WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR EUROPE

WELTGESUNDHEITSORGANISATION
REGIONALBÜRO FÜR EUROPA

ORGANISATION MONDIALE DE LA SANTE
BUREAU REGIONAL DE L'EUROPE

ВСЕМИРНАЯ ОРГАНИЗАЦИЯ ЗДРАВООХРАНЕНИЯ
ЕВРОПЕЙСКОЕ РЕГИОНАЛЬНОЕ БЮРО

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
London June 1999

Synthesis Report

Prepared on behalf of the tri-lateral research team
of Austria, France and Switzerland

Rita Seethaler

Federal Department of Environment, Transport, Energy and Communications, Berne, Switzerland

ADEME

Direction de l'Air et des Transports
France

Austrian Federal Ministry of Environment, Youth and Family Affairs

Umweltbundesamt
Federal Environment Agency – Austria

Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation
Département fédéral de l'Environnement, des Transports, de l'Energie et de la Communication
Federal Department of Environment, Transport, Energy and Communications

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.

Published by

Federal Department of Environment, Transport, Energy and Communications
Bureau for Transport Studies

Kochergasse 10, CH-3003 Bern, Switzerland

June 1999

Bezugsquelle / Source of supply:

Eidg. Drucksachen- und Materialzentrale (EDMZ)
CH-3000 Bern

Bestellnummer / Order number: 801.633e

(GVF-Bericht 1/99)

Project co-ordination and Steering committee:

Dora Carlos, Dr.	World Health Organization, Rome Division, Italy
Thaler Robert, Dipl. Ing.,	Federal Ministry for Environment, Youth and Family Affairs, Division I/5, Transport, Mobility, Regional Planning and Noise, Austria
Morcheoine Alain, Dipl. Ing.	ADEME Agency for Environment and Energy Management, Air and
Elichegaray Christian, Dr.	Transport Direction
Herry Max, Dr.	Consultancy Dr. Max Herry, Austria
Seethaler Rita, lic. rer. pol.	Federal Department of Environment, Transport, Energy and Communications, Bureau for Transport Studies, Switzerland
Sommer Heini, Dr. rer. pol.	Ecoplan, Economic and Environmental Studies, Switzerland

Project Teams:

Air Pollution

Ba Mohamédou, PhD student (F)
Baumann Ruth, Dr. phil. (A)
Elichegaray Christian, Dr. (F)
Filliger Paul, Dr. phil. nat. (CH)
Frangi Jean-Pierre, Dr. (F)
Heldstab Jürg, Dr. phil. nat. (CH)
Morcheoine Alain, Dipl. Ing. (F)
Puybonnieux-Texier Valérie, PhD student (F)
Schneider Jürgen, Mag. Dr. rer. nat. (A)

Epidemiology

Horak Friedrich, MD (A)
Kaiser Reinhard, MD MPH (CH/F)
Künzli Nino, MD PhD (CH)
Medina Sylvia, MD MSc (F)
Oberfeld Gerd, MD (A)
Quenel Philippe, MD PhD (F)
Studnicka Michael, MD MSc (A)

Economy

Chanel Olivier, Dr. (F)
Herry Max, Dr (A)
Martinez, Nathalie, Dr. (F)
Masson Serge, PhD student (F)
Molterer Jutta, Mag. (A)
Scapecchi Pascale, PhD student (F)
Sedlacek Norbert, Dipl. Ing. (A)
Seethaler Rita, lic. rer. pol. (CH)
Sommer Heini, Dr. rer. pol. (CH)
Thaler Robert, Dipl. Ing (A)
Vergnaud Jean-Christophe, Dr. (F)

External Co-referees

Air Pollution:	Eerens Hans, Dr., National Institute of Public Health and the Environment (RIVM), Bilthoven, The Netherlands
Epidemiology:	Krzyzanowski Michal, Dr., WHO European Centre for Environment and Health, Bilthoven Division, The Netherlands
Economy:	Jones-Lee Michael, Prof. Dr., Centre for the analysis of safety policy and attitudes to risk, Department of Economics, University of Newcastle, UK
	Dubourg Richard, Dr., Centre for social and economic research on the global environment, University College London, UK

This project was co-financed by

- the Austrian Federal Ministry for Environment, Youth and Family Affairs within the Austrian activities as lead-country for the preparation of the Transport, Environment and Health segment for the WHO Ministerial Conference on Environment and Health in London 1999. The project was co-ordinated with the Austrian Federal Ministries for Labour, Health and Social Affairs as well as for Science and Transport and the Austrian Medical Association.
- the Federal Environment Agency of Austria
- the Agency for Environment and Energy Management ADEME, Air and Transport Direction, France
- the Federal Department of Environment, Transport, Energy and Communications, Switzerland

Table of Content

Executive Summary

In preparation for 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. This 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 transport (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 the PREDIT towards international co-operation.

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 damage, traffic jams, etc. 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.

In the present tri-lateral project, information about air pollution related effects on human health and the share of traffic-related air pollution was assessed by integrating data on air pollution, epidemiology and economy. The tasks of the three domains may be summarised as follows:

1. **Air pollution: Evaluation of the (road traffic-related) exposure**
   For the three countries Austria, France and Switzerland, the exposure of the residential population to PM10 had to be assessed and the results presented in a fine register defining the population's exposure by concentration classes.

2. **Epidemiology: Evaluation of the exposure-response relationship between air pollution and health impacts**
   The relationship between air pollution and health had to establish to what extent different levels of air pollution affect a population's morbidity and mortality.

3. **Economy: Evaluation of the road traffic-related health impacts and their monetarisation**
   By combining the exposure-response relationship with the exposure to PM10 in each country, the impacts of traffic related air pollution on human health had to be quantified (additional cases of premature death and number and type of additional cases of morbidity) and valued in monetary terms.

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

Based on the average yearly population exposure to particulate matter with an aerodynamic diameter of less than 10 µm (PM10) and the exposure-response function for a number of different health outcomes, the following number of cases attributable to (road traffic-related) air pollution was estimated:

Table E-1: Air pollution attributable health outcomes in Austria, France and Switzerland (1996)

Health outcome	**Additional cases or days due to air pollution**					
	Cases or days attributable to total air pollution			Cases or days attributable to road traffic		
	Austria	France	Switzerland	Austria	France	Switzerland
Long-term mortality (adults≥30 years)	5‘576 3‘370-7‘813	31‘692 19‘202-44‘369	3’314 1‘986-4‘651	2‘411 1‘457-3‘378	17’629 10‘681-24‘680	1’762 1‘056-2‘472
Respiratory hospital admissions (all ages)	3’399 358-6456	13’796 1‘491-26‘286	1‘308 138-2‘488	1‘470 155-2‘792	7’674 829-14‘622	694 73-1‘320
Cardiovascular hospital admissions (all ages)	6‘695 3‘489-9‘960	19‘761 10‘440-29‘362	2‘979 1‘544-4‘425	2‘895 1‘509-4‘307	10’992 5‘807-16‘333	1‘580 819-2‘348
Chronic bronchitis incidence (adults ≥25 years)	6‘158 552-12‘241	36’726 3‘262-73‘079	4‘238 374-8‘436	2‘663 239-5‘293	20’429 1‘814-40‘650	2‘248 199-4‘475
Bronchitis (children < 15 years)	47‘652 21‘008-86‘090	450’218 198‘450-813‘562	45‘446 20‘029-82‘121	20‘606 9‘085-37‘228	250’434 110‘388-452‘544	24‘109 10‘626-43‘565
Restricted activity days (adults ≥20 years)	3'106‘544 2'615‘175-3'604‘519	24'579‘872 20'692'055-28'519‘982	2‘762‘682 2'325'699-3'205‘536	1‘343‘371 1'130'886-1'558'711	13'672‘554 11'509'956-15'864'240	1'465‘600 1'233'782-1'700'534
Asthmatics: asthma attacks (children < 15 years)	34’665 21‘321-48‘174	242‘633 149‘141-337‘151	23’637 14‘532-32‘850	14‘990 9‘220-20‘832	134’965 82‘960-187‘540	12’539 7‘709-17'427
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	93’619 45‘594-142‘598	577’174 281‘130-879‘091	62‘593 30‘490-95‘345	40‘484 19‘716-61‘664	321‘053 156‘378-488‘994	33‘205 16‘175-50‘580

All air pollution-related health effects are only considered for the age groups assessed by epidemiological surveys and above the lowest assessed exposure level of 7.5 µg/m^3 PM10. Due to the larger population size, the number of health outcomes in France are much larger compared to Austria and Switzerland.

Using the willingness-to-pay as a common methodological framework for the monetary valuation, material costs such as medical costs and loss of production or consumption as well as the intangible costs for pain, suffering, grief and loss in life quality were considered. The monetary valuation provided the following results:

Table E-2: Air pollution related health costs in Austria, France and Switzerland in 1996 based on the willingness-to-pay approach*

	Austria		**France**		**Switzerland**	
	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic
Costs of mortality (Mio. 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 (Mio. EUR)	**1 669** 396-3 044	**722** 171–1 316	**10 335** 2 760–18537	**5 749** 1 535–10311	**1 188** 314– 2 134	**630** 167–1132
Total costs (Mio. 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

*willingness-to-pay for a prevented fatality = 0.9 million EUR

All three countries together bear some **49 700 million EUR** of air pollution related health costs, of which some **26 700 million EUR** are road-traffic related. Due to the similar size of their population, in Austria and Switzerland the air pollution related health costs reach similar levels.
In each country, the **mortality costs are predominant**, amounting to **more than 70 %** . Since the same methodology was used in all three countries and the environmental, medical and socio-economic context is quite similar for the three neighbouring countries, the similarity of the results is not astonishing. Within the costs of morbidity, in all three countries together the highest value arises from **chronic bronchitis (74%)** followed by the costs for **restricted activity days (22%)**. For chronic bronchitis, the willingness-to-pay for avoiding this health outcome is considerable (209’000 EUR per case), as this disease signifies a low health status with major constraints to the wellbeing of a victim. For the restricted activity days, although a relatively low willingness-to-pay value of 94 EUR per day is recorded, it is the high number of such days - 30'450’000 days for all three countries together – that inflates the total amount of costs.

Comparing the national per capita costs of air pollution related health effects shows a similar range of values for all three countries for the total air pollution related per capita health costs of **425-1 250 EUR for Austria**, **344-1 004 EUR for France** and **297-892 EUR** for Switzerland. Considering the per capita health costs due to road traffic-related air pollution, the differences between the countries are even lower with a range from **184-541 EUR for Austria (central value 359 EUR)**, **191-588 EUR for France (central value 371 EUR)** and **158-474 EUR for Switzerland (central value 313 EUR)**.

The results of the present study underline the need for action: A periodic observation of the air pollution related health costs based on standardised European methodology has to provide necessary information for a health impact assessment on which effective policy measures of internalisation may be based.

Summary

In preparation for 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. This 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 transport (PREDIT)[2] 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 the PREDIT towards international co-operation.

Introduction

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 damage, traffic jams, 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 do not exist, since they have not to pay for them. By including the external costs, some trips may have produced higher total costs than the total benefit. As a consequence, these trips would have been avoided if all the external costs had to be considered by the driver.

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.

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

With the present project, 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.

Objective

In order to **quantify the road traffic related health costs 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[3].

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:

1. **Air pollution: Evaluation of the (road traffic-related) exposure**
   For the three countries Austria, France and Switzerland, the exposure of the residential population to PM10 had to be assessed. The result had to be presented as a fine register that describes the population's exposure by concentration classes. It had to be considered that the emissions' source is not only 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**
   The relationship between air pollution and health had to be assessed. This step provides for each level of exposure the number of air pollution attributable cases of morbidity and mortality. This evaluation had to be based on the current epidemiologic evidence.

3. **Economy: Evaluation of the road traffic-related health impacts and their monetarisation**
   By combining the exposure-response relationship with the exposure to PM10 in each country, the impacts of traffic related air pollution on human health had to be quantified (number and type of additional cases of morbidity, number of additional cases of premature death) and valued in monetary terms.

The common methodological framework of each of the above mentioned scientific domains and the corresponding results of PM10 population exposure, of air pollution attributable health effects and of the monetary valuation of the air pollution related health effects are presented in detail in three separate technical reports.

[3] Third WHO Ministerial Conference on Environment & Health, London, 16-18 June 1999.

Findings

As one single indicator for urban air pollution, the assessment was limited to particulate matter of less than 10 µm aerodynamic diameter (PM10). For Austria, France and Switzerland the population exposure with PM10 shows relatively similar results, especially concerning the PM10 concentration caused by road traffic (Table S-1).

Table S-1: Population weighted annual average PM10 exposure for Austria, France and Switzerland

PM10 concentration in µg/m^3 (annual mean)	**Austria**	**France**	**Switzerland**
Total PM10	26.0	23.5	21.4
Road-traffic related PM10	8.0	8.9	7.4

Effect estimates from epidemiologic studies are a key component for the assessment of air pollution impacts on health. If available, short- and long-term effects were considered for the assessment. However, overlapping health measures had to be excluded in order to prevent double counting of the impact, especially when monetarizing the effects.

In the present study, the following health outcomes were selected: total mortality based on cohort studies, respiratory hospital admissions, cardiovascular hospital admissions, chronic bronchitis in adults, acute bronchitis in children, restricted activity days in adults, asthma attacks in children and asthma attacks in adults.

For each health endpoint, epidemiologic exposure-response curves were derived from the available literature, using a meta-analytic approach to calculate the variance weighted mean relative risks and applied to the national epidemiologic baseline data for each health outcome (incidence, prevalence). For the three countries, the following number of cases attributable to total air pollution and to road traffic-related air pollution was assessed for 1996 (Table S-2):

Table S-2: Air pollution attributable health outcomes in Austria, France and Switzerland (1996)

Health outcome	Additional cases or days due to air pollution					
	Cases or days attributable to total air pollution			Cases or days attributable to road traffic		
	Austria	France	Switzerland	Austria	France	Switzerland
Long-term mortality (adults≥30 years)	5‘576 3‘370-7‘813	31‘692 19‘202-44‘369	3’314 1‘986-4‘651	2‘411 1‘457-3‘378	17’629 10‘681-24‘680	1’762 1‘056-2‘472
Respiratory hospital admissions (all ages)	3’399 358-6456	13’796 1‘491-26‘286	1‘308 138-2‘488	1‘470 155-2‘792	7’674 829-14‘622	694 73-1‘320
Cardiovascular hospital admissions (all ages)	6‘695 3‘489-9‘960	19‘761 10‘440-29‘362	2‘979 1‘544-4‘425	2‘885 1‘509-4‘307	10’992 5‘807-16‘333	1‘580 819-2‘348
Chronic bronchitis incidence (adults ≥25 years)	6‘158 552-12‘241	36’726 3‘262-73‘079	4‘238 374-8‘436	2‘663 239-5‘293	20’429 1‘814-40‘650	2‘248 199-4‘475
Bronchitis (children < 15 years)	47‘652 21‘008-86‘090	450’218 198‘450-813‘562	45‘446 20‘029-82‘121	20‘606 9‘085-37‘228	250’434 110‘388-452‘544	24‘109 10‘626-43‘565
Restricted activity days (adults ≥20 years)	3'106‘544 2‘615‘175-3‘604‘519	24'579'872 20'692'055-28'519'982	2‘762‘682 2‘325‘699-3‘205‘536	1‘343‘371 1‘130‘886-1‘558‘711	13'672‘554 11‘509‘956-15‘864‘240	1'465'600 1‘233‘782-1‘700‘534
Asthmatics: asthma attacks (children < 15 years)	34’665 21‘321-48‘174	242‘633 149‘141-337‘151	23’637 14‘532-32‘850	14‘990 9‘220-20‘832	134’965 82‘960-187‘540	12’539 7‘709-17‘427
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	93’619 45‘594-142‘598	577’174 281‘130-879‘091	62‘593 30‘490-95‘345	40‘484 19‘716-61‘664	321‘053 156‘378-488‘994	33‘205 16‘175-50‘580

All air pollution-related health effects are only considered for the age groups assessed by epidemiological surveys and above the lowest assessed exposure level of 7.5 µg/m^3 PM10.

In 1996, air pollution caused some 5 600 cases of **premature death** in Austria, some 31 700 cases in France and some 3 300 cases in Switzerland. In Austria 2 400, in France 17 600 and in Switzerland 1 800 cases are attributable to road traffic-related air pollution. According to the epidemiological surveys, the increase in premature mortality is only considered for adults ≥30 years of age.

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

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

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

As may be seen later from the monetary valuation, the premature mortality, the incidence in chronic bronchitis and the very high number of restricted activity days will be of particular relevance for the overall result.

For the monetary valuation of the air pollution related health outcomes, the willingness-to-pay approach was chosen as a common methodological framework. This approach is based on a theoretical foundation of welfare economics in considering the individual utility improvement for a reduction in health related risk. It includes the material costs for ambulant or stationary medical treatment, the loss of capacity leading to production and consumption losses as well as intangible costs of pain, fear, suffering and loss in life quality due to air pollution related health effects. The cost factors applied in the present study are chosen from the most recent economic literature. For the premature mortality the most recent empirical values for the willingness-to-pay of a risk reduction of fatal road accidents of 1.4 million EUR per prevented fatality were applied and corrected downwards to **0.9 million EUR** (Table S-3). This correction considers the lower willingness-to-pay of the higher average age class of air pollution related victims.

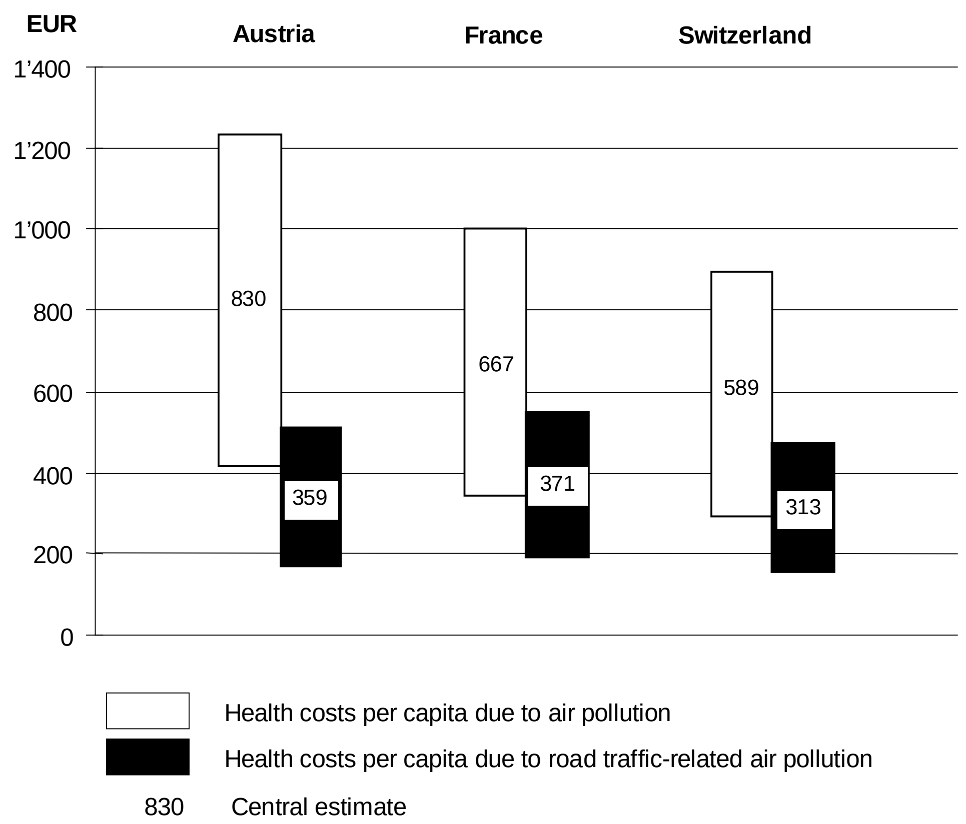
Table S-3: Air pollution related health costs in Austria, France and Switzerland in 1996 based on the willingness-to-pay approach (VPF 0.9 Mio. EUR)

	Austria		**France**		**Switzerland**	
	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic
Costs of mortality (Mio. 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 (Mio. EUR)	**1 669** 396-3 044	**722** 171–1 316	**10 335** 2 760–18537	**5 749** 1 535–10311	**1 188** 314– 2 134	**630** 167–1132
Total costs (Mio. 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 together bear some 49 700 million EUR of air pollution related health costs, of which some 26 700 million EUR are road-traffic related. Due to the similar size of their population, in Austria and Switzerland the air pollution related health costs reach similar level.
In each country, the **mortality costs are predominant**, amounting to **more than 70 %** . Since the same methodology was used in all three countries and the environmental, medical and socio-economic context is quite similar for the three neighbouring countries, the similarity of the results is not astonishing. Within the costs of morbidity, in all three countries together the highest value arises from **chronic bronchitis (74%)** followed by the costs for **restricted activity days (22%)**. For chronic bronchitis, the willingness-to-pay for avoiding this health outcome is considerable (209'000 EUR per case), as this disease signifies a low health status with major constraints to the wellbeing of a victim. For the restricted activity days, although a relatively low willingness-to-pay value of 94 EUR per day is recorded, it is the high number of such days - 30'450'000 days for all three countries together – that inflates the total amount of costs.

Comparing the national per capita costs of air pollution related health effects (Figure S-4) shows a similar range of values for all three countries for the total air pollution related per capita health costs of **425-1 250 EUR for Austria**, **344-1 004 EUR for France** and **297-892 EUR** for Switzerland. Considering the per capita health costs due to road traffic-related air pollution, the differences between the countries are even lower with a range from **184-541 EUR for Austria (central value 359 EUR)**, **191-588 EUR for France (central value 371 EUR)** and **158-474 EUR for Switzerland (central value 313 EUR)**.

Figure S-4 Air pollution related health costs per capita (1996)



The sensitivity of the above presented results is influenced by all three scientific domains, the assessment of PM10 exposure, the air pollution attributable health outcomes and the monetary valuation of the health effects. In general, for each sensitive assumption an ”at least” approach was adopted. The health costs assessed according to the common methodological framework may be considered to be a conservative estimation of the real costs, since

- different PM10 related health effects (e.g. lung cancer, infant mortality) were not considered in 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.

The Charter on Transport, Environment and Health on behalf of the WHO Ministerial Conference on Environment and Health in London 1999, states as a primary goal the achievement of a transport system, sustainable with regards to health and environment. The results of the present case study draw attention to the high impact of (road traffic-related) air pollution on human health, thus underlying the necessity for a re-orientation of both research policy and implementation policy.

First of all, a standardised methodology and technique for a periodic assessment of the populations exposure, and the health and environmental status of that population has to be established in order to provide a comparable monitoring system throughout the European countries. Second, the periodic results from the air pollution related health assessment need to be integrated into the health and environmental impact assessment tools in general, into national accounting systems (e.g. traffic account) and into cost-benefit analysis for specific projects. Finally, an improvement of the different information tools is needed to strengthen the basis for a policy design which aims at the implementation of the polluter-pays principle (e.g. by re-orienting the tax system), which should induce a reduction in air pollution as well as savings in the health system costs in the long run.

1. Introduction

1.1 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, traffic jams, 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 do not exist, since they do not have to pay for them. Including the external costs, their trips would have produced higher total costs than the total benefit. As a consequence, many trips would have been avoided if all the external costs had to be considered by the driver.

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.

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.

1.2 Objective

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

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

The results of this co-operation provide an input for the WHO Ministerial Conference in June 1999[1]

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:

1. **Air pollution: Evaluation of the (road traffic-related) exposure**
   For the three countries Austria, France and Switzerland, the exposure of the residential population had to be assessed. The result had to present a fine register that describes to which level of concentration the number of persons living in each geographic unit are exposed. It had to be considered that the emissions‘ source is not only 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**
   The relationship between air pollution and health had to be assessed. This step provides for each level of exposure the number of air pollution attributable cases of morbidity and mortality. This evaluation had to be based on the current epidemiologic evidence.

3. **Economy: Evaluation of the road traffic-related health impacts and their monetarisation**
   By combining the exposure-response relationship with the exposure to PM10 in each country, the impacts of traffic-related air pollution on human health was quantified (number and type of additional cases of morbidity, number of additional cases of premature death). With adequate methods, these health effects finally had to be valued in monetary terms.

1.3 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 (see annex 1).

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[2].

In all three domains, co-referees from the international scientific community were invited in order to critically advise and comment on the ongoing work (see annex 1).

[1] Third WHO Ministerial Conference on Environment & Health, London, 16-18 June 1999.
[2] Filliger P., Puybonnieux-Texier V., Schneider J., (1999) PM10 Population Exposure;
Künzli N., Medina S., Studnicka M., Oberfeld G., Horak F., (1999) Air Pollution Attributable Cases;
Sommer H., Seethaler R., Chanel O., Herry M., Masson S., Vergnaud J-Ch. (1999), Economic Evaluation

1.4 Structure of the Report

The present summary report is structured as follows:

Chapter 2 presents the general **concept of social, internal and external costs**, thus providing a methodological background.

Chapter 3 discusses the **study design** and outlines its system boundaries.

Chapter 4 presents the **epidemiological foundations and results**.

Chapter 5 describes the assessment of **traffic-related air pollution** and **exposure.**

Chapter 6 presents the quantitative **health effects of road traffic-related air pollution in 1996** and the **economic valuation of health costs.**

Chapter 7 presents the **findings** and discusses the **sensitivity aspects**.

Chapter 8 **recapitulates** the results and draws **conclusions.**

Annex 1 contains the **list of participants.**
Annex 2 contains the tables with the **epidemiological data material**.
Annex 3 contains a description of the evaluation procedure for the assessment of the **willingness-to-pay for mortality risk reduction**.
Annex 4 describes mortality cost assessment based on the **consumption loss** approach in France.
Annex 5 contains the list of **abbreviations** and the **glossary.**

1.5 Acknowledgement

The financial resources and the general project management were contributed by the governmental institutions of the three countries, namely

- by the Austrian Ministry for Environment, Youth and Family ,
- by the Austrian Federal Environment Agency,
- by the French Agency for Environment and Energy Managment, Air and Transport Direction (ADEME),
- by the Swiss Federal Department of Environment, Transport, Energy and Communications (DETEC)

We would like to express our deep appreciation to all those persons and institutions that have supported this study in any form. Special thanks go to the co-referees who have supported the work with their critical advice. All these partners together have contributed with their involvement in a demanding, stimulating and productive multidisciplinary effort.

We thank in particular the European WHO division of Rome and Bilthoven, who offer the platform for the results’ presentation within the Ministerial Conference in London 1999.

2. The concept of social, internal and external costs[3]

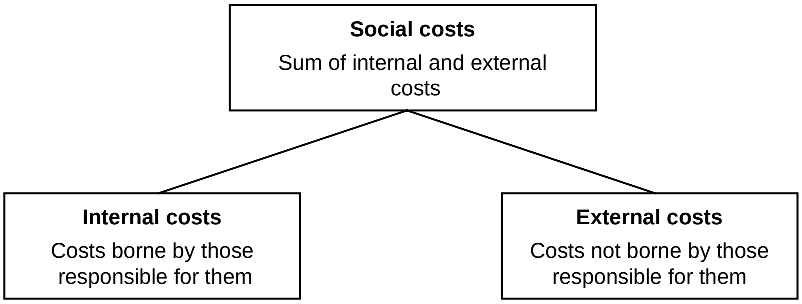
2.1 Definitions

In the economic literature, the concepts of social costs, internal costs and external costs are not used in a uniform manner. However, in the course of investigations to quantify the social costs of transport, the following definitions, which have been adopted for this study, have gradually prevailed:

- Social costs

The social costs of transport comprise all costs to which road transport gives rise and which are borne by society. They consist of internal and external costs (see Fig. 2.1).

Fig. 2.1. Social, internal and external costs



Source: Ecoplan, 1991

- Internal costs

These are costs which motorists themselves pay for their travel. They consist of quantifiable costs (e.g. fuel costs, taxes on the use of the road infrastructure, insurance, etc.) and non-quantifiable costs (such as travel time, the nervous fatigue which accumulates during travel by car, the consequences of accidents personally covered, etc.)

- External costs

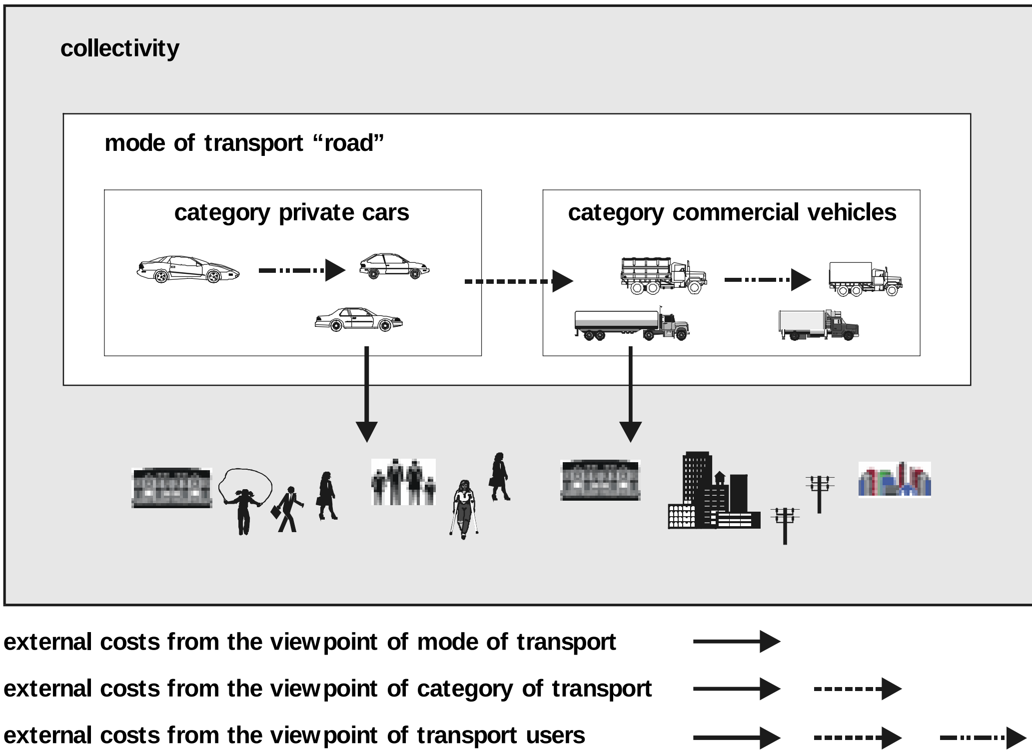
External costs denote that part of social costs borne not by those responsible for them, but by others. Typical examples are noise and air pollution, which adversely affect society as a whole and are not (or only partially) compensated for by motorists.

[3] Source: Sommer H., Neuenschwander R., Walter F., (1991) Soziale Kosten von Verkehrsunfällen in der Schweiz; Ecoplan. Auftrag GVF Nr. 186, Eidg. Verkehrs- und Energiewirtschaftsdepartement, Bern, 1991

2.2 Definition of external costs

The magnitude of the external costs of transport depends primarily on whether they are calculated at the level of the transport mode, the transport category or the transport user. As Fig. 2.2 shows, there are thus three ways of defining external costs.

Fig. 2.2. Possible delimitations for determining external costs



Source: Ecoplan, 1991

According to the mode of transport
The transport system is considered as a whole. In this case, the external costs arise from the fact that the system does not itself bear all the costs that it generates, but passes part of those costs on to society. For example, the costs of transport-related noise impacts are external costs. On the other hand, from this point of view the costs of accidents which are borne not by those who caused them (for example, a motorist), but by another transport user (such as a cyclist), are internal costs, because they remain within the transport system.

According to the category of transport
Here, the costs that arise between different categories of transport but are not borne by those responsible for them, are also considered to be external costs. In an accident, for example, the victim's costs are external when the accident involves vehicles of different categories (such as a goods vehicle and a private car).

According to the transport users
From this point of view, internal and external costs are determined by reference to the single transport users. External costs occur whenever they are not borne by the transport user who generates them.

To assess the various possible delimitations in economic terms, it is important to introduce into the transport system the most efficient possible allocation, i.e. to create an optimal situation from the point of view of society's welfare as a whole. Therefore, the costs must be borne by those users who are responsible for them. Hence, two preconditions must be met:

1. the costs generated by the transport system and **borne by the rest of society** must be paid entirely by the users of this system; and
2. within the transport system, all costs incurred **to the detriment of all other transport users**, **categories of transport or modes of transport,** are borne by those responsible for them.

As a result, in order to create an economically optimal transport system, external costs must be determined **from the point of view of each of the transport users**. That is the only delimitation which ensures that no external cost is overlooked and that the appropriate economic foundations are laid to ensure the polluter-pays principle (internalization). The other points of view should only be considered in the context of a **cost allocation**.

In order to identify whether part of the traffic-related health costs are internal, the following aspects must be considered:

- Given that we are all users of the transport system and thus implicitly accept the resulting air pollution and its consequences and that we are prepared to pay the price, are all health costs internal costs?

  Even if we are all potential road users in one form or another, this in no way suffices to ensure that health costs will be borne by those responsible for them. Such costs depend on the quantity of emissions ”produced”, in other words, the number of kilometres driven: Assuming that two motorists have technically similar vehicles, the one who drives more will generate greater health costs than the other. But under the current price structure, this motorist will not have to bear any additional costs. It is therefore not enough for health costs to be paid globally by all transport users in one way or another. What is essential is that the coverage of these costs should be a function of the harm caused (i.e. proportional to the quantity of pollutants ”produced”).

- What about the health costs incurred by **others** but which are covered by insurance benefits?

Health insurance and/or social security benefits cover the costs of medical treatment and a substantial part of the loss of income of the insured. That also holds for illnesses brought on by transport-related air pollution. The following argument can sometimes be heard: transport-related air pollution does admittedly cause harm to health, but that does not generate external costs, because the latter are covered for the most part by insurance benefits. This line of reasoning is faulty. The insurance benefits cannot be regarded as covering external costs (internalization), because it is not road users who finance the benefits paid to victims of transport-related air pollution, but the product of the premiums paid by all insured people. This means that road users pass on part of the costs to others who are not directly responsible, namely people with health or social security insurance, because the latter must pay higher premiums.

- Are the health costs affecting the **transport users themselves** internal costs because they are borne by them?

  It can be assumed that by definition, all pollutants not produced in the immediate vicinity of motorists (or the road) give rise to external costs. The immediate harm caused to the driver in transit may alone be considered to be internal (provided that it is not passed on to the rest of society through insurance premiums).[4] This ”self-inflicted” damage is not taken up in this study: an assessment of pollution concentration starts from the domicile/place of residence of the total population concerned, and not the pollution to which motorists themselves are exposed during transit. That means that any concentration peaks of motorists in traffic are not included in the calculations. The actual costs of harm to health can thus be considered to be entirely external costs.

As a result, although we are all potential transport users, it cannot be assumed that there are no external health costs. Benefits paid by health or social security insurance funds cannot be regarded as a contribution to covering external costs, because they are financed not by road users as a function of costs generated but by all insured people. The health costs affecting transport users themselves as a result of direct harm during travel should be considered internal costs; however, given the analytical method used, such self-inflicted harm is not taken into account. **In sum, it can be said that all the health costs estimated in this study must be regarded as external costs**.

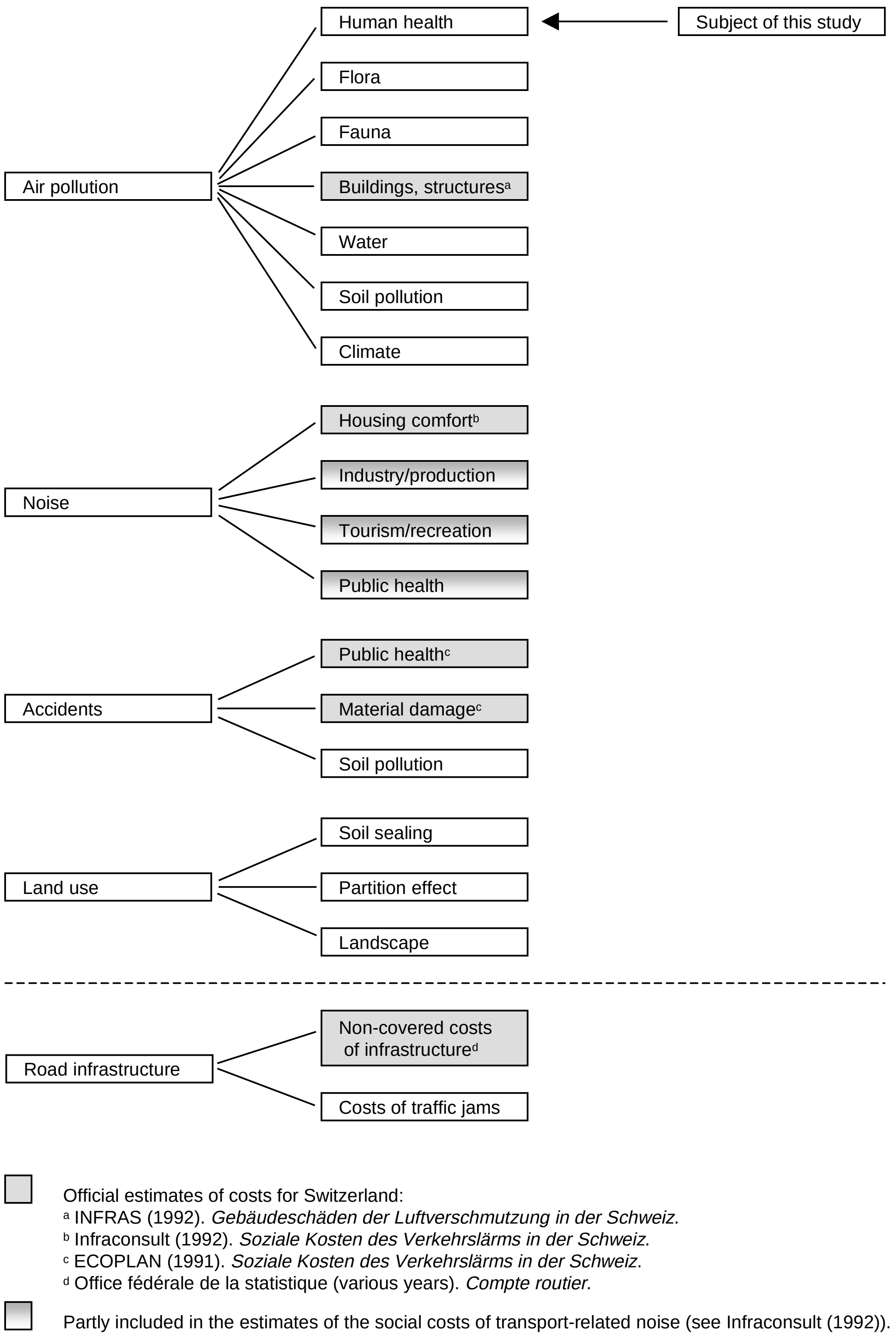
2.3 Health costs as part of road traffic-related external costs

Fig. 2.3 provides an overview of the main areas in which road traffic gives rise to external costs. It shows that traffic endangers human health in many ways, notably through air pollution, noise and accidents.
This study focuses exclusively on the **health costs attributable to road traffic and arising from air pollution**. As can be seen in Fig. 2.3, air pollution affects not only human health but also other areas (flora, fauna, etc.), which go beyond the framework of this study.

---

[4] As already seen in the previous paragraph, ultimately a considerable part of the health costs generated by transport users are not borne by them, but are passed on to others in the form of health insurance or social security premiums.

Fig. 2.3. Areas in which road traffic gives rise to external costs



Source: Ecoplan[5]

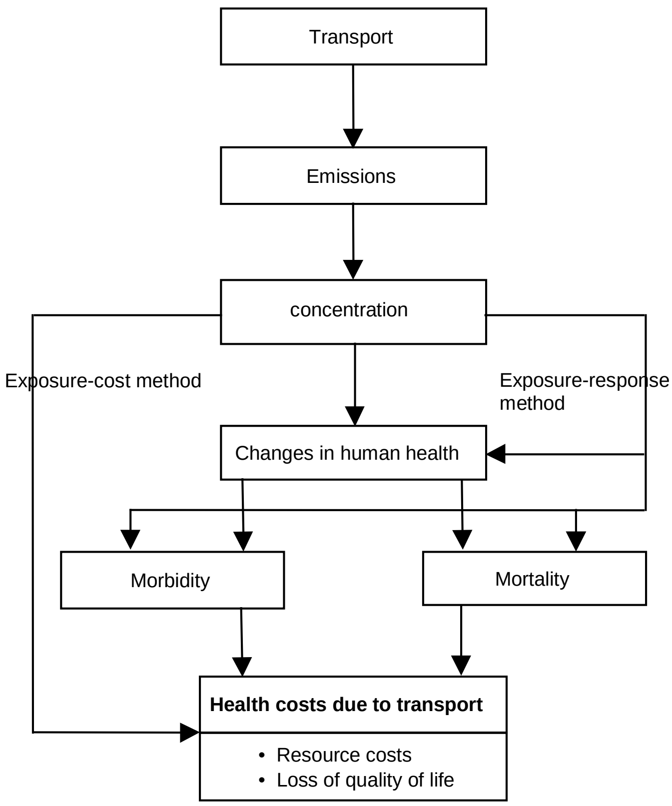
[5] Sommer H., Neuenschwander R., (1996), Monetarization of the external health costs attributable to transport, Consolidated report. GVF-Report nr. 272, Federal Department of Environment, Transport, Energy and Communications, Bureau for Transport Studies, Berne, 1996

3. General characteristics of the common methodological approach

3.1 The chain of interactions

The starting point for the assessment of traffic-related health costs is the chain of interaction shown in Fig. 3.1. Emissions from traffic (and other sources) cause an increase in the concentration of harmful substances in ambient air which has an adverse impact on human health. They may lead to an increase in morbidity and mortality and generate additional costs both in terms of resources (for medical treatment and days of work lost) and as deterioration in the quality of life (suffering of people directly affected by illness, as well as of others as a result of illnesses and premature death).

Fig. 3.1 Chain of interaction between air pollution and health costs



Source: Ecoplan[6]

[6] Sommer H., Neuenschwander R., (1996), Monetarization of the external health costs attributable to transport, Consolidated report. GVF-Report nr. 272, Federal Department of Environment, Transport, Energy and Communications, Bureau for Transport Studies, Berne, 1996

3.2 The study design

In the approach used to quantify road traffic-related health costs, a distinction can be drawn between the **costs of harm** and the **costs of prevention**. This distinction is based on two fundamentally different points of view. The former approach attempts to estimate the damage to health costs due to traffic-related air pollution, whereas the latter seeks to calculate the costs of measures designed to prevent harm from occuring.

The common methodological framework of the present tri-lateral study is based on the exposure-response relationship of the population's exposure to air pollution and the resulting health outcomes. For the monetary valuation of the health costs, the resulting **costs of harm** are estimated for all three countries by using the willingness-to-pay approach. As a partial assessment for the cost of harm, Austria and Switzerland apply the production loss approach, whereas the consumption loss approach is used in France. The cost of prevention is not further explored.

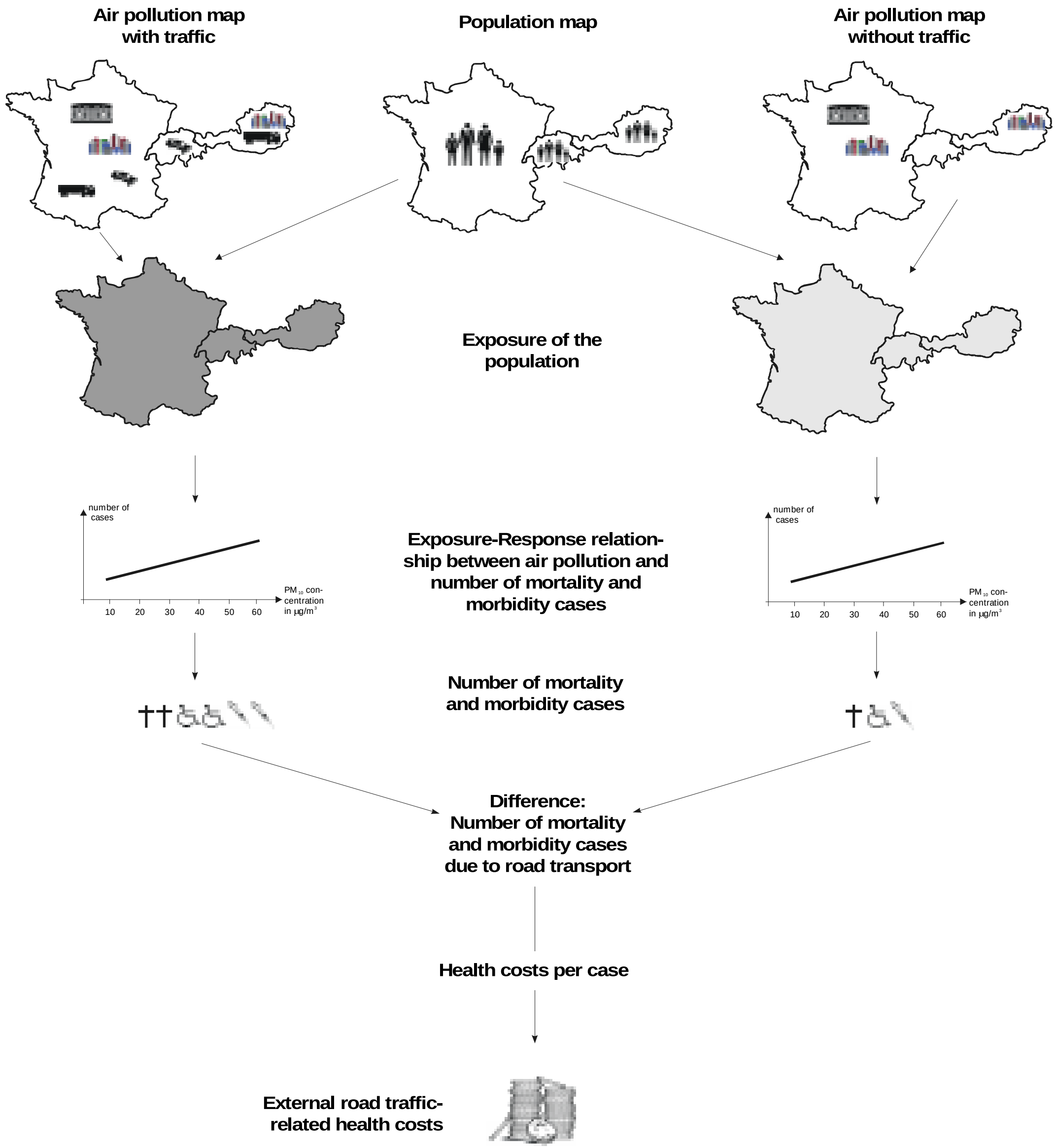
Figure 3.2 presents an overview of the different working stages:

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

- Using epidemiological data regarding the association between air pollution and morbidity and premature mortality, the number of cases of morbidity and/or premature mortality attributed to air pollution is determined for each of the health outcomes separately, using specific exposure-response functions. The same operations are carried out for the theoretical situation in which there is no road traffic-related air pollution.

- The difference between the results of these two calculations corresponds to the cases of morbidity and premature mortality due to road traffic-related air pollution. The costs arising from road traffic-related cases of illness and premature death are then determined by multiplying this figure by a cost estimate (per case of illness or death).

Fig. 3.2 Structure of the study for calculating the costs of morbidity and premature mortality due to road traffic-related air pollution



3.3 Spatial boundaries

The investigations focus on the effects of road traffic -related air pollution on health in Austria, France and Switzerland. They are based on:

- exposure-response functions established at a national and international level between air pollution levels and their effects on the health of the resident population;
- exposure of the resident population to ambient concentration of pollutants assessed on the basis of empirical dispersion models or statistical methods.

3.4 Reference year

The costs of harm to health are calculated in principle for road traffic-related air pollution in **1996**. This has two implications.

Firstly, the findings also include the costs of cases of morbidity and premature mortality counted for 1996 but which may extend beyond 1996. This applies in particular to the costs of resource losses resulting from death or invalidity. Such an approach also takes account of the polluter pays principle from a temporal point of view: transport users in 1996 must bear all the costs that they generated in that year, even if part of those costs arise later.

The harm to health calculated for 1996 is not due solely to pollution produced in 1996, but also to that in earlier years. Likewise, it can be said that the air pollution ”produced” in 1996 also has an impact on later harm to health. The former effect can lead to an overestimation of costs and the latter to an underestimation. Under the hypothesis that the pollutant level remains more or less unchanged, these two effects cancel each other out.

Secondly, whenever possible, the various phases of this calculation utilise the statistical data collected for 1996. The data relating to medical and economic costs and air pollution correspond to the year 1996 or are considered as representative for this year.

Effect estimates and some of the **population baseline frequencies** originate from epidemiologic studies which have been conducted before 1996. Exposure and health outcomes in the population, however, will not have changed considerably from the time period covered by the studies until 1996. Therefore, the results can be applied to the health impact project.

3.5 Types of traffic considered

The costs of traffic-related air pollution determined by this study comprise road traffic (persons and goods) without off-road transport.[7] In the present study, the impacts of air pollution on human health from other transport modes, such as rail, aviation and water borne transport are not included.

3.6 The "at least approach"

Throughout the entire common methodological framework, many assumptions and methodological decisions have to be taken along the various calculation steps in the domain of air pollution, epidemiology and economy. On each level, the method of dealing with uncertainty had to be defined. It has been decided that the main calculation ought to apply an ”at least” approach, thus consistently selecting methodological assumptions in a way to get a result which may be expected to be ”at least” attributable to air pollution. Accordingly, the overall impact of air pollution is expected to be greater than the final estimates. To unambiguously communicate the uncertainty in the common methodological framework, the final results will be reported as a range of impacts rather than as an exact point estimate.

3.7 The lowest assessed level

In the calculations of the public health impact of ambient air pollution it is crucial to decide what level of exposure may be considered as the “reference exposure”. In the present study the lowest assessed level was set at 7.5 $\mu g/m^3$ PM10 annual mean. Therefore, health effects of air pollution are only considered from the exposure level of 7.5 $\mu g/m^3$ upwards. The selection of this level strongly influences the calculation of the additional cases due to the ”total PM10” 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 multiplication 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 (D10)[8].
- the proportion of the traffic-related cases compared to the share that may be calculated using the PM10 concentration partition found in the air pollution report. Therefore, in this study absolute instead of relative numbers are used, whenever possible.

[7] Off-road transport comprises all vehicles equipped with combustion engines with the exception of road vehicles, namely: construction and agricultural machinery, air, shipping and rail transport, military vehicles, etc.
[8] See also Chapter 5.6 and reading example for Table 5-6.

It is to emphasise that the ”lowest assessed level” cannot be considered as a level of no effect. So far, epidemiologic studies give no indication for a ”no-effect treshold” for PM10, although some studies like those conducted in Switzerland[9] include regions with rather low annual mean PM10 levels. However, these studies did not include populations living in regions with PM10 levels below 5-10 $\mu g/m^3$. Therefore, in the present study the risk function was not extrapolated down to zero. This is in line with the ”at least” approach.

[9] Ackermann-Liebrich, 1997; Braun-Fahrländer, 1997

4. The PM10 population exposure[10]

4.1 The assessment of road traffic-related air pollution – the main task

The assessment of the road traffic-related health costs is based on the population exposure to air pollution. As indicator for air pollution, the annual mean of PM10 (particulate matter with an aerodynamic diameter of less than 10 µm) was chosen. The main task of the air pollution part consisted of estimating the residential population's exposure to the ambient air concentration of PM10. The population exposure had to be evaluated for the total PM10 as well as for the road traffic-related PM10 concentration.

4.2 The choice of PM10 as an indicator for air pollution

Air pollution is a mixture of many known and unknown substances. In general, it is not possible to associate a specific health outcome with a single pollutant. The objective is therefore to cover as best as possible the complex mixture of pollutants of significance for health by concentrating attention on some of the more important pollutants, or ”indicator pollutants”, such as PM10 or PM2.5, nitrogen oxides (NOx), carbon monoxide (CO) or ozone (O_3). Within the common methodological framework of this study, it has been decided to estimate the impact of air pollution on human health for one single indicator of ”urban air pollution”. The impact of oxidant pollution – likely to cause at least in part additional and independent health effects (e.g. during summer) – will not be quantified in the present study.[11]

From a measuring point of view, PM10 is the particulate matter capable of passing an inlet of defined characteristics with a 50% sampling efficiency at 10µm aerodynamic diameter.
For PM10, epidemiological evidence is strong and there exists a broad scientific literature from which to extract effect estimates. It has therefore been chosen as an indicator of air pollution for the present study.

4.3 The main working steps

Information about the sources and the spatial distributions of PM10 is still sparse in Austria, France and Switzerland as it is in many other European countries. This is partly due to the fact that PM10 by itself is a complex mixture of particles of different size, different chemical composition from different sources and with different dispersion characteristics. To tackle the complexity of the problem, the use of a fully

[10] Filliger P., Puybonnieux-Texier V., Schneider J. (1999), PM10 Population Exposure – Technical Report on Air Pollution; Technical Report of the ” Health Costs due to Road Traffic-related Air Pollution – An impact assessment project of Austria, France and Switzerland”, Berne 1999
[11] Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Air Pollution Attributable Cases – Technical Report on Epidemiology; Technical Report of the ” Health Costs due to Road Traffic-related Air Pollution – An impact assessment project of Austria, France and Switzerland”, Berne 1999

developed three dimensional model would have been desirable to assess the spatial distribution of PM10. Under the constraint of a very tight time-table and missing input data, this approach had to be abandoned for the present study. Instead, starting from particulate measurements, empirical dispersion models or statistical methods had to be used to calculate the spatial distribution of PM10.

The general methodological framework for the air pollution assessment consisted of four main steps:

a) the collection and analysis of the available data on ambient concentration of particulate matter (Black Smoke BS, Total Suspended Particulate TSP and PM10) for model comparison or correlation analysis between different particle measurement methods.

b) PM10 mapping by spatial interpolation with statistical methods or empirical dispersion modelling

c) The estimation of the road traffic-related part of PM10, and

d) The estimation of the population exposure from a superposition of the PM10 map with the population distribution map.

Furthermore, as a general procedure, the quality of each country’s specific model was checked by comparing modelled results 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.

4.4 The "at least" approach

In the domain of exposure assessment, the following aspects correspond to the selected ”at least” approach prevailing throughout the whole project:

The main goal in air pollution modelling is to simulate the real situation as closely as possible. The "at least" approach is only used if input data is completely missing and has to be estimated based on expert knowledge. "At least" assumptions are then chosen. This means that there is a tendency for the results to be underestimated. In the context of the air pollution part, the results may be regarded as conservative estimates.

4.5 The application of different methods in Austria, France and Switzerland

The ambient concentration of particulate matter is measured by different methods in the three countries. A first estimate of a PM10 emission inventory was only available in Switzerland. The other two countries, Austria and France, had no such data available, which introduced an important restriction determining the methodological choice for the PM10 concentration modelling.

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

- **France** used, until recently, the Black Smoke (BS) method to measure the particle concentrations. Today, some sites are equipped with PM10 samplers as well. Thus, the starting point of the French approach was the available BS data which served as input to a correlation analysis between BS and PM10. It was shown that BS and PM10 measures are about equal at urban background sites. Next, linear relationships were established between the BS measurements and land use categories observed around the monitoring sites. A multiple regression analysis was done for three land use categories separately (urban, suburban and rural). Based on the regression parameters and the land use variables, the PM10 map for the entire territory was established. Secondary particles are considerably underestimated by the measuring of Black Smoke and the PM10-TEOM[12] measuring method; therefore, a correction factor had to be defined based on the European scale EMEP[13] model. Finally, the percentage of road traffic-related PM10 in each grid square was determined using the proportions of transport from the Swiss PM10 model.

- In **Switzerland**, the national monitoring network has been changed from TSP to PM10 measurements, where PM10 is measured by gravimetric filter samplers. In addition, a provisional national PM10 emission inventory was available which was first disaggregated to a square kilometre (km^2) grid. Dispersion functions for primarily emitted PM10 were defined in an empirical dispersion model which was used to establish the concentration of primary PM10. The contribution of secondary particles was modelled by using simple correlations between precursor concentrations and particle products. The proportion of long-range transported particulates was adopted from measurements and European scale models. Finally, the different parts of PM10 were added to the overall PM10 map. The road traffic-related part could be established by simply omitting all the road traffic sources from the emission inventories (from the local as well as the large scale inventories).

---

[12] TEOM method (see Chapter 4.2 of: Filliger P., Puybonnieux-Texier V., Schneider J. (1999), PM10 Population Exposure – Technical Report on Air Pollution; Technical Report of the " Health Costs due to Road Traffic-related Air Pollution – An impact assessment project of Austria, France and Switzerland", Berne 1999

[13] EMEP (1998), Long-range transport of fine secondary particles, as presently estimated by the EMEP Lagrangian model. EMEP/MSC-W, Note 2/98. Norwegian Meteorological Institute, Oslo.

4.6 The background concentration

The determination of the regional PM10 background is a sensitive parameter within the mapping procedure of PM10. This large-scale transported part of PM10 concentration is considerable and can explain more than 50% of PM10 at rural sites. It was found that a correct estimate of the PM10 background is crucial in order to obtain comparable results for the three countries. Whereas in Austria, rural background TSP measurements were used to estimate the PM10 background, France and Switzerland adopted the concentration of the long-range transported secondary particles from European scale models[14] (and partially from rural aerosol measurements). Furthermore, the contribution of road traffic to PM10 background concentration is substantial and may vary in space.

4.7 The estimation of road traffic-related PM10

Many different sources contribute to the PM10 concentration. Road traffic is one important source. From all the transport sources (road, rail, aviation, shipping) it is by far the most important source of PM10[15]. The present study concentrates on road traffic only, since the poor data availability and the time constraint did not allow for any additional assessment of off-road traffic like aviation, railroads or shipping lines.

Information about the road traffic-related part of PM10 may be derived from
- Emission inventories
- Receptor studies
- Dispersion models.

PM10 emission inventories provide by definition the mass of the emitted **primary** particles. The traffic-related part of secondary particles must be estimated indirectly by using the share of the precursor emissions. In many emission inventories, the re-suspended road dust is not yet included, although this is probably a quite substantial part of traffic-related PM10 emissions. If this emission is not included, PM10 emission inventories appear not to be a good basis on which to estimate the traffic-related portion.

Receptor modelling is the term applied for using particle in the atmosphere measurements (including chemical analysis of the composition) to estimate quantitatively the contributions of different source categories to the mass of particles. In its simplest form primary and secondary components of particulate matter are distinguished. At a more sophisticated level, detailed analysis (factor analysis or chemical mass balance modelling) is applied to identify and to quantify the contribution of major sources.

In the scope of the present study, special receptor studies could not be conducted but the information from existing literature was included.

---

[14] EMEP (1997): Transboundary Air Pollution in Europe. MSC-W Report 1/97, Part 1 and 2. Norwegian Meteorological Institute, Oslo.

[15] Berdowski et al., (1997); Particulate matter emissions (PM10 – PM2.5 – PM0.1) in Europe in 1990 and 1993. Netherlands Organisation for Applied Scientific Research TNO-report, TNO-MEP R 96/472.

Dispersion models are capable of quantifying the contributions of all source categories that are included in the emission inventory. However, the quality of their results is strongly dependent on the quality of the underlying emission inventory.

For the present study, it was decided to use all available information on receptor studies, dispersion modelling and emission inventories to estimate the traffic-related part. Austria and Switzerland used dispersion modelling in combination with results from measurement campaigns on different parts of particulate matter and expert judgement. France adopted the results from the Swiss dispersion model.

4.8 The results: PM10 population exposure in Austria, France and Switzerland

The assessment of the population exposure may be based on the place of residence or on personal exposure. The epidemiological exposure-response functions used in the present study report the association of health outcomes with average ambient levels of air pollution, measured at fixed monitors, rather than with personal exposure. Hence, the place of residence has been selected as an assessment criteria for exposure and the PM10 map represents urban conditions typical for the residence of the population. This approach of exposure assessment is thus consistent with the epidemiological exposure assessment to derive exposure-response functions.

Tables 4.8-1 to 4.8-3 present the results of the PM10 population exposure for Austria, France and Switzerland.

Table 4.8-1 Total population exposure to PM10 in Austria, France and Switzerland

PM10 concentration (μg/m³)	Austria	France	Switzerland
0 - 5	0.0 %	0.2 %	0.0 %
5 - 10	0.0 %	0.5 %	1.2 %
10 - 15	11.4 %	5.2 %	5.7 %
15 - 20	14.2 %	31.5 %	31.8 %
20 - 25	22.8 %	33.3 %	42.5 %
25 - 30	27.7 %	12.8 %	14.6 %
30 - 35	8.5 %	7.8 %	3.0 %
35 - 40	4.7 %	4.1 %	0.9 %
40 - 45	3.4 %	1.6 %	0.3 %
45 - 50	3.4 %	1.1 %	0.0 %
> 50	3.9 %	2.0 %	0.0 %
Population 1996	8’059’385	58’258’071	7’081’346

Table 4.8-2 Population exposure to PM10 in Austria, France and Switzerland, without road traffic-related contribution

PM10 concentration (μg/m³)	Austria	France	Switzerland
0 - 5	0.0 %	0.4 %	0.1 %
5 - 10	9.5 %	3.3 %	5.1 %
10 - 15	21.9 %	52.0 %	59.6 %
15 - 20	32.7 %	41.8 %	35.0 %
20 - 25	23.5 %	1.9 %	0.2 %
25 - 30	5.2 %	0.5 %	0.0 %
30 - 35	3.3 %	0.1 %	0.0 %
35 - 40	2.1 %	0.0 %	0.0 %
40 - 45	1.9 %	0.0 %	0.0 %
> 45	0.0 %	0.0 %	0.0 %

Table 4.8-3 Population weighted PM10 average exposure in Austria, France and Switzerland

	PM10 concentration in μg/m³		
	Austria	France	Switzerland
Total PM10	26.0	23.5	21.4
PM10 without share attributable to road traffic	18.0	14.6	14.0
PM10 due to road traffic	8.0	8.9	7.4

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

Within the air pollution study, several **difficulties** had to be overcome. The most serious one, was the **lack of comparable PM10 data**. National PM10 networks must now be established. In Austria and France, this is required under the forthcoming EU regulations. In building up these networks, it is crucial that the PM10 samplers used are compatible with the new European reference method, thus ensuring full comparability with other countries. Beside PM10, also other indicators of particulate matter such as PM2.5 and even smaller fractions should be included. In addition, information on the chemical composition of particulate matter as well as on particle number and particle surface area is crucial in order to assess the origin, the characteristics and the effect of particulate matter in ambient air.

Furthermore, the **establishment of reliable PM10 emission inventories** is another crucial point. Little is known about PM10 emissions from different sources, e.g. road dust resuspension, construction activities etc. Special attention has to be paid to these sources, in order to get reliable emission factors. Receptor studies which try to provide the source apportionment by using measured PM10 components, are a necessary supplement to the emission inventories. Several studies in different regions of Europe should be started and the results compared.
Improvements in the estimation of population exposure are possible if improved input data are available. Many assumptions and estimates had to be made to calculate the population exposure. For all three countries, the air pollution group considers the results for total PM10 exposure as well as for the road traffic-related share to be reasonable and the **best available estimate** on the basis of the now available measurements and emission data.

5. Air pollution attributable health effects

5.1 Air pollution attributable cases – the main task

Within the common methodological framework, the task of the epidemiological part of the study consists of the assessment of the health effects attributable to air pollution. The general methodological approach is based on strong epidemiological evidence about the adverse health effects of current levels of air pollution. Epidemiology is a key science to provide data for impact assessment.

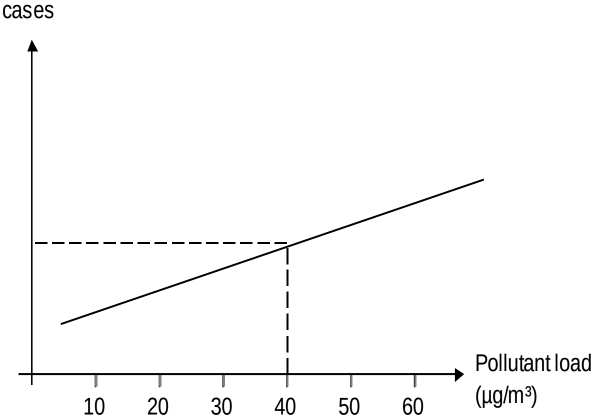
By means of observational assessment, epidemiological surveys study the associations between potential risk factors, such as air pollution exposure, and health status in populations. The observational assessment includes a variety of methods such as objective measures of health and exposure and the collection of subjective data (questionnaires) to control for other important factors. Effects are expressed as exposure-response function between air pollution and the frequency or occurrence of diseases. Only valid epidemiologic studies which adopted adequate designs and sufficiently controlled for confounding factors (e.g. smoking habits) may be used to derive the risk function.

It is to note that epidemiology does not assess the patho-physiologic mechanisms. However, public health risks may be assessed and action may be successfully taken without detailed knowledge about the underlying patho-physiologic mechanisms. For example, the strong association of smoking and a variety of health effects has been clearly established with epidemiologic studies long before the detection of the patho-physiologic mechanisms which lead to the health effects.

5.2 Epidemiological background

As illustrated by graphical means (Figure 5-1), for a given pollutant level (e.g. 40 µg/m3) the frequency of occurrence of a health outcome can be determined if the profile of the curve and its position, i.e. its intersection with the ordinate axis, are known.

Figure 5-1 Theoretical correlation between pollutant level and cases of disease



Source: Ecoplan

The **effect estimate** measures the quantitative variation in the frequency of a health outcome per unit of pollutant load and thus expresses the link between exposure and health effect. In order to determine effect estimates for different diseases, the quantitative results of several national and international studies, meeting a set of scientific criteria, have been used and integrated into a meta-analysis[16].

The **population base line frequency** is the frequency with which a health outcome appears in the population for a defined "baseline pollutant load". As opposed to the effect estimate that does not vary from one population to another, the population base line frequency has to be assessed for each country separately. Combining effect estimate and frequency provides the total number of cases for a selected health outcome (morbidity and mortality) attributable to an increase of 10 $\mu g/m^3$ in the ambient particulate concentration (PM10).

In the present study, the two parameters had to be determined for a whole set of health outcomes. According to epidemiological evidence, air pollution may have short-term effects on health, e.g. the health status of susceptible subjects may change within hours or days after exposure. Furthermore, over the long run, air pollution may repeatedly or continuously compromise health, leading to chronic diseases or limiting defence mechanisms. For the monetary valuation of annual health effects, the adequate approach would be to assess both the total **short-term effects** across one year and the **long-term effect** over a lifetime, expressed in yearly average costs that reflect the total duration of the air pollution related chronic health condition. Based on the epidemiologic literature available, the present study assesses parts of both short-term and long-term effects.

5.3 Health effects considered

There is no disease specifically due to air pollution. The latter can never be considered in any particular case to be the sole or even principal cause of changes in health. However, many studies have shown that air pollution – even for the concentrations of pollutants measured daily in Austria, France and Switzerland – may be harmful to health[17].

Since human health is a multi-dimensional entity which cannot be measured with one single parameter only, the impact assessment has to sum up the air pollution effects of a variety of health outcomes. On the other hand, the epidemiological data do not coincide with the requirements of this project's ultimate purpose which is the

[16] Although there are a number of national studies publishing 'national' exposure-responses, the present study considers meta-analytic summary estimates rather than national estimates. This is in line with epidemiologic reasoning, giving more weight to the overall results of all adequately conducted studies rather than to one single result, in light of the uncertainties and variabilities inherent to each study. Therefore, the periods of data acquisition may vary between the selected studies. This is not of major relevance for the health impact assessment since the derived joint estimates are 'summary measures'. The population baseline frequencies of outcome, in contrast, were obtained from the newest available data. For a detailed methodological description see: Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Air Pollution Attributable Cases – Technical Report on Epidemiology; Technical Report of the " Health Costs due to Road Traffic-related Air Pollution – An impact assessment project of Austria, France and Switzerland", Bern 1999

[17] WHO. Air Quality Guidelines for Europe. 2nd Edition. 1999.

assessment of air pollution related health costs. As a matter of fact, epidemiological research explicitly examines health outcomes which overlap and cannot necessarily be expressed in financial terms. Against this background of conflicting objectives, it was necessary to select several indicators meeting the following three criteria:

- The selected health outcomes are linked to air pollution;
- The selected health outcomes are sufficiently different from each other so as to avoid double counting of the resulting health costs;
- The selected health outcomes can be expressed in financial terms.

According to these selection criteria, for example, the air pollution related decrease in pulmonary function is not considered in the present study, since it occurs in parallel with other respiratory diseases and cannot be related to unique treatment costs.

The health outcomes considered in the present study are listed in Table 5-3. For the above mentioned reasons, **not all** the health outcomes known to be related to air pollution have been included.

Table 5-3 Air pollution related health outcomes considered

Health outcome	**Age**
Total mortality	Adults, ≥ 30 years of age
Respiratory hospital admissions	All ages
Cardiovascular hospital admissions	All ages
Chronic bronchitis incidence	Adults, ≥ 25 years of age
Acute Bronchitis	Children, < 15 years of age
Restricted activity days	Adults, ≥ 30 years of age
Asthmatics: asthma attacks	Children, < 15 years of age Adults, ≥ 15 years of age

5.4 Air pollution and human health

As described in Chapter 4.2 air pollution is a mixture of different substances. For the assessment of air pollution related health effects, the exposure has to be clearly defined. Thereby, specific pollutants that show the strongest possible correlation to health effects are chosen as indicators of the complex mixture. Important examples are particulate matter, nitrogen oxides (NOx), carbon monoxide (CO) or ozone (O_3). In reality, different impact patterns underlie the observed health effects of air pollution:
a) the different pollutants' independent specific effects,
b) the effect of mixtures and
c) the additional effects due to interactions between pollutants.

Epidemiological studies mostly report the effect of an indicator pollutant on health, without assessing the independent effects of the other components of the air pollution mix. Since many pollutants in ambient air are highly correlated due to their common sources, the selection of one or a few indicators is an adequate approach. Thus, a simple addition of the pollutants' specific impacts would lead to an overestimation of the overall impact. Regarding the health aspect, general ambient air pollution in urban regions, characterised by pollutants such as PM2.5, PM10, TSP, NO2, SO2 and others, needs to be distinguished from the additional air quality problem observed during summer only, e.g. oxidant pollution. For the present study it was decided to exclude the impact of oxidant pollution, although it likely causes additional and independent health effects. Instead, the annual mean level of one single indicator was chosen to represent the general ambient air pollution in urban regions. Based on the abundant epidemiological literature and evidence, **PM10** was chosen as an **indicator of air pollution** in the present study. Contrary to larger particles, particles < 5-10 μm in diameter are able to enter the pulmonary tract, where they interfere with the defence system of the bronchial tree and may cause inflammations.

As mentioned above, exposure-response functions will be used which report the association of health outcomes with the ambient average level of air pollution, rather than the association with personal exposure. So far, the impact of personal exposure on health outcomes has rarely been assessed and exposure-response functions for personal exposure are not available. Although the ambient average air pollution is not a perfect estimate for the real individual exposure, fine particles are rather homogeneously distributed across large areas and efficiently penetrate indoors. Thus, the epidemiologic approach can be considered a valuable approximation[18].

So far, epidemiological studies do not indicate a lower threshold for PM10 exposure, below which health effects don't occur. However, in the *epidemiological* literature, health impacts below a concentration level of 5-10 $\mu g/m^3$ (class mean 7.5 $\mu g/m^3$) are not sufficiently assessed and exposure-response curves below this level are not defined. Therefore, the present study does not consider health impacts below this lowest assessed level of 7.5 $\mu g/m^3$ PM10 (as annual mean).

5.5 The "at least approach"

In the domain of epidemiology, the following above mentioned aspects correspond to the selected "at least" approach prevailing throughout the whole project:

- Below the lowest assessed level of 7.5 $\mu g/m^3$ health effects are not considered
- The chosen effect estimates reflect the effect of the pollution mix prevailing in an urban environment. Specific independent effects of single pollutants are not taken into consideration.
- Seasonally limited air pollution related health effects, such as the impact of oxidant pollution in summer, are not considered in the present study.

Accordingly, the results are likely to be underestimated.

[18] Künzli N. , Tager I., 1997, The semi-individual study in air pollution epidemiology: a valid design as compared to ecologic studies. Environ Health Perspect 1997; 105: 1078-1083

5.6 The exposure-response functions of PM10 related health effects

Morbidity

For the assessment of air pollution attributable morbidity, hospital admissions, restricted activity days, bronchitis in children and asthma attacks were included as **short term effects** and applied to the annual observed frequencies of outcome for Austria, France and Switzerland. As a **long term effect**, chronic bronchitis in adults was considered. In order to monetarise yearly air pollution related costs, the effect estimates were applied to the incidence[19] of disease.

Excluded from the present study were short term effects such as school absentees, since they do not allow for monetary valuation. The short and long term impact of air pollution on pulmonary function has not been included in the present study, since this health outcome is related to other health outcomes already included in the assessment.

Cancer morbidity has not been an explicit part of this assessment either. However, mortality due to cancer has indirectly been included as part of the air pollution related impact on total mortality.

Mortality

In the present study, the impact assessment is based on the long-term effect on mortality rates in adult populations.

The impact of air pollution on mortality is a combination of acute as well as cumulative chronic effects. The assessment of each effect, the short-term advancing of death for frail people and the long-term shortening of life time related to air pollution, require different epidemiological study designs.

In the case of **short-term effects**, air pollution levels of a given day or short period of days may trigger an increase in death within days or weeks. Current air pollution levels do not lead anymore to an excess mortality comparable to that observed in London in the 1950s but nevertheless they do bring forward deaths among susceptible people. Short-term effects of air pollution are based on time series studies such as the APHEA project in Europe (Short-term effects of Air Pollution on Health, a European Approach)[20] and assess the temporal association between a rather short exposure period and the number of consecutive deaths.

An important question regarding the observed short-term effects of air pollution on mortality relates to the time of advancement of these deaths, which has to be evaluated[21]. For example, if air pollution episodes only advance death by a few days among an extremely frail population, this effect may be of little public health relevance.

---

[19] Incidence = the occurrence of new cases during the observed year. See glossary p. 5
[20] Katsouyanni K et al, 1996
[21] Quénel P et al, in press; Spix C et al, 1993

In terms of **long-term effects** of air pollution on mortality, the shortening of life-expectancy may be considered to be a consequence of cumulative long-term exposure, leading to both short-term and long-term morbidity. For example, lifetime air pollution exposure may lead to recurrent injury and, in the long term, cause chronic morbidity and, as a consequence, reduce life expectancy. In these cases, occurrence of death may not be associated with the short-term air pollution exposure pattern at all but rather with the course of the chronic morbidity. From a study design perspective, cohort studies address the association of exposure with time to death.

Accordingly, for the purpose of impact assessment, it was decided not to use daily time-series mortality studies to estimate the excess annual mortality but the **change in long-term mortality rates** associated with ambient air pollution.

Two US cohort studies[22] published the exposure-response function of ambient particulate pollution and long-term mortality. After observing large population groups for a period of many years and controlling for a large number of individual risk factors (such as smoking), a correlation between the frequency of death and the pollution level at place of residence was established. These cohort studies yield the additional number of deaths per person-year which may be directly applied to the yearly impact assessment. There is only one other cohort study published so far (Abbey et al 1995). The project, however, reported the impact of the number of hours above cut-off levels of exposure, which can not be translated into the exposure measures used in this project[23]. The impact assessment is, therefore, based on the long-term effect on mortality rates in adult populations (≥ 30 years of age) as reported in the two US studies[24]. In the epidemiological literature, the effect of air pollution has been demonstrated for total mortality. These effects are mostly driven by cardiovascular and respiratory disease.

For each health outcome assessed in the present study, Table 5-6 presents the **effect estimate** in terms of relative risk (column 2) and separately for each country, the **fixed baseline increment** (column 6-8). For each parameter the central value as well as the upper and lower boundary 95% confidence intervals have been established. These absolute numbers of health effects, presented as the number of cases per million inhabitants and per 10 µg/m3 of PM10, result from the country specific differences in frequencies of each health effect at a given concentration base and the population mean exposure level (see Table 4.8.3). These differences in **baseline frequencies** (column 3-5) may result from the different age structure (e.g. for biological reasons an older population has a higher mortality rate than a younger population) or from other factors, such as drinking and eating habits, smoking habits, different health care systems, etc., in the three countries. Therefore, the parameters of fixed baseline increment vary slightly between Austria, France and Switzerland.

[22] Dockery D et al, 1993; Pope CA et al, 1995: six city study and American cancer society study

[23] The most recent publication was not available during the project phase (Abbey, 1999)

[24] Prospective cohort studies report substantially larger effect slopes for long-term exposure than are indicated by daily time series studies. From an economical assessment perspective, the ideal measure to estimate the impact would be *years of life lost* due to air pollution. Unfortunately, the two cohort studies did not provide results in this format. Therefore, we propose quantitative steps and assumptions to transform the number of attributable cases into years of life lost. To be in line with the methods and populations of the two selected US studies, the baseline frequency of deaths per year was restricted to the number of natural deaths (without violent death) occurring among those aged 30 and older. See: Pope CA et al, 1995.

Reading example for Table 5-6:

The relative risk of long-term mortality for a 10 µg/m^3 PM10 increment is 1.043 (column 2), therefore the number of premature fatalities increase by 4.3% for every 10 µg/m^3 PM10 increment. Column 5 shows the number of deaths (adults ≥ 30 years) per 1 million inhabitants in Switzerland (8'263) and the expected number of deaths (7'794), if the PM10 concentrations were on average at 7.5 µg/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 µg/m^3 PM10 increment and per 1 million inhabitants corresponds to the 4.3% increase in mortality (column 2) applied to the baseline frequency of 7'794 deaths [25].

[25] D10 (fixed baseline increment) =7'794 (population frequency) x 0.043 (relative risk)

Table 5-6: Additional cases per million inhabitants and per 10 μg/m^3 of pollutant concentration (of PM10)[26]

	Effect estimate Relative Risk (±95% Confidence Interval)	Observed population frequency, Pe {expected baseline frequency Po at 7.5 μg/m^3 PM10 annual mean} per 1 million inhabitants			Fixed baseline increment per 10μg/m^3 PM10 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 Admission (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 Admissions (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 1409-5774	4 830 2 129-8 728	4 622 2 037-8 352
Restricted Activity Days 1) (adults ≥ 20 years)	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 2) (children < 15 years)	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 2) (adults ≥ 15 years)	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

1 Restricted activity days: total person-days per year
2 Asthma attacks: total person-days with asthma attacks

Pe: frequency as observed at the current level of air pollution
Po: the calculated expected frequency at the reference level of 7.5μg/m^3 PM10

[26] Annex 2 contains the medical definition of each health outcome. Source: Künzli N., Kaiser R., Medina S., Studnicka M., Oberfeld G., Horak F. (1999), Air Pollution Attributable Cases – Technical Report on Epidemiology; Technical Report of the " Health Costs due to Road Traffic-related Air Pollution – An impact assessment project of Austria, France and Switzerland", Bern 1999

5.7 The quantitative results of PM10 related health effects

From the average exposure of the population on the one hand and the epidemiological bases (fixed base line increment per 10 $\mu g/m^3$ PM10 per 1 million inhabitants) on the other hand, the number of health outcomes may be determined (compare also Figure 3.2, page 18).

These calculations may be done for today's exposure with 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.

In 1996 the residential population is

- **8.06 million** inhabitants in **Austria**,
- **58.26 million** inhabitants in **France** and
- **7.08 million** inhabitants in **Switzerland**.

On average, the population is exposed annually

- to **26.0 $\mu g/m^3$ PM10** in **Austria**,
- to **23.5 $\mu g/m^3$ PM10** in **France** and
- to **21.4 $\mu g/m^3$ PM10** in **Switzerland**.

The average annual exposure due to road traffic amounts

- to **8.0 $\mu g/m^3$ PM10** in **Austria**,
- to **8.9 $\mu g/m^3$ PM10** in **France** and
- to **7.4 $\mu g/m^3$ PM10** in **Switzerland**.

In Table 5-7 for Austria, France and Switzerland, the health effects considered in this study are presented for the average annual exposure to total air pollution and for the average annual exposure to road traffic-related air pollution. According to the epidemiological foundations, for each health outcome the respective age group is considered. Knowing the distribution of the different population groups across exposure classes (chapter 4.8) and the exposure-response function (chapter 5.6), the absolute number of health outcomes may be established for each country with or without the road traffic-related share of air pollution .

It needs to be remembered that the health effects are only considered from the exposure class of 5-10 $\mu g/m^3$ PM10 onwards (average 7.5 $\mu g/m^3$ PM10). This restriction reflects the fact that epidemiological studies have not yet included the exposure-response relationship below this level. In addition, it needs to be considered that there is a natural background concentration level which is not man made. For Austria, France and Switzerland this natural baseline pollutant level is estimated to be <7.5 $\mu g/m^3$ PM10. For the further assessment of air pollution measures it is adequate to only consider the air pollution of human activities.

Table 5-7 Additional cases of mortality and morbidity due to air pollution in Austria, France and Switzerland

Health outcome	Additional cases or days due to air pollution					
	Cases or days attributable to total air pollution			Cases or days attributable to road traffic		
	Austria	France	Switzerland	Austria	France	Switzerland
Long-term mortality (adults≥30 years)	5‘576 3‘370-7‘813	31‘692 19‘202-44‘369	3’314 1‘986-4‘651	2‘411 1‘457-3‘378	17’629 10‘681-24‘680	1’762 1‘056-2‘472
Respiratory hospital admissions (all ages)	3’399 358-6456	13’796 1‘491-26‘286	1‘308 138-2‘488	1‘470 155-2‘792	7’674 829-14‘622	694 73-1‘320
Cardiovascular hospital admissions (all ages)	6‘695 3‘489-9‘960	19‘761 10‘440-29‘362	2‘979 1‘544-4‘425	2‘895 1‘509-4‘307	10’992 5‘807-16‘333	1‘580 819-2‘348
Chronic bronchitis incidence (adults ≥25 years)	6‘158 552-12‘241	36’726 3‘262-73‘079	4‘238 374-8‘436	2‘663 239-5‘293	20’429 1‘814-40‘650	2‘248 199-4‘475
Bronchitis (children < 15 years)	47‘652 21‘008-86‘090	450’218 198‘450-813‘562	45‘446 20‘029-82‘121	20‘606 9‘085-37‘228	250’434 110‘388-452‘544	24‘109 10‘626-43‘565
Restricted activity days (adults ≥20 years)	3'106‘544 2'615‘175-3'604‘519	24'579‘872 20'692‘055-28'519‘982	2‘762‘682 2'325‘699-3'205‘536	1‘343‘371 1'130‘886-1'558‘711	13'672‘554 11'509‘956-15'864‘240	1'465‘600 1'233‘782-1'700‘534
Asthmatics: asthma attacks (children < 15 years)	34’665 21‘321-48‘174	242‘633 149‘141-337‘151	23’637 14‘532-32‘850	14‘990 9‘220-20‘832	134’965 82‘960-187‘540	12’539 7‘709-17 427
Asthmatics: Asthma attacks (adults ≥ 15 years, person days)	93’619 45‘594-142‘598	577’174 281‘130-879‘091	62‘593 30‘490-95‘345	40‘484 19‘716-61‘664	321‘053 156‘378-488‘994	33‘205 16‘175-50‘580

In Table 5-7, the negative effects of air pollution are only considered for the age groups assessed by epidemiological surveys and for an exposure above 7.5 µg/m^3 PM10. Furthermore, the results presented are divided into the number of health outcomes related to total air pollution and those related to road traffic share only.

Mortality

In 1996, air pollution caused some **5 600 cases of premature death** in Austria, some **31 700 cases** in France and some **3 300 cases** in Switzerland.

In Austria 2 400, in France 17 600 and in Switzerland 1 800 cases are attributable to road traffic-related air pollution.

According to the epidemiological foundations, the increase in premature mortality is only considered for adults ≥30 years of age and for the exposure class of 5-10 μg/m^3 PM10 (class mean 7.5 μg/m^3) onwards.

Morbidity

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

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

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

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

In 1996, for Austria a 15 000 **asthma attacks in children** (<15 years) and 40 000 **asthma attacks in adults** (≥ 15 years) are attributable to road traffic-related air pollution. France and Switzerland attributed 135 000 resp. 12 500 asthma attacks in children and 321 000 resp. 33 000 asthma attacks in adults were estimated, due to road traffic-related air pollution.

As may be seen later from the monetary valuation, the incidence in chronic bronchitis and the very high number of restricted activity days will be of particular relevance for the overall result.

6. The monetary valuation of air pollution related health effects

6.1 Monetarizing health effects – the main task

After having quantified the air pollution related health effects, based on the average ambient exposure to PM10 of the residential population of Austria, France and Switzerland, the last step consists in valuing the corresponding health costs in monetary terms. For every health indicator the specific costs per case need to be assessed. As with the previous steps, this procedure demands a number of simplifications and sometimes even critical assumptions, which will be presented in the following chapters.

Monetarizing health effects or even fatalities is often criticised outside the community of economic science. In the general public's opinion it is argued that human life cannot be expressed in monetary terms. This criticism is based on a misunderstanding, as the economic science does not try to assess the value of a specific life. What is being measured in monetary terms is the **benefit of a risk reduction** due to a lower pollution level, leading to a decrease in frequency of the different health outcomes.

For this type of assessment, the term **"value of preventing a statistical fatality"** (VPF) is often used in economic theory. It reflects the fact that a decrease in risk is valued before the negative results have already taken place. Hence, it does not value "ex post" a specific human being's life lost due to an air pollution related disease.

6.2 Methods available for the monetary valuation of mortality

In economic theory, two different valuation methods may be used for the assessment of mortality [27] :

- The **gross production / consumption loss:** In this approach, the costs of additional mortality cases are based on 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.

An intense discussion about their adequacy for the environmental impact assessment has been raised in the economic literature.

The gross production / consumption loss approach evaluates the loss caused by premature death from a society's perspective in general, without differentiating for the individual differences in risk of air pollution related mortality or fatal accidents, etc. Its use as a monetary indicator is limited to material aspects of life only. It

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

therefore is often combined with additional values for intangible costs, such as pain, grief and suffering of the victims and their relatives.

The main advantage of this approach consists of its simple and transparent calculation concept and therefore presents a suitable input for the political discussion on policy measures for a reduction in environmental impacts.

However, its main disadvantages are the following:

- The individual aversion of premature death is not considered in this approach, since it only covers material consequences of a fatality.

- Based on the society as a whole, it does not reflect a basic principle of (welfare-) economic theory according to which each valuation has to be based on the variations in the utility for the concerned individuals.

- An appropriate discount rate has to be chosen which has major implications for the valuation.

Another approach consists of the assessment of the **willingness-to-pay (WTP)** for the **value of preventing a statistical fatality (VPF)**. It attempts to estimate the demand (the willingness-to-pay) for an improvement in environmental quality. The central question is, how much are individuals ready to pay to improve their own security or the security of other people. Thus, the sum of individual willingness-to-pay indicates how much value is attributed to an improvement in security or a reduction of environmental impact by the society as a whole. The valuation of a risk reduction in mortality or the value of preventing a ”statistical” fatality is calculated by dividing the individual willingness-to-pay values for a risk reduction by the observed change in risk [28].

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

However, a number of disadvantages are often raised:

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

- If part of income loss is borne by the social insurance system of the country, this loss will not be considered by the individual, although it is part of the society’s costs.

---

[28] Example: A policy measure is able to reduce the yearly risk of fatal road accidents from 4 cases per 10’000 to 3 cases per 10’000. For this risk reduction of 1 case per 10’000, the individuals exposed to risk are ready to pay an average amount of 100 EUR. In this case, the value of a statistical prevented fatality amounts to 1 Million EUR (100 EUR/0.0001 risk reduction). Again, it needs to be recognised that the respondents are not asked about their willingness-to-pay for the avoidance of their own death but about the willingness-to-pay for a change in risk.

- It is often difficult for the individual to be sufficiently aware of the risk level at stake and the consequences on health. Individuals may not be familiar with small variations in risk which may imply large discrepancies between individual valuations.

- The main difficulty of the WTP approach lies in obtaining reliable and correct empirical estimations, because results are highly sensitive to the survey design.

Nevertheless, recent researches provide promising results. The chosen values for the present study are based on a contingent valuation method, where the direct comparison between money and risk of mortality is replaced by a sequence of chained interviews[29].

Most of the VPF values reported in the literature are based on the willingness-to-pay for a reduction in risk of fatal road accidents. The victims of road accidents typically have an average age of 30-40 years and the remaining average life expectancy for this age group is 35 to 45 years. In contrast, the victims of air pollution are on average of much higher age (about 70-80 years) and the remaining life expectancy in this age group is only 10 to 15 years. Since the life expectancy of the different types of risk is not the same, it seems that a VPF value based on road accidents has to be adapted.

6.3 The assessment approach for mortality chosen in the present study

The **common methodological approach** of the present study is based on the concept of **Willingness-to-pay (WTP)** for the **Value of a prevented fatality (VPF).** Unfortunately, so far no empirical studies have been conducted for air pollution related mortality risk[30]. Therefore, empirical results of road accident related WTP are used as a starting point. As mentioned below, these values have to be adapted to the specific context of air pollution. Choosing the WTP/VPF approach as a core method, the present study is based on the **welfare-theoretical foundation**.

The WTP/VPF concept starts implicitly from a **victim's scenario**. The impact of air pollution on the mortality risk is estimated for the cases of premature death (which are real but anonymous cases). It is assumed that there is a group of mortality cases due to air pollution, whereas air pollution has no impact on the rest of the mortality.

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, for the single case, a small reduction in life expectancy. Thus, it is assumed that air pollution constitutes a worsening risk factor for the whole population and not only for a specific subgroup. Its effects are considered to be equally distributed within the entire population.

As **partial assessment**, 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.

---

29 See also the explanations in chapter 6.3.1 and annex 4

30 A study is currently being conducted in France, whose results will not be available before January 2000 (see Greqam (1999), Economic and socio-anthropologic approach of air pollution.

- For **Austria and Switzerland** the partial assessment are established according to an extended version of the **gross production loss approach** based on the **victim's scenario**. 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 both countries.
- In **France** an alternative estimation of the mortality costs is established according to the **net loss of consumption approach**. In addition, these calculations will be based on the **whole population's scenario**.

Figure 6-3 presents an overall view of the chosen methodological approaches used in the present study.

Figure 6-3: Methodological approaches chosen for the cost assessment

	partial assessment		**main approach**
Valuation Methodology	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**

6.3.1 The willingness-to-pay approach for the mortality costs

The willingness-to-pay (WTP) approach for the value of a prevented fatality, or more precisely, for the utility resulting from a lower mortality risk, requires a cost assessment according to the individual preferences of the affected population. In the absence of air pollution related WTP values, and under the prevailing budget and time constraint for the present study, WTP values for fatal road accidents from previous studies had to be used and adapted to the context of air pollution related risk.

Screening the available literature[31] and comparing different studies from the 1990's, indicates a range of WTP values for the prevention of a statistical fatality of 0.7 to 6.1 million EUR. Two recent European studies, one of which was conducted on behalf of the European Community, apply a WTP value of 3.1 million EUR and 2.6 million EUR respectively[32]. In a project of the UK Department of Health for the year 1996,

[31] 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.

[32] WTP 3.1 million EUR → see: Institute of Environmental Studies, Norwegian Institute for Air Research, International Institute for Applied System Research (1997), Economic Evaluation of quality targets for sulphur dioxide, nitrogen dioxide, fine and suspended particulate matter and lead; ZEW / ISI (1997), External Quality Evaluation

WTP 2.6 million EUR (range from 2.1-3.0 Mio EUR) → see: See ExternE (1995), Externalities of Energie, Vol 2: Methodology the air pollution related value of the prevention of a statistical fatality (VPF) is estimated to be 1.2 million EUR (0.8 million £).[33]

The latest empirical study, conducted by Jones-Lee et al.[34] provides a VPF of 1.42 million EUR (range: 0.7-2.3 million EUR) (see annex 4).

Based on these latest results and the experience of former studies **a basic value of 1.4 million EUR** is adopted for the value of preventing a statistical fatality (**VPF**). This choice is supported by the high scientific quality of the quoted "chained survey method", the use of a similar starting value (1.2 million EUR) in a recent study on behalf of the UK Department for Environment, Transport and Regions (DETR) and the fact that it lies in the lower part of the range of the majority of empirical evaluations. This choice is in line with the "at least" approach prevailing throughout the entire project.

As mentioned above, the context of road accident related fatal risk differs from air pollution related risk which is to a large extent involuntary and beyond the responsibility and control of those exposed to it. In addition, while taking the risk of a traffic accident, driving itself offers a direct personal benefit. On the other hand, air pollution related risk is less often connected to a direct personal benefit, although it is to some extent transport induced. Because of this **different risk context**, air pollution related risk aversion is likely to be higher than for fatal road accidents[35]. The impact of the contextual difference between road accident and air pollution related risk on individual aversion is subject to different empirical studies and has produced factors in the range of 1.5 to 2. However, the empirical evidence is not considered to be sufficient and following the "at least" approach, the contextual adaptation of the WTP value is abandoned in the present study.

Based on the available epidemiological literature, a direct conclusion about the age structure of the air pollution related premature deaths is not yet possible. It is, however, known that these fatalities are mostly related to respiratory and cardiovascular disease and lung cancer[36]. In Austria, France and Switzerland, the average age of these respiratory and cardiovascular fatalities is between 75 and 85 years [37]. Hence, the average age of the air pollution related fatalities is much higher than for victims of fatal road accidents (30-40 years of age).

Theoretical as well as empirical evidence indicates a decreasing WTP with increasing age, with reduced remaining life expectancy and with reduced quality of life. For the present study, the relationship adopted is provided by the latest research of Jones-Lee [38]. Weighting the age structure of the fatalities due to respiratory and

---

[33] Department of Health (1999), Economic Appraisal of the Health Effects of Air Pollution, p. 65

[34] 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. see also annex 4: Chilton S., Covey J., Lorraine H., Jones-Lee M., Loomes G., Pidgeon N., Spencer A., New Research Results on the Valuation of Preventing Fatal Road accident Casualties.

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

[36] See: Künzli N. et al., Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases (1999).

[37] Austria: 79.8 years; France: 78.9 years; Switzerland: 80.2 years.

[38] Several studies by Jones-Lee show a reversed U-shaped relationship between the age and the willingness-to-pay. See: Department of Health (1999), Economic Appraisal of the Health Effects of Air Pollution, p. 67 and direct information of M. Jones-Lee (1998).

cardiovascular disease and lung cancer in all three countries by the age factor, an average adaptation factor of 61% is obtained for the present willingness-to-pay (WPT) for a prevented fatality (VPF) value.

Dealing with the fact that no sufficient empirical foundations are yet available, in the present study it was chosen to present two variations for the further calculations:

- **VPF: 0.9 Mio. EUR (=61% x 1.4 Mio. EUR)**
  The age related adaptation of the initial WTP value implies a very strict application of the **"at least-approach"** . The cost reducing adjustment for age is maintained, meanwhile the cost increasing adjustment for the risk context is abandoned
- **VPF: 1.4 Mio. EUR**
  Leaving the initial value unchanged, the adjustment for age and risk context are abandoned.

Table 6.3.1 presents the results of mortality costs based on the willingness-to-pay approach in Austria, France and Switzerland applying a value of prevented fatality of 0.9 and 1.4 million EUR respectively.

According to the epidemiological effect estimates and the base line frequency[39] for each country, Table 3.6.1 presents some **5 600 cases** of air pollution related premature mortality for Austria, **31 700 cases** for France and **3 300 cases** for Switzerland. Based on the assessment of pollutant concentration, the traffic-related premature mortality amounts to **2 400 cases** in Austria, **17 600 cases** in France and **1 800 cases** in Switzerland.

Comparing the figures with the number of annual fatal road accidents, this number seems to be relatively high. First of all it needs to be considered that fatal road accidents are personally identified victims of a road accident whereas the air pollution related premature deaths are anonymous, statistical cases which are part of the total number of fatalities of a country. This part of the annual deaths (violent death excluded) would not have occurred with a lower concentration level of air pollution. 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.

[39] see glossary

Table 6.3.1 Mortality costs for 1996 in Austria, France and Switzerland (1996)
Willingness-to-pay approach

	Austria		**France**		**Switzerland**	
	Cases attributable to total air pollution	Cases attributable to road traffic	Cases attributable to total air pollution	Cases attributable to road traffic	Cases attributable to total air pollution	Cases attributable to road traffic
Air pollution related premature deaths (long-term mortality, (adults ≥30 years)	**5'576** 3'370 – 7'813	**2'411** 1'457– 3'378	**31'692** 19'202 –44'369	**17'629** 10'681 – 24'680	**3'314** 1'986 – 4'651	**1'762** 1'056 – 2'472
Costs of mortality in million EURO "At least" with adjustment for age, without adjustment for risk context	**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
Without adjustment for age and risk context	**7'807** 4'717 – 10'938	**3'376** 2'040 – 4'730	**44'369** 26'883 – 62'117	**24'681** 14'953 – 34'552	**4'640** 2'780 – 6'511	**2'467** 1'478 – 3'461

Looking at the costs of air pollution related premature mortality, the same proportions are obtained for the monetary values as for absolute cases, as the same willingness-to-pay (WTP) for a statistically prevented fatality (VPF) is being used in every country.

Adjusting the cost assessment for the lower WTP due to the higher average age of air pollution related victims, yields in the three countries a value which is nearly 40% lower than without any age adjustment.

Based on the approach without any adjustments, the road traffic-related mortality costs amount to **3 380 million EUR** in **Austria**, to **24 680 million EUR** in **France** and to **2 470 million EUR** in Switzerland.

The ”at least” approach provides road traffic related costs of **2 170 million EUR** for **Austria**, **15 870 million EUR** for **France** and **1 590 million EUR** for **Switzerland.**

6.3.2 Partial assessment of mortality costs

In addition to the common approach chosen for the monetary valuation of mortality costs based on the willingness-to-pay approach, the present study also contains a partial assessment. As mentioned in chapter 6.3, in **Austria** and **Switzerland** the partial assessment is based on the **gross production loss approach** applied to the **victim’s scenario**, whereas in **France**, the **consumption loss approach** is applied to the **whole population’s scenario**. The production and consumption loss approach are both limited to material costs of mortality and do not contain the intangible aspects, such as pain, suffering and loss of life quality of the victim.

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. For Austria and Switzerland, the application of the gross production loss approach allows a comparison with former evaluations of the road traffic-related costs of fatal accidents.[40] In the case of Switzerland the approach is extended by combining the gross production with an additional cost element for immaterial costs for pain, grief and suffering of the victims and their relatives. However, for this intangible cost factor a proxy-value based on the compensation granted by the courts for death and bodily harm is taken as an indicator.

The main methodological characteristics of the gross production loss approach are the following:

- Using the **gross output** as an indicator, the total value of a lifetime’s production is considered. It contains the proper consumption which constitutes a personal benefit for the individual as an integrated part of their total production value contributed to society. As an indicator for the gross output, the total national labour income is divided by the whole population without differentiating by socio-economic characteristics such as unemployment, work at home, retirement or invalidity. This calculation of the average per capita loss of production is based on the assumption that every person regardless of socio-economic status, contributes in one way or another to the welfare and the development of a nation.

---

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

- This average yearly capital loss of production is further determined for the **average number of years** lost due to premature death. Based on epidemiological findings, the average age of victims due to respiratory and cardiovascular disease and lung cancer is 80.2 years in Switzerland and 79.9 years in Austria, where the corresponding life expectancy is **9.5 years** for this age class in Switzerland and **9.7 years** in Austria respectively.
- Considering the number of years lost, the production loss has to be established over a period of many years. It is therefore necessary to apply a real growth rate of production and a rate of discount[41.] For the purpose of this calculation it is assumed that the real growth rate of production corresponds to the rate of discount (2%).

Combining the average national per capita production loss with the average number of life years lost, the following results are obtained for the cases of premature mortality in Austria and Switzerland (see also Table 6.3.2-1).

The national labour income in Austria and Switzerland amount to some 130 thousand millions EUR and 145.9 thousand millions EUR respectively. The resulting average annual income is 18’230 EUR per capita in Austria and 20 600 EUR per capita in Switzerland. Considering an average life expectancy of 9.5 years in Switzerland and 9.7 years in Austria for air pollution related mortality, an average production loss of a fatality amounts to 177'100 EUR in Austria and 195 700 EUR in Switzerland.

[41] When an individual dies or becomes disabled, the loss of time (from work or leisure 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. According to the normal, empirically established time preference, 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, the lower is the value given to future costs (or losses).

The values of growth rate and discount rate depend on the specific situations. An international review on the calculation of the economic costs of road accidents in 13 European countries showed that the applied growth rates 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.)

Table 6.3.2-1 Mortality costs based on the gross production loss in Austria and Switzerland (1996)

	Austria		Switzerland	
	Total air pollution	Road traffic-related air pollution	Total air pollution	Road traffic-related air pollution
Number of deaths due to air pollution (long term mortality, adults ≥30 years)	5’576 3'370 – 7’813	2’411 1'457 – 3’378	3’314 1'986 – 4’651	1’762 1'056 – 2’472
Costs of mortality in million EURO				
Gross loss of production	987 597 –1’383	427 258 - 589	649 389-910	345 207 - 484
Intangible costs (based on compensation payments granted by courts)	–	–	447 268-627	238 142 - 333
In Total million EURO	**987** 597 –1’383	**427** 258 - 589	**1’095** 656 – 1’537	**582** 349 - 817

For the Swiss results, in addition to the production loss, the intangible costs (for pain, grief and suffering) were established based on compensation payments granted by Swiss courts. In the absence of Swiss willingness-to-pay studies for air pollution related mortality, the approximate value for intangible costs amounts to 134 800 EUR, in Switzerland. According to Table 6.3.2-1 air pollution related costs amount to some **987 million EUR** in Austria and **1 100 million EUR** in Switzerland, of which **427 million EUR** and **580 million EUR** respectively are attributable to road traffic-related air pollution.

As an alternative, the partial assessment for **France** was established based on the **whole population scenario** applying the consumption loss approach (see also annex 5). The number of air pollution related years of life lost was calculated for the whole population in a first step. In a second step, the average life expectancy for the whole population was established for a hypothetical situation with reduced air pollution.[42] The difference between the two results indicates the survival rate and the life expectancy without traffic-related air pollution. The life expectancies are computed for each gender separately due to differences in death rates between male and female (see Table 6.3.2-2).

---

[42] See Annex 4

Valuing the loss of human life based upon the **household final consumption** per inhabitant based on the **whole population scenario** is motivated by several reasons. First of all, consumption seems to be a reliable approximation for the individual utility of material aspects of life, as most of our everyday acts require expenses (dwelling, food, travel, health care, leisure, etc.) in order to satisfy fundamental needs. This approach also constitutes a convenient way to avoid a direct valuation of human life which is always a 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. In addition, by using the whole population approach, the resulting size of the average loss of life expectancy does not demand any discounting.

The final household consumption in France amounts to some 726.2 thousand millions EUR in 1996. Thus, per inhabitant a final consumption per year of 12 583 EUR is obtained.

Table 6.3.2-2: 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 Mio. 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	

According to Table 6.3.2-2, in France the costs of air pollution related mortality, based on the loss of consumption, reach a value of **3 916 million EUR**, of which **2 216 million EUR** are road traffic induced[43].

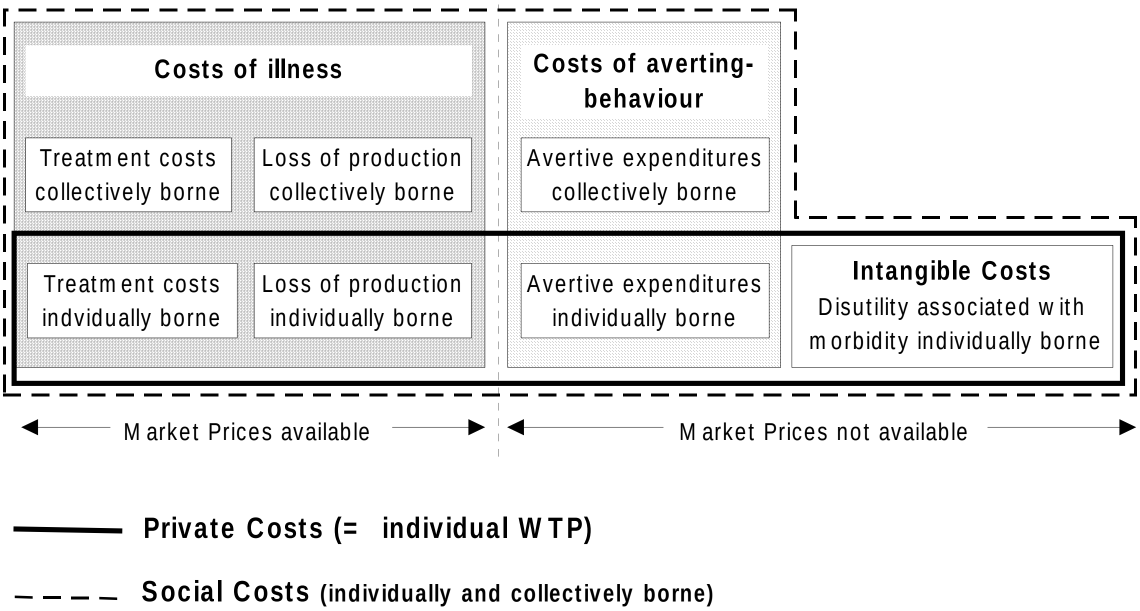
6.4 The monetary valuation of morbidity

6.4.1 Methods available for the monetary valuation of morbidity

From an economic point of view, the costs of morbidity may be subdivided by two main criteria, namely by the cost component and by the entity in charge of paying them. As shown in Figure 6.4.1-1, the costs of illness, the costs of averting behaviour and the intangible costs are three different components. They are either borne privately or in the case of cost of illness and costs of averting behaviour collectively as well.

43 On the whole, 311'225 years are lost due to air pollution. According to the victims scenario, 31'692 premature deaths are due to air pollution. Thus, the 311'225 years correspond formally to a victims 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 provide such close results.

Figure 6.4.1-1 : Overview on the costs of morbidity



Costs of illness (COI) contain the loss of production due to a possible incapacity to work and the medical treatment costs. They determine the "material part" of the health costs and may be assessed on the basis of real market prices (loss of earnings, costs for medicaments, costs per day in hospital, etc.).

Costs of averting-behaviour result from a different behaviour due to air pollution. The abstention from outdoor sport activities during a summer day with high ozone concentration, the installation of air filters or a different choice of residential location to avoid high levels of air pollution are some current examples. The higher the costs for avoiding measures, the smaller will likely be the number of air pollution related morbidity cases. Considering the extent of avoiding measures taken so far, neglecting the costs of averting behaviour may result in a considerable under estimation of the morbidity costs. However, for the assessment of these costs market prices are mostly in-existent.[44]

The third essential component of morbidity costs are the **intangible costs** reflecting the individual loss of the victims utility and consist of pain, grief and suffering due to a disease. Based on empirical evidence, the risk aversion of morbidity is mainly determined by these inconveniences (losses in utility).[45]

In order to draw a complete picture of the total morbidity costs, individually borne private costs and the costs borne collectively, e.g. by a social security system, have to be considered. All components together constitute the social costs of morbidity.

Similar to the methodological possibilities for the monetary valuation of mortality, the morbidity may be assessed with different methodological approaches. For the costs

---

[44] 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.

[45] Compare e.g. Maddison D. (1997), Valuing the morbidity effects of air pollution, p. 9. MIMEO

of illness (COI) containing the production loss and medical treatment costs, the **damage cost approach** is used. Based on market prices, it assesses all individually as well as collectively borne material costs. However, for the costs of averting behaviour and the intangible costs, this approach is not suitable, since market prices are mostly in-existent.

The **willingness-to-pay approach** focuses on the individually borne costs (private costs). It establishes the individuals utility of a risk reduction in air pollution related morbidity and reflects all costs the individual expects to bear in case of disease, such as loss of earnings, costs of averting behaviour or intangible costs.

As mentioned above (chapter 6.2) the advantage of the willingness-to-pay approach consists of its integration of material and intangible costs, that cannot be measured by any other method but which are often considerably higher than material costs. However, the disadvantage consists of its limitation to individually borne costs, especially when a large part of health costs is borne by collective means.

The following procedure is chosen for the assessment of morbidity costs:

As **partial assessment** the morbidity costs are estimated by the costs of illness approach (COI) only, without taking the intangible costs into account. Clearly, this procedure leads to a considerable under-estimation of the real morbidity costs.

A better approximation for the estimation of social costs of morbidity is obtained by using the **willingness-to-pay approach.** In this approach the privately borne intangible costs are included and reflect the aversion against the risk of morbidity related restrictions (such as limited mobility, pain, grief and suffering). Yet, this approach does not cover all the social costs, since it does not include the collectively borne cost elements at all.

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

6.4.2 The willingness-to-pay approach for the morbidity costs

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 separately,[46] namely :

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

Unfortunately, the literature on WTP based, air pollution related morbidity costs is very rare in Europe and most available studies refer to the US context. Their application to Europe is not completely appreciated and recent results provide lower

[46] For a detailed description of the symptoms see: Künzli et al., Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases (1999), chapter 4.9.

results for a European country [47] . The different socio-cultural background and the difference in health care and insurance system demand for an application of country specific WTP results. In spite of this problem, the present study had to be based on existing values since the available resources did not allow for an empirical survey within this project.

A further problem prevailing in literature is the lack of comparability between the different definitions of a given health status. In contrast to mortality, morbidity can be assessed at very different stages with inherent differences in the victims health status. In recent literature this problem is tackled by combining WTP values with a ”health status index”[48] . This procedure ranks the morbidity related reduction in wellbeing on a scale from 0 to 10, based on various symptoms and their effect on the patients social, physical and mobility activities. This statistical relationship between morbidity and its effects on health status for some health indicators with a known WTP value, could then be used to establish the WTP for air pollution related health outcomes. This procedure was applied to bronchitis, asthma attacks and restricted activity days. For hospital admissions and chronic bronchitis empirical results from other studies had to be adopted, since the above quoted literature on health status index did not provide any WTP values for these health outcomes.

Table 6.4.2-1 presents the WTP for avoiding different air pollution related health outcomes.

Table 6.4.2-1 WTP for the avoidance of air pollution related health outcomes

Health indicator	**WTP-Value (EUR)**	
Respiratory Hospital Admission	7’870	per admission(49)
Cardiovascular Hospital Admission	7’870	per admission(50)
Chronic Bronchitis	209’000	per case(50)
Bronchitis	131	per case(51)
Restricted Activity Day	94	per day(51)
Asthmatics: Asthma attacks (person day)	31	per attack(51)

Applying these WTP values to the number of air pollution related cases in each country, the total costs for each health outcome may be estimated[52].

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

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

49 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 Methodolgy.

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

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

52 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.

The following Tables 6.4.2-2 to 6.4.2-4 present the number of cases and the total air pollution related costs as well as the road traffic-related costs for each health outcome in Austria, France and Switzerland.

Table 6.4.2-2 Costs of air pollution related morbidity according to the 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 (million EUR)	Cases or days	Costs (million 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)	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)	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 Cost of morbidity		**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** vary strongly for the different health outcomes:

- From **2,7 million** EUR for **acute bronchitis in children** older than 15 years to **560 million EUR** for the **chronic bronchitis** in adults (incidence);
- concerning the categories in days, from about **half a million EUR** for **asthma attacks** in children younger than 15 years to some **130 million EUR** for the **restricted activity days** of adults.

In Austria, the total morbidity costs amount to some **1 670 million EUR** of which some **720 million EUR** are attributable to **road traffic-related air pollution**.

Table 6.4.2-3 Costs of air pollution related morbidity according to the 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 (million EUR)	Cases or days	Costs (million 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)	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)	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 Cost of morbidity		**10 334.7** 2 760.0–18 536.6		**5 748.7** 1 535.2–10 311.0

The WTP based values for France provide even larger variations in the attributable to **the road traffic** related costs for different health outcomes:

- From **33 million** EUR for **acute bronchitis in children** older than 15 years to **4’270 million EUR** for the **chronic bronchitis** in adults (incidence) and
- concerning the categories in days, from about **4 million EUR** for **asthma attacks** in children younger than 15 years to **1'290 million EUR** for the **restricted activity days** of adults.

In France, the total costs amount to some **10 300 million EUR** of which some **5 700 million EUR** are attributable to **road traffic-related air pollution**.

Table 6.4.2-4 Costs of air pollution related morbidity according to the willingness-to-pay approach in Switzerland 1996

	Morbidity attributable to air pollution with road traffic share		Morbidity attributable to road traffic	
	Cases	Costs (million EUR)	Cases	Costs (million 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)	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)	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 Cost of morbidity		**1 187.8** 314.0 – 2 133.6		**630.1** 166.7 – 1 131.8

Using the WTP approach, the costs of morbidity in Switzerland attributable to **the road traffic share** show a very similar variation as in Austria:

- From **3.2 million** EUR for **acute bronchitis in children** older than 15 years to **470 million EUR** for the **chronic bronchitis** in adults (incidence);
- concerning the categories in days, from about **0.4 million EUR** for **asthma attacks** in children younger than 15 years to **138 million EUR** for the **restricted activity days** of adults.

In Switzerland, the total morbidity costs amount to some **1 200 millions EUR** of which some **630 million EUR** are attributable to **road traffic-related air pollution**.

Compared to the mortality costs (see table 6.3.1), the morbidity costs are to a **factor 3** lower. Nevertheless, they have to be regarded as considerable costs.

6.4.3 Cost of illness (COI) as partial assessment of morbidity costs

As Figure 6.4.1-1 shows, in the cost of illness 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 and must be interpreted imperatively as a lower boundary of the real morbidity 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, with and without a job, etc. A differentiation of the production loss according to the socio-economic status of a person (working, jobless, retired, working at home, etc.) is not necessary.

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[53]
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[54]
Average gross production loss per day	50 EUR	55 EUR	56.5 EUR

- **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

---

53 Public subsidies included.

54 Public subsidies included.

and their costs were evaluated[55]. This value has been adopted for all three countries.
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 of 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[(56)]	220 EUR	220 EUR	220 EUR
Average disease duration per case (assumption)	15 years	15 years	15 years

- **Bronchitis**
  For bronchitis, the treatment costs are assessed based on the medication use (medication turn over) and amount to some 25 EUR in Austria, 39 EUR in France and 33 EUR per case in Switzerland.
  Similar to the chronic bronchitis, for the assessment of the production loss data on the corresponding disability of work are lacking.

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

- **Restricted activity days**
  In epidemiological literature, a homogeneous definition for restricted activity days is missing. It may comprehend days laid up with disability for 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.

- **Asthma Attacks**
  The assessment of treatment costs is again based on the above mentioned special evaluation for Switzerland. The treatment costs are calculated on the base of the daily dose of bronchiodilators. Per day, these costs amount to an average of 0.3 EUR for Austria and 0.55 EUR for France and Switzerland per asthma attack.

---

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

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

Once again, the estimation of the production loss had to be abandoned, since it is not know how often and to which 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[57]	0.55 EUR

Tables 6.4.3 - 1 to 6.4.3 - 3 present the partial assessment of morbidity costs as follows:

In **Austria**, air pollution related costs of illness in 1996 amount to some **105 million EUR**, with a road traffic-related share of **45 million EUR (43%).** Using the cost of illness approach, the costs of morbidity attributable to the road traffic share vary considerably for the different morbidity categories: comparing the health outcomes, from **0,5 million EUR for bronchitis of children** older than 15 years to some **28 million EUR for cardiovascular hospital admissions** (all ages).

According to the size of the population in **France**, the air pollution related costs of illness in 1996 amount to a total of **297 million EUR**, with a road traffic-related share of **165 million EUR (55%).** Unlike in the two other countries, the **chronic bronchitis in adults** induces the highest costs with **67 million EUR**, followed by the **cardiovascular hospital admission (52 million EUR)** and the **respiratory hospital admission (35 million EUR).**

In **Switzerland** the air pollution related costs of illness in 1996 amount some **55 million EUR** with a road traffic-related share of some **29 million EUR (53%).**
As in the case of Austria, the **cardiovascular hospital admission** are responsible for most of the costs (**15 million EUR**), followed by the costs for **chronic bronchitis in adults** (**7.4 million EUR)** and the costs for **respiratory hospital admissions (5.5 million EUR)**.

As mentioned above, it needs to be pointed out that missing data prevented the assessment of the production loss for various health outcomes. In contrast to the WTP approach, the cost of illness do not contain intangible costs (pain, grief and suffering). However, the wish, not to fall ill is to a large extent determined by these intangible costs. Compared to the WTP results (tables 6.4.2.1-3) 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.

- 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 on the willingness-to-pay indicate that restricted activity days cause considerable

[57] Based on the Swiss value.

troubles. Even if the WTP-value per day is not very high, the large number of restricted activity days leads to a high total amount.

Table 6.4.3-1: Costs of illness due to air pollution in Austria 1996

Austria	Morbidity attributable to total air pollution				Morbidity attributable to road traffic-related air pollution			
	Cases or days	Loss of production (Mio. EUR)	treatment costs (Mio. EUR)	costs of illness (Mio. EUR)	Cases or days	Loss of production (Mio. EUR)	treatment costs (Mio. EUR)	costs of illness (Mio. EUR)
Respiratory hospital admissions (all ages)	3 339 358 - 6 456	3.3 0.4-6.3	15.1 1.6-28.6	18.4 1.9-34.9	1 470 155-2792	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)	6158 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)	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 cost of illness in Mio. EUR				**104.6** **38.0-173.7**				**45.2** 16.4-75.1

Table 6.4.3-2: Costs of illness due to air pollution in France 1996

France	Morbidity attributable to total air pollution				Morbidity attributable to road traffic-related air pollution			
	Cases or days	Loss of production (Mio. EUR)	treatment costs (Mio. EUR)	costs of illness (Mio. EUR)	Cases or days	Loss of production (Mio. EUR)	treatment costs (Mio.	costs of illness (Mio. 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)	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 cost of illness in Mio. EUR				**296.8** **75.3-534.3**				**165.1** 41.9-297.2

Table 6.4.3-3 Costs of illness due to air pollution in Switzerland 1996

Switzerland	Morbidity attributable to total air pollution				Morbidity attributable to road traffic-related air pollution			
	Cases or days	Loss of production (Mio. EUR)	treatment costs (Mio. EUR)	costs of illness (Mio. EUR)	Cases or days	Loss of production (Mio. EUR)	treatment costs (Mio. EUR)	costs of illness (Mio. 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)	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 cost of illness in Mio. EUR				**54.8** **18.0-93.2**				**29.0** 9.5-49.4

6.5 The ”at least approach”

As in both of the other domains, air pollution and epidemiology , the economic assessment of the air pollution related health costs contain a number of assumptions. In general, the single decisions have all been taken according to the "at least" approach - either for methodological reasons or for reasons of restricted data availability.

For the assessment of **mortality** related health costs, the **willingness-to-pay approach** was chosen as common methodological framework, leading for two reasons to a conservative estimate:

- The willingness-to-pay approach is based on individual perceptions of mortality risk and does not include collectively borne costs. According to the different health care systems, these costs may be a considerable part of the social costs of air pollution related morbidity.
- In absence of empirical results, the adopted willingness-to-pay approach was based on WTP values for fatal traffic accidents. However, a number of empirical studies indicate a risk context related increase in WTP for air pollution related mortality. Not considering the risk context related adjustment , the present study tends towards a low WTP value, especially when the age related adjustment factor decreasing the WTP value, is used alone.

The partial assessment of **mortality** related health costs is based on the **production /consumption** loss approach. This procedure is an extreme implementation of the "at least" approach in so far, as it does not include a major aspect of mortality risk related costs, namely the intangible costs. Even the Swiss extended production loss approach, integrating the compensation payments granted by courts, offers a very low and insufficient proxy for this cost component.

Due to the three morbidity cost components - cost of illness, cost of averting behaviour and intangible costs - which may be borne collectively or privately, a complex structure results for the cost assessment. Unfortunately, no methodological approach is available, covering all the cost components, whereas those available, have often common interfaces. Thus, for methodological reasons, choosing one approach only, avoids the problem of double counting but does never cover the entire air pollution related morbidity costs. Being on the "at least" side is therefore inherent to this choice.

Again, for the assessment of **morbidity** related health costs, the **willingness-to-pay approach** was chosen as common methodological framework. As mentioned above, it only reflects the privately borne cost components without considering collectively borne costs.

The partial assessment of **morbidity** related health costs is based on the cost of illness (COI) approach. Since it does not include the intangible costs, it provides a very extreme interpretation of the "at least approach" . In addition, for some health outcomes, the cost of illness included the medical treatment costs only, as for the production loss related to these health outcomes, no data is presently available. This restriction is imposed to chronic bronchitis in adults and asthma attacks. In absence of empirical data, for the very great number of restricted activity days no costs of illness could be established at all.

All the above mentioned restrictions for the assessment of air pollution related costs of mortality and morbidity combined, lead to a very cautious result, which may be interpreted as the "at least" occurring monetary valuation.

7. The results: Air pollution related health costs in Austria, France and Switzerland for 1996

7.1 Recapitulation of findings

Comparing the WTP based assessment and the lower boundary cost estimation, a large difference appears between the two results. As the willingness-to-pay approach integrates the material and intangible costs, it is considered to be a more realistic approximation of the total social costs. For this reason, the **willingness-to-pay** approach is considered to be the **common methodological framework** for the economic valuation of health costs. It includes the material costs such as costs for ambulant or stationary treatment, reduced capacity leading to production or consumption losses as well as the intangible costs of pain, fear, suffering, diminished pleasure and loss in life quality.

Table 7.1 presents an overview of the air pollution related health costs in Austria, France and Switzerland based on the willingness-to-pay approach for the year 1996. The results are based on a **value for a prevented fatality** of **0.9 million EUR** (including an adjustment for an age related decrease in WTP). Using the WTP value of 1.4 million EUR for a prevented fatality (without any adjustment), provides 55% higher results for mortality costs.

Table 7.1 Air pollution related health costs in Austria, France and Switzerland in 1996 based on the willingness-to-pay approach (VPF 0.9 Mio. EUR)

	Austria		**France**		**Switzerland**	
	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic
Costs of mortality (Mio. 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 (Mio. EUR)	**1 669** 396-3 044	**722** 171–1 316	**10 335** 2 760–18537	**5 749** 1 535–10311	**1 188** 314– 2 134	**630** 167–1132
Total costs (Mio. 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

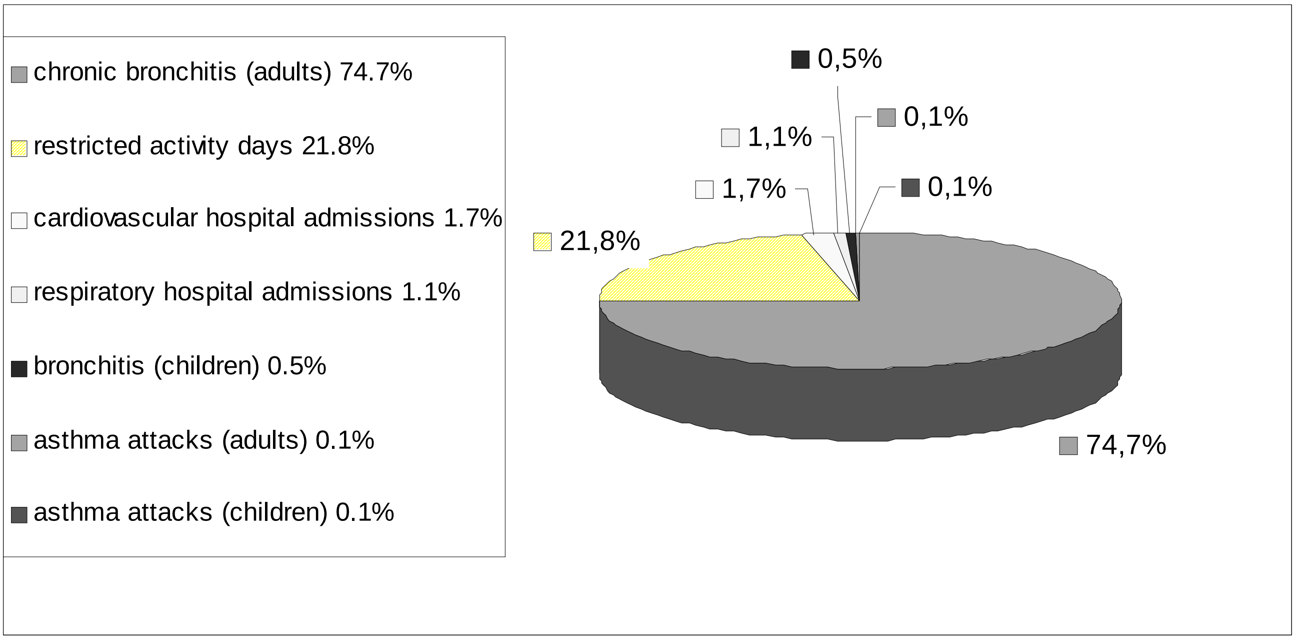
Due to the similar size of their population, in Austria and Switzerland the air pollution related health costs in 1996 reach a similar level of **6 700 million EUR** and **4 200 million EUR** with a traffic-related amount of **2 900 million EUR** and **2 200 million EUR** respectively. In France the overall air pollution related health costs amount to

38 900 million EUR of which a **21 600 million EUR** are road traffic-related. All three countries together have to bear some **49 700 million EUR** of air pollution related health costs, of which some **26 700 million EUR** are road traffic-related.

In each country, the **mortality costs are predominant**, amounting to **more than 70 %** . Since the same methodology was used in all three countries and the environmental, medical and socio-economic context is quite similar for the three neighbouring countries, the similarity of the results is not astonishing.

As shown in Figure 7-2, within the **costs of morbidity**, for all three countries together by far the highest value arises from **chronic bronchitis (74%)** followed by the costs for **restricted activity days (22%).** For chronic bronchitis, the willingness-to-pay for avoiding this health outcome is considerable (209'000 EUR per case), as this disease signifies a low health status with major constraints to the wellbeing of a victim. For the restricted activity days, although a relatively low willingness-to-pay value of 94 EUR per day is recorded, it is the high number of such days - 30'450'000 days for all three countries together – that inflates the total amount of costs.

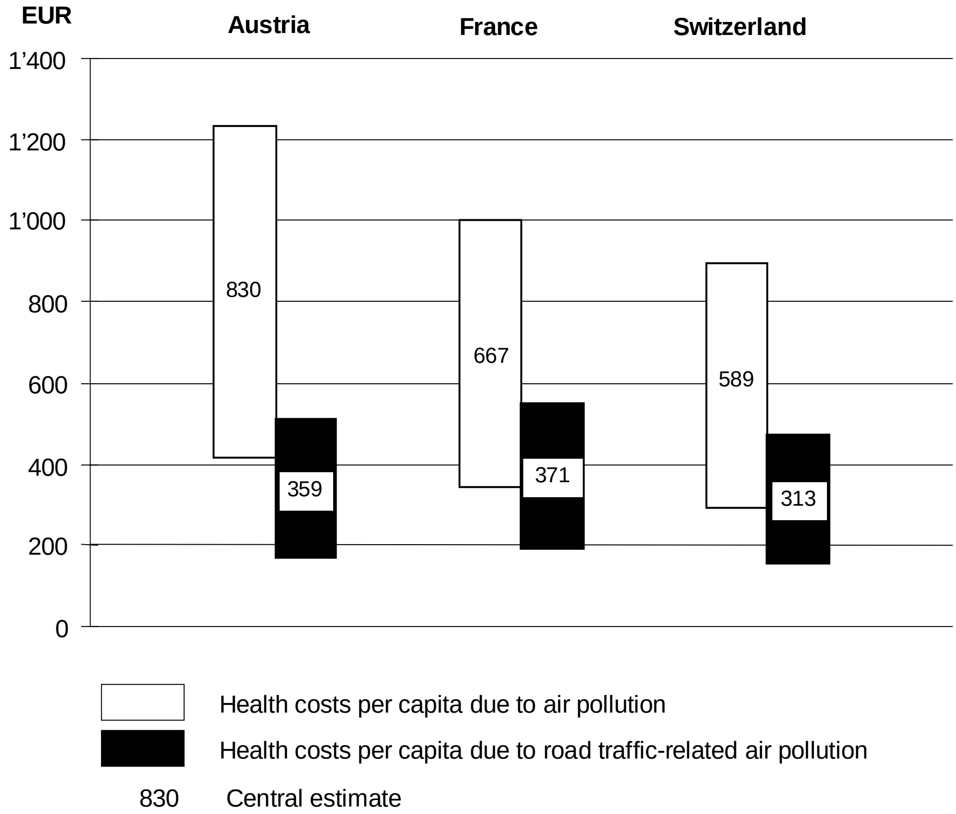
Figure 7-2 Total air pollution related morbidity costs by health outcome for Austria, France and Switzerland together (1996)



Total amount 13'191 mio. EUR

In order to compare the results between the three countries, **Austria, France** and **Switzerland** a conversion into per capita costs is necessary (Figure 7-3).

Figure 7-3 Air pollution related health costs per capita (1996)



Comparing the **total air pollution related costs per capita**, the differences observed between the three countries are of some significance although the ranges largely overlap. The highest per capita costs are registered for **Austria (425-1 250 EUR)**, followed by **France (344-1 004 EUR)** and **Switzerland (297-892 EUR per capita**). However, in view of the range of uncertainty (shown in Figure 7-3), the differences are within the uncertainty range of the models.

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 (baseline frequency) and air pollution related specificity. In fact, in Austria the highest population mean PM10 exposure of 26.0 $\mu g/m^3$ was estimated, compared to the other countries (France: 23.5 $\mu g/m^3$; Switzerland: 21.4 $\mu g/m^3$). The incremental cases of premature mortality per each increase of 10 $\mu g/m^3$ PM10 and per million inhabitants is somewhat higher in Austria (374 cases) compared to France (340 cases) and Switzerland (337 cases). Both effects together are the reason for the somewhat higher level of air pollution related health costs in Austria.

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 values (100%=313 EUR central value; 158-474 EUR) and only 3% higher than the Austrian values (100%=359 EUR; 184-541 EUR). The relatively modest differences are due to the similar absolute level of the road traffic-related air pollution. The estimations provide a road traffic-related population weighted mean concentration of 8.9 µg/m³ PM10 in France[58], of 8.0 µg/m³ PM10 in Austria and of 7.4 µg/m³ PM10 in Switzerland.

Comparing the **total air pollution related health costs** relative to the **gross domestic product** (GDP) the countries share are again similar, with **3.8% for Austria** (range: 2.0%-5.8%), **3.2%** for **France** (range:1.7%-4.9) and **2.1%** for **Switzerland** (1.1%-3.2%). Again, the **road traffic-related health costs** in percent of the national GDP vary much less between the three countries (0.6-2.3% of GDP) and for all three nations together, the average road traffic related share of GDP amounts to **1.7%.**

According to the country specific needs, in addition to the WTP-approach a **partial assessment** has been estimated for 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 compensation payments granted by courts for fatal accidents as a very low proxy for the intangible costs.

Table 7-6 Partial assessment of road traffic-related health costs in (1996) based on the gross production / consumption loss approach

	Austria		**France**		**Switzerland***	
	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic	Costs attributable to total air pollution	Costs attributable to road traffic
Costs of mortality (Mio. EUR)	**987** 597-1 383	**427** 258-598	**3916** 2 403-5 472	**2 216** 1 352-3 118	**1 095** 656-1 537	**582** 349-817
Costs of morbidity (Mio. EUR)	**105** 38-174	**45** 16-75	**297** 75-534	**165** 42-297	**55** 18-93	**29** 10-49
Total costs (Mio. 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

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

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

58 As mentioned above, due to a lack of data, the assessment of the road traffic-related share of PM10 concentration in France was based on Swiss results.

The differences between the countries are mainly based on the country specific calculation methods. Different cost levels for the production or consumption loss approach and the medical treatments have been applied in each country.

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).
The **interpretation of the estimated partial assessment** may therefore not neglect that a **considerable part** of road traffic-related health costs (the intangible costs, such as pain, suffering, grief, fear of mortality and morbidity) is **not included** (or in the case of Switzerland, insufficiently included).

7.2. Sensitivity aspects

The range of the present results indicate that the results are based on a set of assumptions and decisions, incorporating a certain degree of uncertainty. As mentioned above, the assumptions always conform to the ”at least” approach. Hence, the present results must be regarded as a minimal cost level.

The sensitivity of the total results depends firstly on the number of cases of premature mortality and their predominant costs. The following aspects have a particular 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 [59]

An approximate PM10 emission inventory was available for Switzerland. No equivalent data were available for the other two countries. This represented an important restriction and determined the choice of method for modelling the PM10 concentrations.

The quality of the country specific models was 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, which is in line with the 'at-least' approach of the overall project.

Many assumptions and estimations had to be made for the calculation of the population exposure. The air pollution team judges the results of total PM10 exposure and of the road traffic share as "best available estimate" that could be

[59] For an detailed discussion, see Health Costs due to Road Traffic-related Air Pollution, PM_{10} Population Exposure (1999).

obtained on the basis of the now available measurements and emission data. The differences of the PM10 population exposure between the countries are relatively small and within the uncertainty range of the models. Nevertheless, the differences may show the tendency that in (Eastern) Austria the PM10 concentration is higher due to a higher PM10 background.

b) Exposure-Response relationship for the identification of air pollution related premature mortality [60]

The exposure-response function for air pollution related long term mortality, used in the present study, is based on two comprehensive US cohort studies, where over many years the long-term effects of air pollution on mortality were observed within large populations. The scientific quality of these studies is indisputable.

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

- The two American studies cover a range of exposure similar to those found in Austria, France and Switzerland.
- The relationship between air pollution and short-term mortality was demonstrated for France and Switzerland as in many countries throughout the world. The findings are consistent with U.S. findings. Thus, extrapolation from U.S. to Europe may be reasonable for long-term effects as well, thereby confirming the fact that the exposure-response relationship is applicable for low or medium levels of exposure.

As a conclusion, the empirical evidence on exposure-response relationship is based on qualitatively high scientific research and may be applied to Austria, France and Switzerland.

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 research 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 road accident risk valuation by 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

---

[60] For an detailed discussion, see Health Costs due to Road Traffic-related Air Pollution, Air Pollution Attributable Cases (1999).

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 air pollution related victims are older than 75 to 80 years. This value was used in the above summary table 7.1.

On the other hand, an increase in WTP based on the risk specific context was not adopted in the main approach, although different empirical findings indicate 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 air pollution domain as well as in epidemiology and economy, in the case of sensitive assumptions or data uncertainties, the "at least" approach was adopted.
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

– not all PM10 related health effects (e.g. lung cancer, infant mortality) were considered;
– the additional effects of other pollutants (e.g. ozone) were not considered;
– for the monetary valuation generally prudent cost factors were chosen.

8. Recommendations, open questions and further research needs

The Charter on Transport, Environment and Health on behalf of the WHO Ministerial Conference on Environment and Health in London 1999, states as a primary goal the achievement of a transport system, sustainable with regards to health and environment.

The present case study on Health Costs due to Road Traffic-related Air Pollution in Austria, France and Switzerland, is a first step and responds to the principles and guiding strategies of the Charter in various ways.

As an interdisciplinary research project, it corresponds to the Charter’s attempt for a multi-sectoral integration and co-operation in health and environment oriented research. Its results may be understood as an input to a transport policy which is oriented to sustainable development, protecting and promoting health and safety issues and seeking to implement the polluter-pays principle.

The general requirements for the action plan of the Charter are of relevance in two ways for the present project:
- In providing a state of air pollution related health effects, the present project supports the definition of specific goals for future policy orientation.

- It contributes to the identification and collection of relevant data and to the design of adequate methodological approaches, both of which constitute the necessary steps towards a sound and reliable monitoring system, generating information for politicians and the general public.

However, despite its overall consistency with the recommendations formulated in the Charter on Transport, Environment and Health, the present case study must be regarded as a first step, demanding for some important improvements in data collection as well as in methodological design.

In the domain of **air pollution**, an important improvement consists of the establishment of comparable PM10 monitoring networks, according to the forthcoming EU regulations. In building up these networks, it is crucial to use PM10 samplers compatible with the new EU reference method, ensuring full comparability of results. Besides the PM10, other indicators of particulate matter such as PM2.5 and even smaller fractions should be included. Additional information on the chemical composition of particulate matter as well as on particle number and particle surface area must be assessed in order to identify the origin and characteristics of particulate matter in ambient air. Of further importance is the establishment of reliable PM10 emission inventories. Little is known about PM10 emissions from different sources, e.g. road dust re-suspension, construction activities, etc. Special attention has to be paid to these sources in order to obtain reliable emission factors. Receptor studies, providing the source apportionment by using measured PM10 components, are necessary in addition to the emission inventories. Several studies in different European regions should be conducted and the results compared.

In the domain of **epidemiology** further research has to focus on the exposure-response functions of particulate matter of different size, composition and content and on the mechanisms of effects of particulate pollution. It has to be investigated, whether the exposure-response function of different health outcomes has to be based on different pollution indicators (e.g. surface area of diesel derived particles for the health endpoint of lung cancer and allergic rhinitis, surface area of fine particles for the health endpoint of cardio-vascular disease). Concerning the health endpoints, further studies are needed to improve the quantification of morbidity. Particularly, cohort studies on mortality and morbidity should be conducted, in order to assess the years of life and the quality of life lost. In parallel to air pollution related health effects, the assessment of noise-related health effects should be integrated into the design of empirical research, thus allowing for a vice versa controlling of the effects of a simultaneous exposure to air pollution and noise in urban areas.
Finally, for future health impact assessments, personal exposure distribution data must be evaluated and used as input for the establishment of personal exposure-response functions.

In the **economic** domain, special efforts have to be dedicated to the willingness-to-pay approach for the determination of health costs. It is necessary to conduct empirical studies on air pollution related risk assessment, separately from fatal traffic accident-related risk for different European countries. Thus, the differences of risk context and socio-cultural context are taken into account. This additional research on willingness-to-pay has to be carried out separately for all different air pollution related health outcomes considered.

Despite the chosen ”at least” approach prevailing throughout all three scientific domains, the results of the present study show once more that the air pollution related health effects are not a marginal problem. This evidence is not yet fully taken into account by the political decision process.

Responding to the information obtained from the present study, the political agenda setting should be oriented towards:

- an increase in health and environment related research in the domain of air pollution and noise,
- a development of impact assessment tools integrating the health and environment relevant information into the monitoring of global and local policies,
- the design of cost-benefit analysis techniques which integrate the monetarised health and environmental impacts into the evaluation process of infrastructure and policy design,
- an integration of monetarised external effects into the national accounting system (e.g. the traffic accounts).

In doing so, the present case study may serve as a methodological starting point for the health cost assessment in other European countries.

Finally, besides the above mentioned improvements in research and information use, the primary goal of a health and environmentally oriented policy must be the reduction of cases of premature mortality and morbidity attributable to (road traffic-related) air pollution by implementing an adequate mix of instruments such as the effective application of the polluter-pays principle (e.g. by introducing limitations on exhaust emissions, especially for fine particles or by re-orienting the tax system, etc.). Such a strategy should induce a reduction in pollution and savings by the health cost system. In order to reach this goal, the public awareness has to be raised and access to information has to be guaranteed permanently.

Annex 1: Project Partners

Austria	
Baumann Ruth, Dr. phil.	Federal Environment Agency ltd., 1090 Vienna, Austria
Herry Max, Dr.	Planungsbüro Dr. Max Herry, 1040 Vienna, Austria
Horak Friedrich, MD	University Children's Hospital, Vienna, Austria
Molterer Jutta, Mag.	Federal Ministry of Environment, Youth and Family Affairs, Division I/5, Transport, Mobility, Regional Planning and Noise 1010 Vienna, Austria
Sedlacek Norbert, Dipl. Ing.	Planungsbüro Dr. Max Herry, 1040 Vienna, Austria
Oberfeld Gerd, MD	Austrian Medical Association, Unit for Environmental Medicine, 1010, Vienna, Austria
Schneider Jürgen, Mag. Dr. rer. nat.	Federal Environment Agency ltd., 1090 Vienna, Austria
Studnicka Michael, MD	Centre for Pulmonary Disease, 1145 Vienna, Austria
Thaler Robert, Mag. Dipl. Ing.	Federal Ministry of Environment, Youth and Family Affairs, Division I/5, Transport, Mobility, Regional Planning and Noise, 1010 Vienna, Austria
France	
Ba Mohamédou, PhD student	IFEN, French Institute for the Environment 45000 Orléans, France
Chanel Olivier, Dr.	CNRS-GREQAM, French National Centre for Scientific Research, (Quantitative Economic Research Team) 13002 Marseille, France
Elichegaray Christian, Dr.	ADEME, Agency for Environment and Energy Management, Air and Transport Direction 75737 Paris cedex 15, France
Frangi Jean-Pierre, Prof. Dr.	The Laboratory of Environment and Development (University Paris 7) 75251 Paris cedex 05, France
Martinez Nathalie, Dr.	ADEME, Agency for Environment and Energy Management, Air and Transport Direction 75737 Paris cedex 15, France
Masson Serge, PhD student	BETA Laboratory, University of Strasbourg I, (Quantitative Economic Research Team) 67070 Strasbourg, France
Medina Sylvia, MD MSc	National Institute for Public Health Surveillance (InVS), Health and Environment Unit 94415 Saint Maurice cedex, France
Morcheoine Alain, Dipl. Ing.	ADEME, Agency for Environment and Energy Management, Air and Transport Direction 75737 Paris cedex 15, France
Puybonnieux-Texier Valérie, PhD student	The Laboratory of Environment and Development (University Paris 7) 75251 Paris cedex 05, France
Quenel Philippe, MD PhD	National Institute for Public Health Surveillance (InVS), Health and Environment Unit 94415 Saint Maurice cedex, France
Scapecchi Pascale, PhD student	ADEME and GREQAM, French National Centre for Scientific Research (Quantitative Economic Research Team) 13002 Marseille, France
Vergnaud Jean-Christophe, Dr.	EUREQUA – CNRS French National Centre for Scientific Research (Quantitative Economic Research Team) 75647 Paris cedex 13, France

Switzerland	
Filliger Paul, Dr. phil. nat.	Swiss Agency for the Environment, Forests and Landscape, 3003 Berne, Switzerland
Heldstab Jürg, Dr. phil. nat.	INFRAS, Consulting Group for Policy Analysis and Implementation, 8002 Zurich, Switzerland
Kaiser Reinhard, MD MPH	Institute for Social and Preventive Medicine, University Basel, 4051 Basel, Switzerland / National Institute for Public Health Surveillance (InVS), Health and Environment Unit 94415 Saint Maurice cedex, France
Künzli Nino, MD PhD	Institute for Social and Preventive Medicine, University Basel, 4051 Basel, Switzerland
Seethaler Rita, lic. rer. pol.	Federal Department for Environment, Transport, Energy and Communications, Bureau for Transport Studies, 3003 Berne, Switzerland
Sommer Heini, Dr. rer. pol.	ECOPLAN, Economic and Environmental Studies 6460 Altdorf, Switzerland

Co-referees		
General advise:	Dora Carlos, Dr.	Regional Advisor, Environmental Epidemiology, WHO, European Centre for Environment and Health, Rome Division, Italy
Air Pollution	Eerens Hans, Dr.	National Institute of public health and the environment (RIVM), Bilthoven, The Netherlands
Epidemiology	Krzyzanowski Michal, Dr.	Environmental Epidemiologist, WHO European Centre for Environment and Health, Bilthoven Division, The Netherlands
Economy	Jones-Lee Michael, Prof. Dr.	Centre for the analysis of safety policy and attitudes to risk, Department of Economics, University of Newcastle, Newcastle upon Tyne NE1 7RU, UK
	Dubourg Richard, Dr.	Centre for social and economic research on the global environment, University College London WC1E, UK

Annex 2: Epidemiological Data

Table 1: Health outcomes included and not included in the assessment

Included in the Impact Assessment	Not included
• Total mortality (adults ≥30 years; long-term effect) • Respiratory hospital admissions (all ages) • Cardiovascular hospital admissions (all ages) • Chronic bronchitis (adults ≥25 years) • Acute bronchitis (children <15 years) • Restricted activity days (adults ≥20 years) (RAD) • Asthmatics: asthma attacks in children <15 years asthma attacks in adults ≥15 years	• Acute (short-term) effects on mortality • Infant mortality • Intrauterine mortality • Emergency room visits • Respiratory symptoms in adults • Respiratory symptoms in children • Lung function • School absentees • Cancer *) • Physical performance • Eye irritations • Increase in bronchial reactivity

*) in terms of mortality: implicitly included; not included in terms of morbidity

Table 2: Additional cases per million inhabitants and per 10 μg/m^3 of pollutant concentration (of PM_{10})

Health outcome	Effect estimate **Relative Risk** (±95% Confidence Interval (CI))	Observed population frequency, P_e {and expected baseline frequency, P_0 at 7.5 μg/m^3 PM10 annual mean} Per 1 Mio. inhabitants			Fixed baseline increment (D10) per 10 μg/m^3 PM10 and 1 Mio. Inhabitants **Cases D_{10}** **(D_{10low}, - D_{10upp} based on ±95% CI estimates)**		
		A	**F**	**CH**	**A**	**F**	**CH**
Total 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 Admissions (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 Admissions (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) [1)]	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 [2)]	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) [2)]	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)

1 Restricted activity days: total person-days per year
2 Asthma attacks: total person-days with asthma attacks

Pe: frequency as observed at the current level of air pollution
Po: the calculated expected frequency at the reference level of 7.5 μg/m^3 PM10

Table 3: Underlying definitions of health outcomes in the epidemiologic studies used for the air pollution impact assessment

Health outcome	Definition	Sources (References)
Long-term mortality (adults ≥30 years)	death rate, excluding violent death / accidents, ages 25-75 and >30 years, respectively	Dockery DW et al, 1993 Pope CA et al, 1995
Respiratory Hospital Admissions (all ages)	hospital admissions for respiratory disease: ICD9 460-519, all ages ICD9 466, 480-487, 493, 490-492, 494-496, all ages ICD9 480-487, 490-496, all ages (not all papers state that only unscheduled admissions have been included)	 Spix C et al, 1998 Wordley J et al, 1997 Prescott GJ et al, 1998
Cardiovascular Hospital Admissions (all ages)	hospital admissions for cardiovascular/circulatory disease: ICD9 410-436, all ages ICD9 390-459, all ages ICD9 390-459, all ages ICD9 410-414, 426-429, 434-440, all ages (not all papers state that only unscheduled admissions have been included)	 Wordley J et al, 1997 Poloniecki JD et al, 1997 Medina S et al, 1997 Prescott GJ et al, 1998
Chronic Bronchitis Incidence (adults ≥25 years)	symptoms of cough and/or sputum production on most days, for at least three months per year, and for 2 years or more, age >=25 years	Abbey DE et al, 1993
Bronchitis (children <15 years)	bronchitis in the last 12 months (parents or guardian's answer), ages 10-12, 8-12 and 6-15 years, respectively	Dockery DW et al, 1989 Dockery DW et al, 1996 Braun-Fahrländer C et al, 1997
Restricted Activity Days (adults ≥20 years)	any days where a respondent was forced to alter normal activity, due to respiratory disease ICD9 460-466, 470-474, 480-486, 510-516, 519, and 783, age 18-65 years	Ostro B et al, 1990
Asthmatics: Asthma attacks (children <15 years)	lower respiratory symptoms, age 6-12 years asthma, age 7-15 years lower respiratory symptoms, age 7-13 years	Roemer W et al, 1993 Segala C et al, 1998 Gielen MH et al, 1997
Asthmatics: Asthma attacks (adults ≥15 years)	wheeze, age 18-80 years shortness of breath, age 18-55 years wheeze, age 16-70 years	Dusseldorp A et al, 1995 Hiltermann TJN et al, 1998 Neukirch F et al,1998

Annex 3: New research results on the valuation of preventing fatal road accident casualties*

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 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.

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

* 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.

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 £vx100,000. On this basis, the WTP-based "value of preventing a fatality" (VPF) for road project appraisal is simply £vx100,000.[1]

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.

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.[2]

---

[1] 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÷100,000. In turn, total willingness to pay will be £v x N, so that aggregate willingness to pay *per fatality prevented* is again given by £v x 100,000.

[2] 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.

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.

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 valuation 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 x 100,000 = £2.5m. 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 x 100,000 = £1m. 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 desirablity 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:

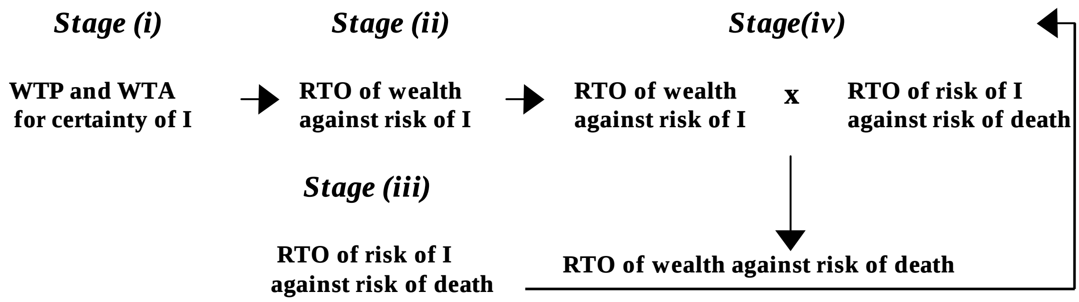
(i) Respondents were first presented with contingent valuation questions designed to elicit (a) their willingness to pay (WTP) for the *certainty* of a quick and complete cure for a particular *non-fatal* road injury, I, of lesser severity, and (b) their willingness to accept compensation (WTA) for the 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.[3]

(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

---

[3] 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 expressed as a w*eighted 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.

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 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)[4] 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[5] .

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.

---

[4] 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 loses to the rest of society) it is necessary to add an allowance for these avoided losses, to ”raw” WTP-based figures.

[5] 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.

SUSAN CHILTON
University of Newcastle upon Tyne

GRAHAM LOOMES
University of Newcastle upon Tyne

JUDITH COVEY
University of York

NICK PIDGEON
University of Wales, Bangor

LORRAINE HOPKINS
University of Wales, Bangor

ANNE SPENCER
University of York

MICHAEL JONES-LEE
University of Newcastle upon Tyne

8/6/98

Annex 4: Partial assessment of mortality based on the consumption loss approach in France

The number of air pollution related years of life lost is calculated for the whole population in a first step. In a second step, the average life expectancy for the whole population is established for a hypothetical situation with reduced air pollution. The difference between the two results indicates the survival rate and the life expectancy without traffic-related air pollution. The life expectancies are computed for each gender separately due to differences in death rates between male and female

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.

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

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 + ½ 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

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

where

- B is the baseline exposure level of 7.5 µg/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

Table 0-1: Lost life expectancies due to air pollution exposure

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

* 1994 mortality data

Valuing the loss of human life based upon the **household final consumption** per inhabitant based on the **whole population scenario** is motivated by several reasons. First of all, consumption seems to be a reliable approximation for the individual utility of material aspects of life, as most of everyday acts require expenses (dwelling, food, travels, health care, leisure, etc.) in order to fill fundamental needs. This approach 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. In addition, by using the whole population approach, the resulting size of the average loss of life expectancy does not demand for any discounting.
The final household consumption in France amounts to some 726,2 thousands millions EUR in 1996. Thus, per inhabitant a final consumption per year of 12.583 EUR is obtained.

Table A5-2: 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 Mio. 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	

According to Table 6.3.2-3, in France the costs of air pollution related mortality based on the loss of consumption reach a value of **3’916 million EUR**, of which **2’216 million EUR** are road traffic induced.(4)

4 On the whole, 311’225 years are lost due to air pollution. According to the victims scenario, 31’692 premature deaths are due to air pollution. Thus, the 311’225 years correspond formally to a

Annex 5: List of Abbreviations and Glossary

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
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)
$\mu g/m^3$	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
PM10	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). PM10 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 Mircobalance
TSP	Total Suspended Particulates
UBA	Umweltbundesamt (Federal Environment Agency ltd., Austria)
WHO	World Health Organisation

---

victims 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 provide such close results.

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 *exacerbation*.
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 *chronic bronchitis* 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 *internal* and *external* costs. This corresponds to the total (social) costs to the national economy incurred as a result of a given activity.

Literature

Technical Reports:

Filliger P., Puybonnieux-Texier V., Schneider J., (1999), PM10 Population Exposure – Technical Report on Air Pollution; Technical Report of the " Health Costs due to Road Traffic-related Air Pollution – An impact assessment project of Austria, France and Switzerland", Berne 1999

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

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

Other references:

Abbey D.E., Nishino N., McDonnel W.F., Burchette R.J., Knutsen S.F., Beeson W.L., Yang J.X., (1999), Long-Term Inhalable Particles and Other Air Pollutants Related to Mortality in Nonsmokers. Am. J. Respir. Crit. Care Med. 1999 159: 373-382

Ackermann-Liebrich U, Leuenberger P, Schwartz J et al. (1997), Lung function and long term exposure to air pollutants in Switzerland. Am J Respir Crit Care Med 1997;155:122-129

Braun-Fahrländer C, Vuille J, Sennhauser F et al. (1997), Respiratory health and long-term exposure to air pollutants in Swiss schoolchildren. Am J Respir Crit Care Med 1997;155:1042-1049

Berdowski et al., (1997); Particulate matter emissions (PM10 – PM2.5 – PM0.1) in Europe in 1990 and 1993. Netherlands Organisation for Applied Scientific Research TNO-report, TNO-MEP R 96/472

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

COST 313, (1994), Coût socio-économique des accidents de la route, Rapport final, Publié par la Commissin des Communautés Européennes, Direction générale XII, Bruxelles/Luxembourg

Department of Health UK (1999), Economic Appraisal of the Health Effects of Air Pollution, London.
Dockery DW, Pope A, Xu X et al. An association between air pollution and mortality in six U.S.Cities. N Engl J Med 1993; 329(24):1753-9.

ECOPLAN (1993), Soziale Kosten von Verkehrsunfällen in der Schweiz; Aktualisierung für das Jahr 1993, Bern.

EMEP (1997): Transboundary Air Pollution in Europe. MSC-W Report 1/97, Part 1 and 2. Norwegian Meteorological Institute, Oslo.

EMEP (1998), Long-range transport of fine secondary particles, as presently estimated by the EMEP Lagrangian model. EMEP/MSC-W, Note 2/98. Norwegian Meteorological Institute, Oslo.

ExternE (1995), Externalities of Energie, Vol 1: Summary / Externalities of Energie, Vol 2: Methodology

GREQAM (1999), Economic and socio-anthropologic approach of air pollution : a study in a French department, Marseilles, Prepared for the French Environment Ministry, work in progress.

IMIB, Institut für Medizin Informatik Biostatistik, (1996), Monetarisierung der verkehrsbedingten Gesundheitskosten: Behandlungskosten

Jones-Lee M.W. et al. (1998), On the Contingent Valuation of Safety and the Safety of Contingent Valuation: Part 2 - The CVG/SG “Chained” Approach

Katsouyanni K, Schwartz J, Spix C et al. (1996), Short term effects of air pollution on health: a European approach using epidemiologic time series data: the APHEA protocol. J Epidemiol Comm Health 1996, 50 (supplement 1):S12-S18

Künzli N., Tager I., (1997), The semi-individual study in air pollution epidemiology: a valid design as compared to ecologic studies. Environ Health Perspect 1997; 105: 1078-1083

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

Navrud S. (1998), Valuing Health Impacts from Air Pollution in Europe - New Empirical Evidence on Morbidity, Accepted Paper for the World Congress of Environmental and Resource Economists, June 25-27 1998, Venice, Italy.

Ostro B., Chestnut L. (1998), Assessing the Health Benefits of Reducing Particulate Matter Air Pollution in the United States, in: Environmental Research, Section A 76, p. 94-106.

Pearce D. (1996), Health effects of ozone and nitrogen oxides in an integrated assessment of air pollution, prepared for the United Nations Economic Commission Europe and the World Health Organization

Pope CA III, Thun M, Namboodiri M et al. (1995), Particulate air pollution as a predictor of mortality in a prospective study of U.S.Adults. Am J Respir Crit Care Med 1995; 151(3):669-74.

Quénel P, Zmirou D, Dab W et al. Premature deaths and long-term mortality effects of air pollution (letter to the editor). Int J Epidem, in press

Sommer H., Neuenschwander R., (1996), Monetarization of the external health costs attributable to transport, Consolidated report. Ecoplan on behalf of the Bureau for Transport Studies, GVF-Report nr. 272, Federal Department of Environment, Berne, 1996

Sommer H., Neuenschwander R., Walter F., (1991), Soziale Kosten von Verkehrsunfällen in der Schweiz; Ecoplan. Auftrag GVF Nr. 186, Eidg. Verkehrs- und Energiewirtschaftsdepartement, Bern, 1991

Viscusi W.K. (1993), The Value of Risks to Life and Health, in: Journal of Economic Literature, Vol. XXXI, p. 1912-1946.

Wacholder S et al, (1995), When measurement errors correlate with truth: surprising effects of nondifferential misclassification. Epidemiology 1995; 6 (2): 157-161

WHO. Air Quality Guidelines for Europe (1998). 2nd Edition. WHO Regional Office for Europe, Copenhagen, in pressWHO. Overview of the environment and health in Europe. Background document for the Third European Union Ministerial Conference Transport, Environment and Health London 1999. WHO Regional Office for Europe, Copenhagen, 1998 (http://www.who.dk/London99/ Welcome.htm).