austria, France and Switzerland, this is justified for several reasons.

7 For an detailed discussion, see Filliger P., Puybonnieux-Textier V., Schneider J. (1999), Health Costs due to Road Traffic-related Air Pollution, PM₁₀ Population Exposure.

8 For an detailed discussion, see Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases.

- The two American studies cover a range of exposure similar to that found in Austria, France and Switzerland.
- The relationship between air pollution and short-term mortality was demonstrated for France and Switzerland through different studies based on national data. The findings are entirely consistent with international findings, thereby confirming the fact that the dose-response relationship is applicable for low or medium levels of exposure.

In sum, it can be said that the exposure-response relationship used stems from qualitatively reliable studies. It is possible to transpose this relationship to Austrian, French and Swiss conditions without encountering methodological problems.

c) Valuation of mortality

In the present study, the main approach for the monetary valuation of mortality risk is based on the willingness-to-pay approach. This approach has a sound theoretical (welfare oriented) foundation and has the advantage, compared to other approaches, that it includes material costs (production or consumption loss) as well as intangible costs (pain, fear, suffering and grief) in its assessment.

In the framework of this study it was not possible to conduct empirical surveys on the willingness-to-pay for a reduction in air pollution related mortality risk. Therefore, the value of preventing a statistical fatality had to be based on existing studies. The chosen starting value of 1.4 million EUR per statistical fatality prevented was adopted from a scientifically well founded study of Jones-Lee. Its resulting value is comparatively low, since in other studies the valuation of air pollution related mortality risk is based on 3.1 million EUR or more.

Empirical studies have shown that the willingness-to-pay for a mortality risk reduction does decrease with increasing age. Therefore, in addition to the basic value of 1.4 million EUR in the main approach, a reduction to 0.9 million EUR per mortality case was chosen as second variant, taking into account that a considerable part of air pollution related victims are older than 75 to 80 years. The value of 0.9 million EUR per mortality case was used in the summary tables of this Chapter.

On the other hand, an increase in WTP based on the risk specific context was not adopted in the main approach, although there is various empirical evidence that air pollution related risk is less accepted (and would result in higher WTP values), since it is beyond the responsibility and control of the people affected by air pollution.

On the whole, one may conclude that the chosen approach provides values in the lower part of the empirical results and therefore presents an „at least“ approach.

Summarising: In the case of sensitive assumptions or data uncertainties the „at least“ approach was adopted in all three domains (air pollution, epidemiology and economy).

The health costs presented for the main methodological approach (Table 5-1) may be considered to be a conservative estimation of the real costs. The real costs are expected to be higher, since

- the different PM₁₀ related health effects (e.g. infant mortality) were not considered in the absence of available data;
- the additional effects of other pollutants (e.g. ozone) were not considered;
- for the monetary valuation generally prudent cost factors were chosen.

5.4 Recommendations

In general **public awareness** about the negative impacts of air pollution on health status has to be raised by providing access to respective information.

The magnitude of assessed health costs in the present study clearly indicates **a need for action**: not only making statements about the need for reducing air pollution **but defining objectives and setting a concrete time schedule** for their realisation is necessary. The reliability and the importance of this information is enough to justify such measures.

From an economic perspective the **polluters pay principle** comes to the fore: It has to be ensured that air pollution related health costs are covered by the polluter (participants in traffic, households, industry) and cannot be imposed on others or the community as a whole.

Imposing these costs on the polluter (in other words, internalising external costs) will create the necessary financial incentive for a reduction of activities causing air pollution (e.g. by using public transport modes more frequently instead of private cars or by using low emission vehicles) or for a further increase of avoiding measures (e.g. the use of filters in diesel engines or in industrial production facilities).

A further important measure is to **include air pollution related health costs in all cost-benefit analysis** of road infrastructure projects and of policy measures and actions which are directed against a further increase in traffic flows.

Of course, these avoiding and renouncing oriented measures are related to costs themselves. These costs have to be compared to the utility (the decreased health costs including the immaterial costs) in order to determine the optimal measure. For this task, the present study provides a necessary base: According to the monetarised health effects it can be shown to what extend long-term health costs may be reduced when air pollution is reduced.

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6 Open questions and future areas of research needs74

6 Open questions and future areas of research needs

In the economic field, the open questions and the corresponding needs for further research can be summarised as follows:⁽¹⁾

a) **Empirical survey of the willingness-to-pay (WTP) for a reduction in air pollution related mortality and morbidity risks**

In chapter 3 and 4 the advantages and disadvantages of the assessment of air pollution related mortality and morbidity with different methods (willingness-to-pay versus production loss or consumption loss) were discussed extensively. It was shown that from a methodological point of view, the WTP-approach offers undoubtedly several advantages.

In contrast to the production loss approach, the WTP-approach offers the possibility to assess in addition to the material costs (e.g. loss of production, treatment costs) also the intangible costs (pain, suffering, fear and loss of life quality). These costs are according to the different health outcomes at least as significant or even more important than the material costs.

The WTP-approach also has the advantage that it is based on a sound theoretical foundation of welfare economics, since the cost evaluation is based on the individual valuations of a reduction in health risk.

However, in practical application it has to be admitted that the extent of this individual valuation is subject to a high degree of uncertainty. Particularly missing are those empirical surveys that:

- concentrate on the European context
- cover the special circumstances of air pollution related risk (which is to a large extent involuntary and beyond the control and responsibility of those exposed to it)
- consider the fact that air pollution related health outcomes manifest themselves to a considerable part with the elderly.

Thus, empirical surveys on the willingness-to-pay for a reduction in air pollution related health risks are for most of the European countries urgently needed. In such studies, the methodological design has to focus specially on the validity and the reliability of results. Empirical surveys are necessary for mortality and morbidity. The following aspects need to be considered in particular:

1 For open questions and research need in the domain of air pollution and epidemiology, see the corresponding technical reports:

Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases; Filliger P., Puybonnieux-Textier V., Schneider J. (1999), Health Costs due to Road Traffic-related Air Pollution, PM₁₀ Population Exposure.

- Studies on the **WTP for a reduction of air pollution related mortality**
 - The risk context related to: Is it true, as presumed, that the air pollution related mortality risk is much less accepted than, for example, the road accident related risk? Does this lead to a higher willingness-to-pay and to what extent?
 - Age and life expectancy: how does the willingness-to-pay change with increasing age of the respondents? Which influences of the remaining life expectancy may be observed?
 - To what extent does the willingness-to-pay correlate to socio-cultural influences of the awareness and acceptance of risk?

- Studies on the **WTP for a reduction of air pollution related morbidity**
 - Health outcomes assessed: The WTP survey has to contain those health outcomes that are specially correlated with air pollution:
 - Cost components assessed: It needs to be clarified, which cost components of the respondents need to be considered (only intangible costs or also individually borne treatment costs and costs of lost income). In regards to a possible combination of the WTP-approach with the cost of illness approach, a survey should only contain the intangible costs.⁽²⁾
 - The risk context related to: For the factors of age and the socio-cultural differences in risk acceptance, the same requirements are needed as in the case of mortality assessment.

As mentioned above, the WTP surveys need to be conducted for several European countries in order to reflect the country specific context (e.g. social insurance systems and health systems) as well as the cultural differences. In order to reach this goal, a co-ordinated procedure based on a similar survey design is necessary.

b) Age structure of the victims

As discussed extensively in chapter 3, WTP values for the mortality risk reduction depend also on the age of the surveyed person. In the same way, the production loss and the consumption loss depend on the age and on the average life expectancy of the victims.

In the context of this study, no explicit information about the age structure of air pollution related mortality was available from epidemiological studies. In order to calculate the costs, together with the epidemiological team, assumptions about the age distribution of the victims had to be developed. Based on the epidemiological evidence that air pollution related mortality occurs mostly in relation to respiratory and cardiovascular disease and lung cancer, the calculations were based on the age structure of these health outcomes. For a future assessment of the health costs, the underlying hypothesis needs to be verified by empirical evaluations of the age structure of air pollution related mortality.

2 As explained in chapter 4, WTP normally covers only the individually borne costs. According to the institutional context, treatment costs and costs of production loss that are to a different extent not covered by the victims but by insurance payments, are mostly not contained in the answers about WTP values (see graph 4-1). In order to cover the total health costs, a combination of the WTP-approach with the cost of illness approach (treatment costs and costs of production loss) has to be considered. In order to avoid double counting, this needs a WTP valuation that only covers the intangible cost components.

c) The evaluation of absence from work related to different health outcomes

In estimating the morbidity costs, it has been shown that for different health outcomes (chronic bronchitis, bronchitis, restricted activity days, asthma) the necessary information about the related absence from work is missing. Thus, a quantification of the production loss of these health outcomes had to be abandoned. A future assessment of air pollution related health costs should not neglect this production loss any longer, since it might be substantial especially for severe cases of chronic bronchitis (eventually with invalidity) and for the large number of restricted activity days. However, this demands that for single health outcomes empirical evaluations about the absence from work are to be conducted.

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7 Annex: New Research Results on the Valuation of Preventing Fatal Road Accident Casualties⁽¹⁾

An Article of Susan Chilton, Judith Covey, Lorraine Hoppkins, Michael Jones-Lee, Graham Loomes, Nick Pidgeon, Anne Spencer

7.1 The Rationale for Willingness-to-pay Based Monetary Values of Safety

Two hard facts confront those who have to make decisions about the level of provision of public safety. First, safety is usually not costless; and second, society has limited resources. Consequently, a responsible decision about any proposed public safety improvement will require a judgement as to whether the resultant reduction in risk is worth more than the other good things that could be provided if the resources required to implement the safety improvement were diverted elsewhere.

How easily can such a judgement be made? Intuitively, most of us might agree that a safety improvement that is expected to prevent a number of premature deaths, but which would cost just a few thousand pounds, would be well worth it. Equally, most people would probably feel that if it would cost several millions of pounds to prevent, at best, only a few minor injuries, then there would be many better ways to spend the money. In more typical less extreme cases, however, the decision may not be quite so straightforward.

Clearly, if it were possible to obtain an acceptable measure of the *monetary value of safety*, then this would go a long way towards resolving the difficulty. Given such a measure, safety improvement benefits could be weighed explicitly against other costs and benefits - such as capital costs and time savings - in reaching a decision for or against any particular safety project. Indeed, without an explicit measure of the monetary value of safety, serious inconsistencies are likely to emerge in the decision-making process. But how do we arrive at such monetary values of safety?

The key to this question is that members of the public not only stand to benefit from improved public safety, but also ultimately *pay* for it (either directly through, say, fares on public transport, or indirectly through taxation). Thus, if social decisions are to take account of the preferences of those who will be affected by these decisions then values of safety should reflect the rate at which members of the public are willing to trade off safety against other desirable things that might be purchased. In short, there is a very persuasive case for basing values of safety for use in public sector project appraisal on people's *collective willingness to pay for it*.

So, under this "willingness-to-pay" (WTP) approach to the valuation of safety we should ideally like to discover how much members of the public would be willing to pay for improvements in their own (and possibly other people's) safety. The total sum elicited would then be a clear reflection of what the safety improvement was worth to people in the affected group, relative to alternative ways in which they could have spent their limited incomes.

Of course it might be objected that the values of safety that emerge from this approach will

1 In addition to the authors, others who have contributed to the research reported in this article are Jane Beattie (who sadly died in March, 1997) Trevor Carthy, Paul Dolan and Angela Robinson.

tend to be lower for groups of people with below average incomes and higher for those who are better off. It is essentially for this reason that most advocates of the WTP approach would recommend the application of *uniform* values of safety, reflecting the aggregate willingness to pay of a *representative sample* of the population as a whole.

7.2 Estimating WTP-Based Values of Safety

Consider a road safety improvement that is expected to reduce the number of premature deaths during the coming year by *one* for every 100,000 members of a given population. Notice first that the safety improvement would reduce each person's risk of premature death during the coming year by an average of 1 in 100,000. Now suppose that members of the population concerned are, on average, each willing to pay £*v* to effect the safety improvement. This means that for each death prevented, there are 100,000 people willing, between them, to pay £*v* × 100,000. On this basis, the WTP-based "value of preventing a fatality" (VPF) for road project appraisal is simply £*v* × 100,000.⁽²⁾

Clearly, in the above example, average individual willingness to pay, £*v*, for the average individual risk reduction of 1 in 100,000 is a reflection of the rate at which individuals in the group concerned are willing to trade off wealth against risk, so that empirical work on the valuation of safety tends to focus upon these individual wealth/risk trade-off rates.

Broadly speaking, two types of empirical estimation procedure have been employed to derive WTP-based values of safety. These are known respectively as the "revealed preference" (or implied value") and the "contingent valuation" (or "expressed value") approaches. Essentially, the revealed preference approach involves the identification of situations in which people actually do trade off income or wealth against physical risk - for example, in labour markets where riskier jobs can be expected to command clearly identifiable wage premia. By contrast, the contingent valuation approach involves asking a representative sample of people more or less directly about their willingness to pay for improved safety, (or, sometimes, their willingness to accept compensation for increased risk).

The problem with the revealed preference approach when applied to labour market data is that it depends on being able to disentangle risk-related wage differentials from the many other factors that enter into the determination of wage rates. The approach also presupposes that workers are well-informed about the risks that they actually face in the workplace.

By contrast, the contingent valuation approach allows the researcher to go directly and unambiguously to the relevant wealth/risk trade-off - at least, in principle. On the other hand, the contingent valuation approach has the disadvantage of relying upon the assumption that people are able to give considered and accurate answers to hypothetical questions about typically small changes in already very small risks.

2 An alternative but equivalent way to calculate the VPF is to appreciate that if a total of *N* people are affected by the safety improvement, then the overall number of fatalities prevented will be $N \div 100,000$. In turn, total willingness to pay will be £*v* × *N*, so that aggregate willingness to pay *per fatality prevented* is again given by £*v* × 100,000.

7.3 The Current DETR Value for the Prevention of a Road Fatality

Since 1988 the Department of Transport (DoT) - now the Department of the Environment, Transport and Regions (DETR) - has used a value for the prevention of a road accident fatality based on the willingness-to-pay methodology. This VPF is now well-established and is used by other departments as the starting point for the valuation safety. However this value, currently £848,000 in 1996 prices, is not the result of a single study but is an update of a “consensus” figure arrived at in 1988 following a comprehensive review of the then-existing WTP empirical literature, followed by a period of consultation with experts in this field. The literature showed a wide range of empirical estimates and the value chosen, £500,000 in 1987 prices, was set at the lower end of this range in order to temper a radical change of methodology (i.e. adoption of the WTP approach in place of the former output loss-based methods) with an element of caution.

Subsequent research carried out by some of the authors of this article established WTP-based values for the prevention of non-fatal casualties, linked to the roads VPF. Full accounts of the research and the Department’s methods have been published by the Transport Research Laboratory.⁽³⁾

The importance of the DETR VPF, which is widely used in cost-benefit analysis in the transport context and in other areas, led to consideration of reassessing the value within the context of a broader safety valuation study, as described in the next section.

7.4 The HSE/DETR/HOME Office/Treasury Project

Given that WTP-based values of safety are intended to reflect the preferences of members of the public, it is clearly possible that these values will vary from one hazard context to another, reflecting differing degrees of dread at the prospect of death or injury in different circumstances, together with differing perceptions of the extent of voluntariness, control, responsibility, etc., associated with different kinds of risk. For example, many people view the risks arising from nuclear power generation as insidious, involuntary, outside their own control, poorly understood and the responsibility of other people. By contrast, the risks associated with sporting and recreational activities are mostly perceived to be essentially voluntary, more controllable, well-understood and largely one’s own responsibility. It would therefore not be surprising if the WTP-based VPF for nuclear power generation were to be (possibly substantially) higher than its counterpart for sporting and recreational activities.

In view of the possible “non-transferability” of WTP-based values of safety, in 1995 the HSE, in conjunction with the (then) DoT, the Home Office and the Treasury, commissioned a programme of research - to be undertaken by the Universities of Newcastle upon Tyne, York, Sussex and Bangor - aimed at estimating a “tariff” of WTP-based values of safety for a number of different contexts. As part of this project, it was decided to use some form of the contingent valuation approach in order to re-estimate the DETR WTP-based roads VPF. However, given the difficulties people tend to have in dealing with the money/risk trade-offs involved in direct contingent valua-

3 See, for example, Jones-Lee, M., Loomes, G., O’Reilly, D., and Philips, P. *The Value of Preventing Non-Fatal Road Injuries: Findings of a Willingness-to-Pay National Sample Survey*. TRL contractor Report 330, Crowthorne, Transport Research Laboratory.

tion questions, it was necessary to conduct an extensive programme of piloting prior to carrying out a roads VPF main study.

During early piloting, the research team devoted a good deal of attention to a problem which is quite common in contingent valuation studies, namely a tendency for an uncomfortably large proportion of respondents to be insufficiently sensitive to the size of the risk reduction under consideration. In particular, in each of two phases of piloting, approximately 40% of respondents reported *identical* willingness to pay for two risk reductions, one of which was three times as large as the other. In addition, a further 40% reported a willingness to pay for the larger risk reduction that was only between one and two times their willingness to pay for the smaller risk reduction. The problem this causes is that the estimate of the VPF derived from one set of responses is liable to be significantly different from the estimate derived from the other set of responses, even though both sets come from the same sample of people.

For example, suppose that the average stated willingness to pay for a risk reduction of 1 in 100,000 is £25, on which basis the VPF would be $£25 \times 100,000 = £2.5\text{m}$. But suppose that the average stated willingness to pay for a risk reduction of 3 in 100,000 is only a few pounds more - say, £30. Since this £30 per head is to prevent *three* deaths for every 100,000 people, it works out at £10 per head for each death prevented - i.e. a VPF of $£10 \times 100,000 = £1\text{m}$. So if individuals' responses to survey questions are insensitive to the difference between two rather small risk reductions, we can end up with very different VPFs, depending upon which size(s) of risk reductions the researchers happen to present to people. Clearly, such disparities in the VPF can lead to very different conclusions concerning the attractiveness of any given safety project or the desirability of one project relative to another.

What gives rise to this insensitivity? Listening to tape recordings of individual interviews and follow-up focus group meetings suggests: (a) that many people find the risk reductions so small that they are difficult to get a real "feel" for, so that this information tends to be marginalised; (b) that this is compounded by the fact that *any* safety improvement is seen as a "good thing", with the precise magnitude of the risk reduction being treated as of only secondary importance (and in some cases, no importance at all); and (c) that when considering how much this "good thing" is worth, many respondents simply report an amount which, if foregone, would not seriously disrupt their normal expenditure and savings patterns - which for many people seems to be a sum in the region of £50-£200 per annum.

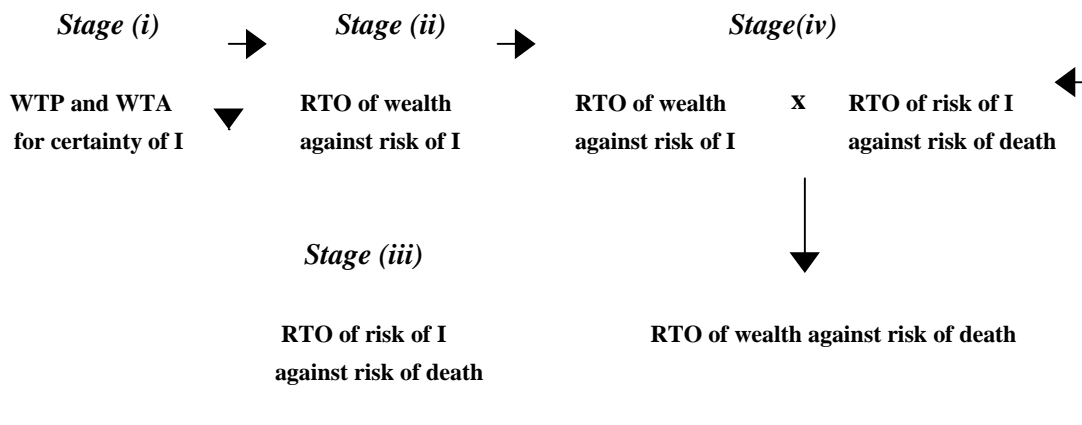
All this suggested that in order to obtain more robust estimates of WTP-based values of road safety it would be necessary to proceed in a less direct, more highly structured way, breaking down the money/risk trade-off into less daunting, more manageable steps. Subsequent piloting therefore aimed to refine an approach which essentially involved four stages, namely:

- (i) Respondents were first presented with contingent valuation questions designed to elicit (a) their willingness to pay (WTP) for the *certainty* of a quick and complete cure for a particular *non-fatal* road injury, I, of lesser severity, and (b) their willingness to accept compensation (WTA) for the certainty of sustaining the same injury.
- (ii) On the assumption that a respondent's underlying preferences obey minimal conditions of consistency and regularity, these WTP and WTA responses can then be used to infer the broad order of magnitude of the rate at which the person concerned is willing to trade off wealth against risk of the non-fatal road injury, I.⁽⁴⁾

4 In fact, it can be shown that an individual's rate of trade-off of wealth against risk of the non-fatal injury, I, can be

- (iii) Respondents were then presented with a question aimed at eliciting their willingness to trade off risk of the non-fatal injury, I, against the risk of death.
- (iv) Finally, the estimated rate of trade-off of wealth against risk of the non-fatal injury derived from stage (ii) is “chained” to the “risk-risk” trade-off results obtained at stage (iii) in order to infer the respondent’s implicit rate of trade-off of wealth against risk of death.

In summary, denoting a rate of trade-off by RTO, the four-stage approach can be represented schematically as follows:



This four-stage approach has several advantages over the procedure that was employed in the first two pilot studies. In stage (i), the contingent valuation questions, as such, relate to a non-fatal injury of a type that most respondents can more readily conceptualise on the basis of their past experience of injury and illness. Moreover, these questions do not require respondents to trade off money directly against risk. To the extent that respondents *are* required to think about risk, the task involved in the “risk-risk” question in stage (iii) is framed entirely within the domain of physical risk and is therefore a comparison of “like with like” - and is similar in principle to the kind of judgement entailed by many decisions about health care treatments which are intended to improve people’s health, but carry at least some risk that the patient could end up worse off.

Later pilot work on the four-stage approach suggested that the vast majority of respondents found the various questions much more manageable than appears to have been the case with the direct money/risk of death trade-offs in the earlier pilot study questions. In addition, responses showed clear evidence of sensitivity to variations in the severity of the non-fatal injury to which the questions related, as well as evidence of a broadly acceptable level of internal consistency.

On this basis, a main study was carried out during the latter half of October and the first half of November, 1997 and involved a quota sample of 167 respondents selected by professional market research organisations on the basis of gender, age and social class quotas specified by the research team to reflect OPCS national breakdowns. The sample was drawn from Newcastle (45 respondents), York (43 respondents), Brighton (54 respondents) and Bangor (25 respondents) and

expressed as a *weighted average* of the WTP and WTA responses elicited at stage (i), with the relative weights depending on the structure of the individual’s underlying preferences and attitudes to risk. The research team therefore explored the implications of various different assumptions concerning these preferences and attitudes and based its estimates of the rate of trade-off on a range of representative “middle cases”. Details of the argument, which is somewhat technical, are available from the authors on request.

interviews were conducted on a one-to-one basis by members of the research team.

On the whole, the main study findings point towards a roads VPF (including an allowance of some £65,000 for avoided net output losses and medical and ambulance costs)⁽⁵⁾ in a range from about £500,000 to £1,500,000. As tends to be the case in this sort of study, the distribution of individual responses is widely spread, with implied wealth/risk trade-off rates differing (often substantially) from one respondent to another. In addition, while the majority of respondents are located at the lower end of the distribution, a minority at the upper end have very high rates of trade-off (i.e. in statistical parlance, the distribution is heavily “skewed to the right”). In view of this, it is not surprising that the median (or middle) response is substantially smaller than the mean (or average), with the roads VPF based on the median in the region of £500,000 and the figure based on the mean in the £1,000,000 to £1,500,000 range⁽⁶⁾.

To the extent that aggregate willingness to pay for safety is reflected in mean rather than median responses, there is clearly a case for placing somewhat more emphasis on the range of VPFs entailed by mean responses. On the other hand, there is an argument that, if anything, people’s responses to hypothetical willingness-to-pay questions may overstate what they would *actually* be prepared to pay, which would suggest giving at least some weight to the median response. Thus, all things considered, any figure in the range £750,000 to £1,250,000 could be regarded as being broadly acceptable. This range clearly encompasses the current DETR value of about £850,000, so that the research reported in this article provides a broad endorsement of the DETR figure and no change in the latter is recommended.

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5 An individual’s net output is defined as the excess of his or her gross-of-tax lifetime output over and above lifetime consumption. To the extent that individual willingness to pay for safety tends not to reflect avoided losses of net output or avoided medical and ambulance costs, (and hence avoided losses to the rest of society) it is necessary to add an allowance for these avoided losses, to “raw” WTP-based figures.

6 The range for the mean reflects alternative assumptions concerning the structure of underlying individual preferences and attitudes to risk. As far as the figures based on means are concerned, it should be noted that these have been calculated with the two most extreme responses at the upper end of the distribution trimmed out. This was done because these responses were *very* much larger than the rest, giving rise to serious doubts about their reliability, especially as they may well be the result of a compounding of errors in the four-stage estimation process. In addition, in computing means it was also necessary to omit a few cases in which responses to the “risk-risk” trade-off question, literally interpreted, did not allow finite wealth/risk trade-off rates to be computed.

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9 List of Abbreviations and Glossary

9.1 List of abbreviations

ADEME	Agence de l'Environnement et de la Maitrise de l'Energie
BMAGS	Bundesministerium für Arbeit, Gesundheit und Soziales (Austria)
BTS	Bureau for Transport Studies, Federal Department of Environment, Transport, Energy and Communications (Switzerland)
CO	carbon monoxide
COI	cost of illness
COPD	chronic obstructive lung disease
CORINAIR	Core Inventory of Air pollutants
GIS	Geographical Information System
GREQAM	French National Centre for Scientific Research (Quantitative Economic Research Team)
ICD	International Classification of Diseases
InVS	Institut de Veille Sanitaire (France)
ISPM	Institut für Sozial- und Präventivmedizin der Universität Basel (Institute for Social and Preventive Medicine, Basle University)
$\mu\text{g}/\text{m}^3$	micrograms per cubic meter
NACE	Nomenclature des Activités économiques de la Communauté Européenne
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_3	ozone
SAEFL	Swiss Agency for the Environment, Forests and Landscape
PM_{10}	Particulate matter with an aerodynamic diameter of 10 μm or less (more precisely, particles which pass through a size selective inlet with a 50 efficiency cut-off at 10 μm aerodynamic diameter). PM_{10} is the thoracic fraction (particles that pass the larynx) of the particulate matter in the atmosphere.
SAPALDIA	Swiss Study on Air Pollution and Lung Diseases in Adults
SCARPOL	Swiss Study on Childhood Allergy and Respiratory Symptoms with respect to Air Pollution
SNAP	Selected Nomenclature of Air Pollutants
SO_2	sulfur dioxide
TEOM	Tapered Element Oscillating Microbalance
TSP	Total Suspended Particulates
UBA	Umweltbundesamt (Federal Environment Agency Ltd., Austria)
VPF	value of preventing a statistical fatality
WHO	World Health Organisation
WTP	willingness-to-pay

9.2 Glossary

AI Code	List prepared by the Swiss Disability Insurance Fund to classify cases of disability by cause of illness. The AI Code is not identical with the ICD Code.
Asthma	The respiratory tract of patients with this ailment is highly sensitive to a wide variety of irritations. A narrowing of the bronchial tubes following a contraction and an abundant release of bronchial secretions trigger particularly severe attacks of dyspnoea as well as coughing fits and sputum of very viscous phlegm.
Baseline frequency	Frequency with which a health indicator appears in a population for a defined “basic pollution level” (for example, 10 µg/m ³ of PM10).
Beta attenuation	Measurement principle used in automated PM monitors. Is based on the attenuation of beta-radiation by the sample.
Bronchitis	Irritation of the bronchial tubes, which together with the bronchioles (the smallest ramifications) and the trachea form the system which conveys air to the lungs. The acute inflammation of the bronchial tubes usually occurs in the course of illnesses associated with colds.
Chronic bronchitis	A chronic inflammation of the bronchial tubes is diagnosed when there is “coughing and sputum on most days for a period of at least three months for two consecutive years”. The essential feature observed in the course of the illness over several years is the presence of periods of <i>exacerbation</i> .
COPD	Generic term for chronic obstructive pulmonary diseases, such as chronic bronchitis, pulmonary emphysema or asthma.
Effect estimate	Index to describe the effects of air pollution on certain health outcomes. In this study, the effect estimates indicate the relative variation (in percent) of the health risk per 10 µg/m ³ of pollution.
Emissions	Emanations of pollution at the source.
Epidemiology	Study of the analysis of the distribution of illnesses, physiological variables and social consequences of illnesses in human population groups, as well as factors influencing this distribution (WHO definition).
Exacerbation	Acute inflammatory episodes in the course of <i>chronic bronchitis</i> which increasingly damage the functioning of the lungs.
External costs	Costs borne not by those responsible for them, but by others.
Exposure-response	Quantified relation between air pollution exposure and health outcome; see effect estimate.
Health outcome	Indicator of an adverse effect on health as a consequence of air pollution exposure
Gaussian model	Model to estimate the dispersion of pollutants in the atmosphere
ICD9 Code	International Classification of Diseases: list of illnesses, causes of death

and illnesses published by WHO (1997, in 9th revision), on the basis of which, *inter alia*, statistics on the causes of death are compiled.

Internal costs	Costs borne by those responsible for them.
Incidence	Index of new illnesses: the number of new cases per unit of time (usually one year) in a defined population as a proportion of that population.
Morbidity	Measure of the frequency of an illness in the population without distinguishing between incidence and prevalence.
Mortality	Number of persons who died in a population as a proportion of that population.
Off-road transport	All fuel-burning mobile sources not used on roads (for example, building machinery, agricultural and forestry vehicles, as well as air, shipping and rail transport).
Prevalence	Number of cases of a given illness at a specific time as a proportion of number of inhabitants.
Receptor studies and models	Analysis of samples of particles with a view to determining the pollutant sources; different from dispersion models, in which concentrations are calculated on the basis of emission data on (wind-borne pollution).
Social costs	Sum of <i>internal</i> and <i>external</i> costs. This corresponds to the total (social) costs to the national economy incurred as a result of a given activity.

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