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External Costs of Road, Rail and Air Transport - a Bottom-Up Approach

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Non-Technical Summary

Externalities are changes of welfare which are caused by economic activities without being reflected in market prices. Applied to transport, negative externalities are the costs imposed on society and the environment that are not accounted for by the producers and consumers of transport services. The paper describes the calculation of the environmental and health externalities caused by air pollutants, accidents and noise of different transport modes on the route Frankfurt-Milan. The evaluation of the external costs is based on a bottom-up approach which means that the starting point for the analysis is the micro level. The calculation of the external costs involves four stages: emissions, dispersion, impacts, and damages. These steps are derived from the damage-function approach which has been developed in the ExternE project (European Commission DG XII, 1995). The analysis starts with the exposure (number and kind of kilometres driven). Burdens in the form of air pollutants, noise and accidents occur. In the second stage, burdens are translated into concentrations. The results of this stage are emission levels relating to the modes of transport. The third stage involves the identification and quantification of impacts, which are divided into human health, environmental, and climate effects. The last stage includes the valuation of the impacts, or in some cases directly of the burdens. The valuation methods are based on willingness to pay analyses. The arising external costs of passenger and goods transport on road, railway, and in the air are compared for one trip (ECU/person-kilometre (pkm) or tonnes-kilometre (tkm)) in the base year 1995.

The paper focuses on the calculation of road traffic externalities due to air pollutants. An integrated model for the calculation of road emissions, the dispersion of these emissions, the quantification of impacts by applying exposure-response functions and the valuation of the impacts will be presented. The integrated model consists of three models which are linked together. The model "Workbook on Emission Factors for Road Transport" analyses the emissions on roads/motorways. This complex computer programme allows the choice of the parameter emission type (hot and cold emission factors), vehicle category (cars, vans, trucks, busses, motorbikes and country-specific vehicle-mixes), traffic situation (type of road, speed, traffic flow) as well as the reference year and the slope of the road. The bottom-up calculated emissions are the basis for the two dispersion models "MLuS" (a leaflet about air pollutants on roads) and "Ecosense" to calculate the external costs of interurban road transport. While MLuS only aims to analyse the concentration change due to emissions of road traffic in a very local scale (up to 200 meter around the street), Ecosense covers the dispersion of emissions up to several 1000 km. The link of the two dispersion models works by relating the concentrations and impacts to geographical sectors around the motorway.

Noise emissions are calculated by a computer programme based on the German traffic noise protection ordinance for road and rail traffic. Route specific information like speed, traffic situation, surface, and noise reduction facilities is taken into account.

For passenger road traffic, total external costs amount to about 44 ECU/1000 pkm on the route Frankfurt - Milan, including the impact categories air pollutants (15.6), global warming (5.2), noise (3.8), and accidents (19.6 ECU/1000 pkm). Concerning a comparison of the transport modes, external costs of passenger road traffic are about 9 times as high as those of rail traffic and about twice as high as those of air traffic. For goods transport by road, the total external costs (30.6 ECU/1000 tkm) are about 11 times as high as those of rail traffic. It can be concluded that the bottom-up approach for the route-specific external cost analysis produces plausible results in comparison to top-down approaches.

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Abstract

This paper aims to describe the calculation of environmental and health externalities caused by air pollutants, accidents and noise from different transport modes (road, rail, air) on the route Frankfurt-Milan. The investigation is part of the QUITS project (QUITS = Quality Indicators for Transport Systems), commissioned by the European Commission DG VII. The evaluation of the external costs is based on a bottom-up approach. The calculation involves four stages: emissions, dispersion, impacts, and costs, following the impact pathway approach. An integrated model for the valuation of environmental and health costs due to air pollutants will be presented consisting of three computer programmes which are linked together. For passenger road traffic, total external costs amount to about 44 ECU/1000 pkm on the route Frankfurt -Milan, including the impact categories air pollutants (15.6), global warming (5.2), noise (3.8), and accidents (19.6 ECU/1000 pkm). Concerning a comparison of the transport modes, external costs of passenger road traffic are about 9 times as high as those of rail traffic and about twice as high as those of air traffic. For goods transport by road, the total external costs (30.6 ECU/1000 tkm) are about 11 times as high as those of rail traffic.

Keywords: external costs, transport systems, environmental impacts, bottom-up approach

1 Introduction

This paper describes the most important results of the external quality valuation in the QUITS project* funded by the European Commission (DG VII) under the Transport RTD Programme of the 4th Framework Programme. The objective of QUITS was to develop a methodology for valuing internal and external quality dimensions of transport systems.

A uniform methodology is applied for calculating external costs of transport for different types of impacts and transport modes. The evaluation of the external costs of road, rail and air traffic for both passenger and goods transport is based on a bottom-up approach, which means that the starting point for the analysis is the micro-level. We adopted the impact pathway approach developed in the ExternE project (IER *et al,* 1997). Due to limited space, this paper will focus on the comparison of external costs between modal alternatives for the route Frankfurt - Milan. This Origin-Destination relation is transnational, covers all major kinds of transport-related externalities and offers a real modal choice.

2 General Framework for the Valuation of Transport Externalities

2.1 External costs of transport

Table 1 gives a survey of the different categories of external costs of transport activities, as described in a report of the project Pricing European Transport Systems (PETS, 1997).

Table 1: Transport externalities

			Internal Costs		External Costs
			to individuals	to the sector	
Social Costs	Environmental Costs	fauna & flora	own disbenefits (individual)	own disbenefits (sector)	uncovered environmental costs
		energy			
		noise			
		air,water,land			
		landscape eff.			
		vibrations			
	Congestion Costs		time lost by the user (and the increase of other direct costs)	time lost by other users (and the increase of other direct costs)	costs provoked on others outside the transport sector
	Accidents		own accident costs and costs covered by insurances	costs covered by insurances	uncovered accident costs
	Infrastructure Costs		tolls, vehicle and fuel taxes	unperfected allocation of costs	uncovered infrastruct. costs
	Transport Expenditure		fuel/vehicle costs or tickets and fares	unperfected allocation of costs	costs covered by others

* QUITS: Quality Indicators for Transport Systems carried out by ISIS: Istituto di Studi per l´Informatica e i Sistemi (coordinator), ENEA: Ente per le Nuove Tecnologie, Enegia e l´Ambiente, INISTENE: Institut d´Evaluation des Stratégies sur l´Energie et l´Environnement en Europe, ZEW, ISI-Fraunhofer, WHO-ECEH

Sources: adapted from Button, 1993a and CEMT, 1996; cited from PETS (1997)

Externalities are changes of welfare which are caused by economic activities without being reflected in market prices (Rothengatter, 1993). With regard to the transport sector, relevant external costs are negative externalities which occur when transport consumers/producers impose higher costs on society than they bear themselves. In the enclosure of this paper, the external costs of transport include:

- air pollution,
- climate change,
- traffic noise, and
- accidents (as far as they are not internalised through insurance premiums).

Due to a lack of micro-data, infrastructure costs (as far as they are not covered by charges) and subsidies were not analysed in detail and will not be presented here.

An ongoing debate revolves around the question whether *external benefits* have to be considered in valuation studies. Some studies tried to identify specific external benefits of transport, like regional development effects or productivity benefits (Aberle, 1995). However, a critical review of these studies shows that nearly all benefits of transport services have to be paid by the users, i.e. the benefits are *internal* and included in market prices, respectively.

Congestion, as a non-environmental effect, induces external costs between individuals, but not between the transport system and other systems. Hence, from the perspective of the QUITS project, congestion is part of the internal quality of the transport system, which is not included in this paper.

2.2 Valuation of health risks due to air pollutants and accidents

The valuation of mortality is often criticized from an ethical standpoint for putting monetary values on human lives. From an ethical point of view, it is argued that monetary valuation "neglects to account for the popularly perceived 'right' not to be subjected to physical harm by other people" (Goodstein, 1994) and that people would value a certain human life infinitely high. However, such a standpoint cannot explain the real behaviour of people, because it would imply that legislation can prevent all external health effects and that people are willing to pay infinitely high amounts of money for risk reduction.

In reality, people weigh the costs and benefits of investments in seat belts, air bags, or earthquake protection carefully. This economic behaviour of people is the object of research in studies valuing risks to life and health. Values of mortality and morbidity risks are derived from individual preferences revealed by people´s market behaviour or by contingent valuation surveys.

Thus, the value of statistical life (VSL) is used in economic studies as a measure of welfare losses caused by risks to life. Mathematically, the average willingness to pay (WTP) for reduced mortality risks is divided by the risk reduction being valued. For instance, the VSL is 1 million dollars if the average WTP for a risk reduction of 1 in 10,000 is $ 100. It is important to mention that the VSL is not a measure of the life of a known individual or the death of a specific individual. Rather it refers to the statistical risks before the damage occurs, i.e. it is not known which individuals will actually be damaged, but it can be ascertained to what extent damages are to be expected. The economic value of a health risk is the amount an individual is willing to pay to avoid a risk, or the amount for which the individual would be willing to accept the risks (Ewers *et al*, 1994).

In the ExternE study commissioned by the European Commission, a meta-analysis of contingent valuation and hedonic pricing studies was made. Thus, a VSL of 2.6 million ECU was recommended (European Commission, 1994). For the base year 1995, this value was updated to 3.1 million ECU (i.e. 2.6 million ECU in 1990-prices adjusted with the consumer price index to 1995-prices, IER *et al*, 1997). The VSL is a rough, average value for an average risk reduction and does not distinguish between determinants like the age at exposure, latency or future quality of life, which are important factors for the individual WTP. In the ongoing ExternE project (phase III) it was decided to introduce values of a life year lost (VLYL). The approach is based on the assumption that the VLYL is independent of people´s age and life expectancy. There is little empirical evidence for this assumption in the literature, especially for acute mortality (IER *et al*, 1997). Concerning the limited empirical evidence of each approach with regard to acute mortality, values for both VSL and VLYL (and years of life lost (YOLL), respectively) were calculated in QUITS. For chronic mortality, only YOLL values will be quantified due to a lack of VSL impact data. Due to limited space, only values calculated on the basis of the YOLL concept will be presented here.

In analogy to mortality risks, morbidity risks can be estimated by using contingent valuation and hedonic pricing studies or by calculating production losses. The latter is referred to as costs of illness (COI). COI values calculate medical treatment plus lost earnings. A survey of the methods and their empirical evidence is given in Rennings (1995).

For the QUITS project the following values were used (1995 prices in ECU):

- mortality with a VSL of 3.1 million ECU,
- non-fatal accidents with the values from a recent study commissioned by the British Transport Research Laboratory (TRL) (in 1995 ECU values: 134,320 ECU for a serious, 13,210 ECU for a minor accident) and
- other morbidity effects with ExternE values (see Chapter 3.2).

As was shown by Rennings (1995), these social costs are only partially internalised through compensations paid by health insurance companies and employers´ liability insurance associations. Such compensations are mainly based on the costs of illness. For morbidity, COI covers around 30 per cent of the induced social costs. Compensation for mortality risks exists in the form of rents for surviving dependants. However, even an average rent of ECU 10,000 per year paid for a period of 25 years covers less than 10 per cent of VSL. Thus, it can be concluded that around 30 per cent of non-fatal and not more than 10 per cent of fatal health effects are internalised through payments made by health insurance companies and employers` liability insurance associations.

Although external costs of health risks depend on income and different values can be calculated for different European countries (Kageson 1993), in QUITS we preferred using an average value for the European Union.

2.3 Valuation of global warming

In several contributions, damage cost calculations of climate change like those of Nordhaus (1991) and Cline (1991) were criticised from an ecological perspective in particular. It was argued that mere neoclassical optimisation concepts tend to ignore the ecological, ethical and social dimensions of the greenhouse effect, especially issues relating to an equitable distribution and a sustainable use of non-substitutable, essential functions of ecosystems. Most of the critical arguments pointing out the limits of traditional cost-benefit-analysis can be found in the IPCC Second Assessment Report (IPCC 1995).

Responding to the IPCC´s criticism, Fankhauser *et al* (1995) and Tol (1996b) derived a research agenda for the economic assessment of climate change impacts including:

- improved damage estimates for less developed countries;
- improved estimates of non-market losses, especially of morbidity and effects on the ecosystem;
- assessment of the importance of variability and extreme events;
- models of the process of adaptation and the dynamics of vulnerability;
- formal uncertainty assessments and analyses of the outcomes;
- improved comparisons and aggregations of estimates between countries;
- improved comparisons and aggregations of estimates between generations;
- ensuring consistency between economic and non-economic impact assessments.

With regard to this research agenda, first advances are observable, especially concerning the handling of intra- and intertemporal equity questions. Additionally, some efforts have been made towards a more dynamic modelling of climate change damages, which will not be discussed in this paper (for details see Tol 1996a).

Concerning intergenerational equity, the concept of time-variant discounting was introduced (Azar *et al*, 1996, Rabl, 1996) and then applied in QUITS. Thus, the following range of discount rates was used:

- 0 per cent as a rate for long-term effects which can be expected to rise with income (> 30 - 40 years),
- 1 per cent as rate for social time preference (STP) ignoring individual time preference (ITP) (other long-term effects),
- 3 per cent as a rate for STP including ITP (standard discount rate for short-term effects, < 30 - 40 years) and,
- 6 per cent as a rate for the opportunity costs of capital representing market interest rates.

The concept of time-variant discount rates seems to be consistent with the principles of welfare theory. While 3 per cent can be used as a standard discount rate, lower rates can be applied for long-term global warming effects.

Intragenerational equity questions were addressed in contributions by Fankhauser *et al* (1995) and Azar *et al* (1996). Both use an equity weighting approach: on the basis of the existing estimates of global warming damages, willingness to pay values are adjusted in the aggregation process. While aggregating estimates for single countries or world regions to a global value, the damages are weighted by the inverse of income. Damages of rich countries are weighted down and damages of poor countries are weighted up by adjusting these damages to the average annual per capita world income. The reason for the adjustment is the „decreasing marginal utility of money and for the same reason we can argue that a given (say one dollar) cost which affects a poor person (in a poor country) should be valued as a higher welfare cost than an equivalent cost affecting an average OECD citizen" (Azar *et al* 1996). Thus, equity weighting leads to the result that damages and deaths in developed countries do not count more than in developing countries.

It is obvious that equity weighting and the discount rate chosen will have a substantial influence on the level of investments for stabilizing the global temperature that can be justified by mere economic reasons. In the IPCC report with a range of $ 5 -125 marginal costs per tonne of carbon, the lower bound of the range is derived from the Nordhaus study. Using mainly Nordhaus parameters and a model that takes the retention of carbon in the atmosphere into account, Azar *et al* (1996) introduce time-variant discount rates and equity weighting as described above. In doing so, they calculate marginal damages in the range of $ 260 - 590 per tonne. This is roughly 50 to 100 times higher than the Nordhaus value.

In QUITS, we used the results of the global warming sub-task of the ExternE Phase III, which took both inter- and intragenerational equity into consideration (Table 2). For other greenhouse gases, CO_2 equivalents will be used according to Schimmel *et al* (1996) and Hauschild *et al* (1996). The CO_2-equivalents are e.g. 21 for methane, and 2 for CO.

Table 2: Recommended global warming damage estimates for use in the ExternE study

	Low	High
ECU (1995)/tC		
Conservative 95 % confidence interval	14	510
Illustrative restricted range	66	170
ECU (1995)/tCO_2		
Conservative 95 % confidence interval	3.8	139
Illustrative restricted range	18	46

Source: Eyre *et al* (1997)

2.4 Valuation of noise nuisance

Nearly all valuation studies on noise nuisance deal with the transport sector. Either the hedonic pricing method or the contingent valuation method are appropriate techniques for valuing welfare losses caused by noise nuisance (Pommerehne *et al*, 1992). The most common method in this field is the hedonic pricing approach. Only a few contingent valuation studies are available. Some other studies (e.g. Planco, 1990) calculate avoidance costs which are only adequate for estimating a lower bound of noise damage (Wittenbrink, 1992).

Noise emissions of transport activities affect humans mainly in two ways:

- negative physiological effects, e.g. change in heart rate, and blood pressure. 2% increase in heart attack risk (Ising *et al*, 1992).
- negative psychological effects, e.g. annoyance, disturbance of communication and recreation, insomnia, loss of (mental) productivity.

Due to the fact that over 60% of the noise nuisance is determined by psycho-social factors and not directly by the physical burden measured in Leq, the CVM seems to be the appropriate monetisation method. Furthermore, our valuation relates to 5 dB(A)-classes instead of 1 dB(A)-steps, because a change in the latter cannot be perceived and therefore not reported by the persons affected. This subjective perception of noise makes it difficult to measure marginal impacts. Another reason for the fact that even for very low traffic density the marginal costs of transport noise are very close to zero, is the rule in physics according to which the addition of sound sources is described by a logarithmic function.

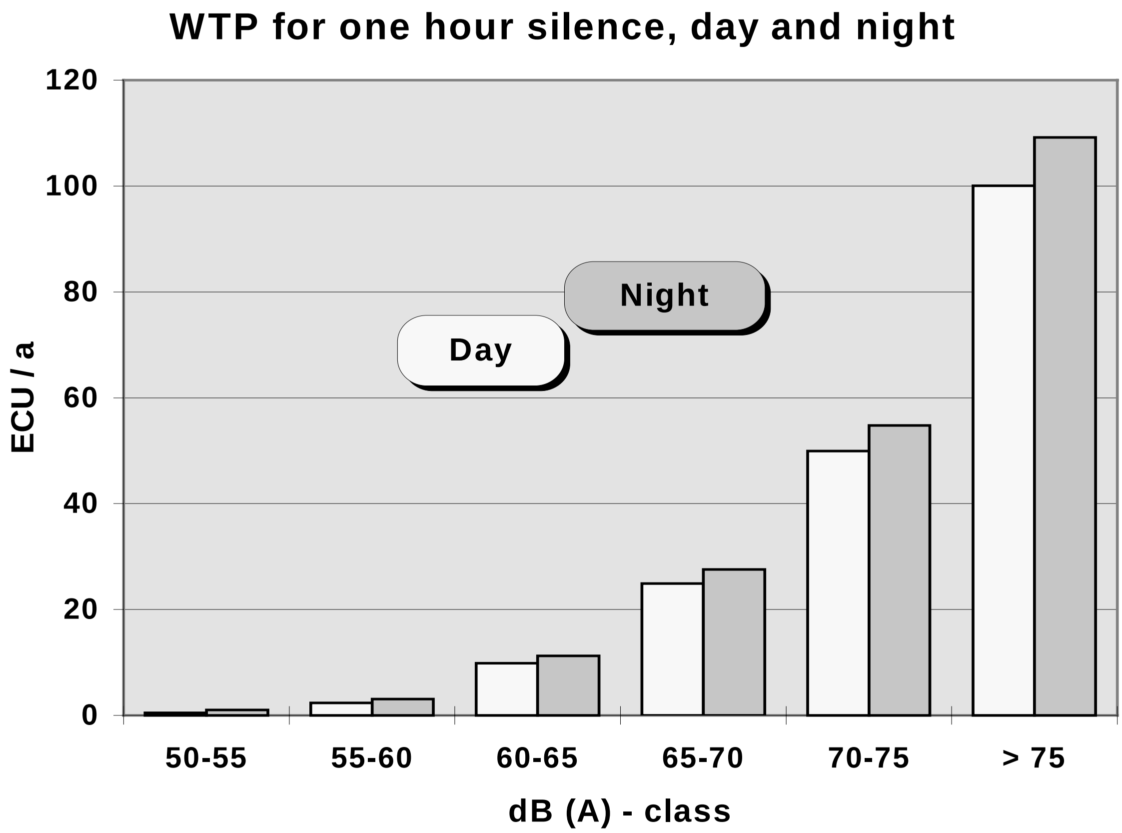
Table 3: Noise costs per person exposed

Leq in dB (A)	**50-55**	**55-60**	**60-65**	**65-70**	**70-75**	**>75**
Road: ***ECU/year***	15.46*	61.85	247.41	618.52	1237.04	2474.08*
Rail: ***ECU/year***	3.87**	15.46*	61.85	247.41	618.52	1237.04

* additionally given by IWW/INFRAS (1995); ** own estimation
Source: Hansson (1985) cited from IWW/INFRAS (1995). The original Hansson values are given in 1991 Swedish kronor.

Our approach is founded on the Swedish valuation study by Hansson (1985) cited from IWW/INFRAS (1995). There are two reasons for this choice. First, the figures calculated by Hansson represent a (European) mean of current assessments. Second, values for noise nuisance classes >60 db(A) are included, too (IWW/INFRAS 1995). The applied "railway bonus" of 5 dB(A), which is prescribed in the German noise protection ordinance 16. BImSchV (BMV 1990), becomes evident in a shift of valuation classes to the right (see Table 3). The reason for the bonus is that at the same emission levels Leq. noise from trains annoys people less than noise produced by road traffic

Figure 1: Willingness to pay for one hour of silence, day and night in ECU per year



From the bottom-up analysis we derive separate emission values for day and night, as prescribed in the above mentioned ordinance. Hence it is necessary to make a distinction in the valuation process. We, therefore, consider the WTP functions for silence evaluated by Weinberger *et al* (1991). The specific values for one hour of silence are, of course, higher for the night than for the day, as it is shown in Figure 1.

To get specific values (ECU/pkm and ECU/tkm), we follow the Planco study (1991). For road traffic, the external costs for day and night are divided between passenger and goods traffic according to a 1:10 ratio. For rail traffic, the differences between passenger and freight traffic have already been taken into consideration in the formulas for the bottom-up emission calculation. In general a freight train is about three to four times louder than a passenger train (IWW/INFRAS 1995).

3 Methodological Framework for Measuring Environmental and Health Impacts of Transport Systems

3.1 Overall approach

The method which will be used to evaluate external costs is a "bottom-up" approach for the route Frankfurt - Milan. This means that the starting point for the analysis is the micro-level. The bottom-up approach applies detailed models of emissions and impacts and offers several advantages compared to top-down approaches, which are widely used in damage assessment. Different fuels, technologies and sites with different traffic situations (speed, congestion, slope, etc.) can be addressed. This makes it possible to develop a more comprehensive, consistent accounting framework for estimating external costs of transport activities. QUITS focused on the analysis of the external costs caused by the current traffic situation on the route, thus, main results are calculated for a given technology mix. Besides, for road and rail traffic specific values are calculated for the main technologies (petrol cars with and without catalytic converters, diesel cars, highspeed trains).

The calculation of the external costs involves four stages: emissions (burdens), dispersion (concentrations), quantification of impacts, and external costs. These steps are derived from the damage-function approach developed in the ExternE project (European Commission, 1994).

It has to be mentioned that in the external valuation methodology the emphasis is on the use of infrastructure for transport activities. The impacts of fuel production (in the case of road and air traffic), vehicle production, maintenance and disposal and the supply of infrastructure are not taken into account. This is in contrast to the ExternE methodology which takes impacts from all stages of the fuel cycle into consideration.

The methodological approach of the QUITS externality analysis is summarised in Table 4, and will be used in this paper, too. The first column lists the transport modes considered (passenger and freight transport for road and rail traffic as well as passenger air traffic) and the accompanying transport technologies. The next four columns include the four stages of the damage pathway:

Table 4: QUITS methodological approach of the externality analysis

Traffic modes (technologies)	**Burdens (emissions)**	**Dispersion modelling, concentrations**	**Quantification of impacts**	**Valuation of impacts (burdens)**
Road traffic	Air pollutants:	**Emission source: linear**	Human health:	Direct valuation
a) passengers	- CO_2	Integrated model:	- Mortality	methods:
- "car" - mix:	- CH_4 (CO_2-equivalent)	• 0 - 200 m: ln-function	- Morbidity	- Contingent valuat.
petrol with	- CO (CO_2-equivalent)	from MLuS-model		method (CVM)
and without	- SO_2	• 200 - 5,000 m: em-	Environmental:	- Market simulation
cat,	- NO_X	pirical exp.-function	- Materials:	
diesel	- Particulates (PM_{10},...)	• >5,000 m: EcoSense	*maintenance*	Indirect valuation
b) goods	- Benzol	Results:	*facades of*	methods:
- mix of vans,	- HC	Concentration changes:	*buildings*	- Hedonic price
light and	- non-methane HC	SO_2, NO_X, PM, nitrates,	- Crops:	analysis (HPA)
heavy trucks	- Pb	sulphates, acid deposit.	*yield losses*	- Wage risk analysis
Rail traffic	- other micro-pollutants	**Emission source: point**	- Forests:	(WRA)
a) passengers	Other pollutants:	Model used:	*timber losses*	- Travel cost
- conventional	- soil	• EcoSense		approach
- high-speed	- water	Results:	Climate:	- Production losses
b) goods	Accidents	Concentration changes:	- Global	- Avoidance costs
- only electric.	Noise	SO_2, NO_X, PM, nitrates,	warming	- Costs of illness
powered trains	Others	sulphates, acid deposit.		(COI)
Air traffic	- vibration	**Emission source: linear**	Non-environm:	
a) passengers	- cutting-off-effects	• rough calculation	- infrastructure	
-diff. airplanes	- visual intrusion	with EcoSense	- subsidies	

Source: Weinreich *et al* (1998)

The analysis starts with the exposure (number and kind of kilometres driven). **Burdens (mainly emissions)** in the form of air, soil and water pollutants, noise, or vibrations and possibly also accidents occur. The burdens can be quantified for one trip or for one year, i.e. the reference year 1995. For the calculation of airborne road traffic emissions a specific model (Workbook on Emission Factors for Road Transport, short: hb-efa; Infras, 1995) is used allowing a very complex analysis of road traffic emissions on particular routes, both for passenger and freight transport. The programme requires users to choose from the following parameters:

- emission type(s): "hot" emission factors, cold-start boosts, evaporation emissions (after the engine has been switched off and/or as a result of tank breathing); only available for cars, for trucks only hot emission factors
- vehicle category(ies): cars, vans, trucks, busses, motorbikes
- reference year and – related to the reference year – a typical mix of vehicle types within each vehicle category (e.g. cars = weighted mix of conventional petrol cars, different types of catalytic converters, conventional diesel cars, diesel US- and EURO-norm; trucks = mix of different diesel technologies depending on age)
- kind of pollutants: CO, HC, NO_X, PM (particles), CO_2, Pb, SO_2, CH_4, non-methane HC, benzol
- traffic situation: type of road (e.g. motorway, different kinds of urban roads), speed, traffic flow (number of vehicles/hour, stop-and-go traffic, congestions)
- slope (0 %, 2 %, 4 %, 6 %)

Depending on the parameters chosen, the programme calculates the resulting emission factors (in g/vehicle-km) for each vehicle category (assuming a typical mix of vehicle types of the reference year) or for each vehicle type. Road emissions are calculated by taking into account the country-specific vehicle mix on each part of the route (see Table 5).

Table 5: Country-specific vehicle mix (cars and trucks), share in %

cars	**D**	**CH**	**I**	**trucks**	**D**	**CH**	**I**
petrol with cat.	66.2	73.3	16.1	**70's and 80's**	72.7	84.0	75.0
petrol (no cat.)	12.7	19.9	68.4	**EURO1**	22.7	16.0	25.0*
diesel	21.0	6.8	11.3	**EURO2**	4.6	0.0	
other	0.0	0.0	4.3				

*) On the assumption, that all 90's trucks correspond to the EURO1 norm
Sources: Infras, 1995 (D, CH); A.C.I. (1996); estimates made by ISI

For the other transport modes, emissions are calculated for the different technologies (airplane types, train engines), taking into account the route-related vehicle flows and occupancy (load) factors, the specific energy consumption, and the accompanying emission factors. For rail traffic, the country-specific emission factors of electricity generation (fuel mix of the railway electricity generation) are used.

Besides the calculation of air pollutants, the first stage of the damage pathway approach includes the counting of accidents (see Chapter 3.5) and the calculation of noise emissions from rail and road traffic (see Chapter 3.4).

In the second stage, burdens are translated into concentrations. The results of this stage are emission **levels (concentrations)** relating to the modes of transport. In the case of road transport, the dispersion of airborne emissions is calculated with an integrated model which is explained in the next chapter. The dispersion of noise is quantified taking into consideration the population concerned along the road/rail track. For accidents, this stage of the analysis is not relevant.

The third stage is the **quantification of impacts**, which are divided into human health, environmental, climate, and non-environmental effects. These impacts have to be identified and – if possible – quantified by exposure-response functions. The impacts on human health (mortality and morbidity) can be caused by both accidents and pollutants. The environmental and climate impacts are caused by emissions or concentrations.

The fourth stage includes the **valuation of the impacts**, or in some cases directly of the burdens. The valuation methods listed in the column are based on willingness to pay analyses. The results of this evaluation process are expressed in monetary units, i.e. external costs.

A question which has to be answered for the concrete realization of the impact pathway methodology is which impacts should be included and next which emissions should be taken into account in the assessment of the impacts chosen. Methane (CH_4), carbon monoxide (CO), and carbon dioxide (CO_2) are known to contribute to the greenhouse effect. Therefore, they are included in the analysis of climate change costs according to their global warming potential.

Sulphur dioxide (SO_2), oxides of nitrogen (NO_X), carbon monoxide (CO), and particulate matters (PM) are responsible for impacts on human health, crops, forests, and materials, both directly and as secondary pollutants formed in the atmosphere. A weakness of this analysis is that the assessment of transport requires a distinction between different size fractions of particulate matter, PM_{10} and $PM_{2.5}$, which is not made in the model. This differentiation would be important due to the very fine nature of transport particulate emissions.

Ozone, as a major photochemical oxidant, results from atmospheric chemical reactions between hydrocarbons and oxides of nitrogen in the presence of sunlight. At present, no regional model of ozone formation and transport is applicable to the European situation. There are some simplified approaches to the assessment of ozone effects (Rabl and Eyre 1997 and Hurley and Donan 1997, cited from IER et al 1997). They provide damage factors of 1,500 ECU/t NO_2, 930 ECU/t NMVOC, and 130 ECU/t CH_4. However, these results are not site specific and for that reason not included in our analysis.

Other air pollutants which are quantified in the emission model are not included in the further calculation of external costs due to limited availability of reliable exposure-response functions. Some substances have been identified as potential initiators of cancer. But, "carcinogens, which were expected to play an important role due to their high specific toxicity, proved to be of much lower importance compared to the particles" (IER et al 1997).

3.2 An integrated model for the external cost analysis of interurban road traffic

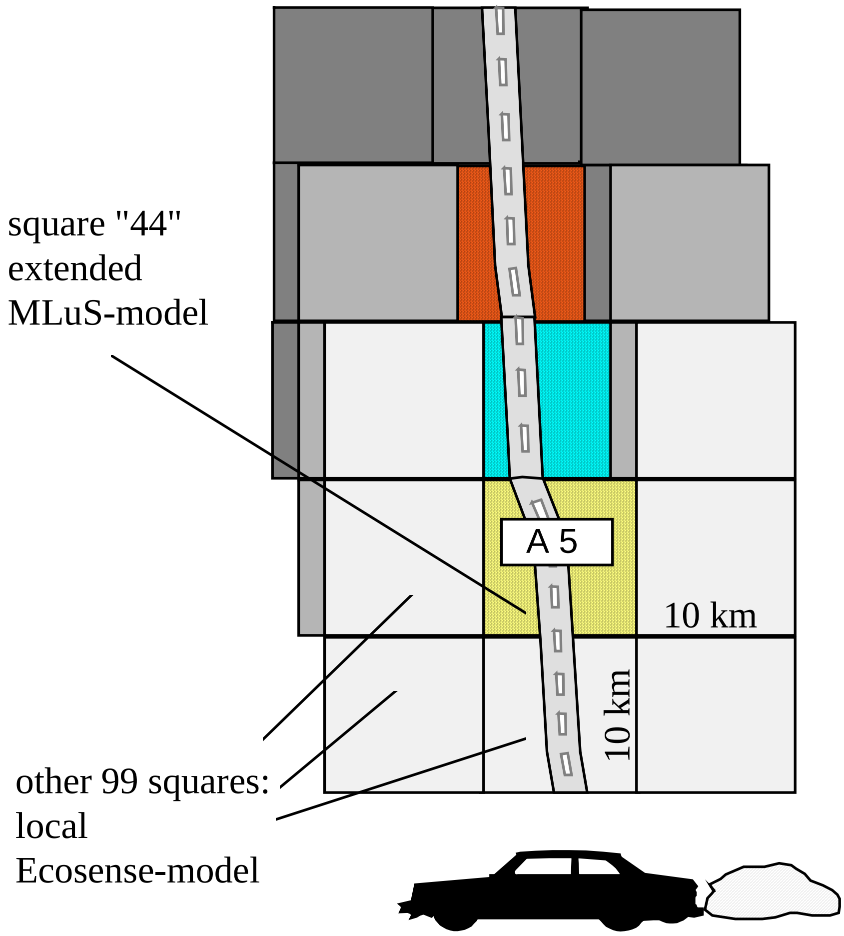
An integrated model will be presented for the calculation of road emissions, the dispersion of these emissions, the quantification of impacts by applying exposure-response functions and the valuation of the impacts. The use of the integrated model is limited to roads along which there are no or only a few buildings. This applies to nearly all segments of the route Frankfurt - Milan, as this interurban connection consists of a motorway running through the three countries concerned. It has to be mentioned that the results should not be transferred to the analysis of urban transport systems without making major modifications to the model. At least the dispersion in street canyons has to be included.

The integrated model consists of three models linked together. The model "Workbook on Emission Factors for Road Transport" analyses the emissions on roads/motorways as shown in the previous chapter. The bottom-up calculated emissions are the basis for the two dispersion models "MLuS" and "Ecosense" to calculate the external costs of interurban road transport. While MLuS only aims to analyse the concentration change due to emissions from road traffic on a very local scale (up to 200 metres around the road), Ecosense covers the dispersion of emissions over much greater distances up to several thousand kilometres.

Ecosense was developed as an integrated computer system for the assessment of environmental impacts and external costs resulting from electricity generation systems (IER 1997). Based on the impact pathway approach, the model provides relevant environmental and population data and two air transport models (local: up to 100 km distance, regional: focus on the chemical formation of secondary pollutants) required for an integrated impact assessment of airborne pollutants. MLuS is a static regression model based on concentration measurements which were made at different distances of up to 200 metres from the edge of the road along three German motorways (Forschungsgesellschaft für Straßen- und Verkehrswesen, 1996). In order to link the two dispersion models it is necessary to extend the MLuS scale to a range of 0 to 5,000 m. The dispersion function of the air pollutants included in the MLuS model is used and extrapolated to 5,000 m.

The two dispersion models are linked to form an integrated model by relating the concentrations and impacts to geographical sectors. The whole route Frankfurt - Milan is divided into route segments, each about 10 km in length. A 10x10 km square is related to each route segment the road runs through. For each square around the road the dispersion of the emissions is calculated using the extended MLuS model. The 10x10 km square is placed in such a manner that on each side of the motorway there is an area about 5 km wide. We apply the extended MLuS model for calculating the concentration change up to 5 km on both sides of the motorway. The valuation of the external costs of road traffic relating to the inner 10x10 km square has to be made step by step following the impact pathway. Therefore, the recipients of the impacts have to be identified and located, and the exposure-response-functions used in the EcoSense model have to be applied for the quantification of the impacts. In the last step, we will value the impacts in a way that is similar to the valuation method in the EcoSense model applied.

Figure 2: Methodology of linking the two dispersion models



The local EcoSense model yields results for a grid of 100x100 km made up of 100 squares 10x10 km in size. The point source of air pollutants (normally the power plant) is located at the centre of square "44" which lies in the middle of the whole grid. As road traffic is a linear source of emissions, we calculate the dispersion within square "44" by using MLuS as explained above. The assumption is made that any concentration beyond the inner 10x10 km square is analysed as a point source emission. Thus, we apply the local EcoSense model beyond this inner square for the calculation of the concentration change due to air pollutants emitted while driving through square "44". The values relating to the concentration change in the inner square must be subtracted from the result of the local EcoSense model run to avoid counting square "44" double. The whole procedure is repeated for each route segment. The methodology of linking the two dispersion models is illustrated in Figure 2. It has to be mentioned that concentration changes in the direct neighbourhood of square "44" calculated by the local EcoSense model lie within the range of the figures of the extended MLuS model at a distance of 5,000 m.

In a next step the route segments of each country involved in the route are aggregated to national route sections. The amount of emissions produced by driving through these route sections is the input data for the regional EcoSense model to calculate the dispersion, environmental and health impacts as well as the resulting external costs. Technically, the emissions are directly fed into the database system of the regional EcoSense model, which is divided into 100 x 100 km squares for the whole of Europe. Existing background concentrations have to be taken into account.

At present, we assume for all sites (all countries) on our route the same meteorological data as an input for the local EcoSense model (in the regional model the climate data is included), because the collection of this hourly data is extremely difficult.

The data for population, buildings, agricultural areas and forests around the motorway are calculated by using district data in Germany, canton data in Switzerland, and regional data in Italy.

For the quantification of health impacts E-R functions are applied for acute mortality, respiratory hospital admissions, cerebrovascular hospital admissions, cardiovascular hospital admissions, emergency room visits (ERVs), restricted activity days, acute effects in asthmatics, respiratory symptoms in the general population, chronic mortality, and chronic morbidity. Crops, forests and material are chosen as priority environmental impacts. In selecting the E-R functions we followed the recommendation of the ExternE project group (IER *et al*, 1997). The applied E-R functions are all included in the current EcoSense model 2.0 and listed in the final report of QUITS (Weinreich *et al* 1998). A comprehensive overview of the applicability and reliability of E-R functions is given in the reports of the ExternE project (European Commission 1994) and, especially for transport purposes, in the report by IER *et al* (1997). The latter gives a survey of the epidemiological literature with the resulting E-R functions and includes levels of uncertainty.

3.3 Dispersion and impact modelling for rail and air traffic

As far as possible the same burden categories, impact groups and ER-functions are used in the calculations for each transport mode. Concerning air traffic, no appropriate dispersion model is available which includes the specific conditions for emitting air pollutants high up (above 1,000 m). Thus, neglecting the emitting character of line sources, we assume that all the air pollutants are emitted at the two airports: half in Frankfurt and half in Milan. This crude approach allows us to use EcoSense for the dispersion, impact assessment and calculation of external costs as a rough estimate of the effects of air traffic air pollutants. It is obviously not feasible to quantify local impacts from air traffic. Thus, only the regional EcoSense model is applied. The environmental and health effects may be overestimated (not all air pollutants come down to the ground), but it can be argued too that the high global warming potential of high-level emissions leads to an underestimation of these impacts (Schumann, 1996).

Electrified rail traffic only produces air emissions from power plants as a point source. The dispersion of emissions from rail traffic is treated like in the energy sector. The regional EcoSense model is applied with an assumed location for the emission source, due to very limited information about the locations of the railway electricity plants. We argue that since obviously the power to run a locomotive on a South German route will not come from North Germany, an artificial point in the middle of the national route section is assumed. Thus again, the calculation of local impacts does not seem to be appropriate. Applying the regional impact quantification to airborne emissions from all transport modes ensures the comparability of the results.

3.4 Noise

Noise is unwanted sound or sounds of a duration, intensity, or other quality that causes physiological or psychological harm to humans (Marvin, 1993). Because of the complexity of noise, objective burdens are difficult to evaluate. The perception of sound as noise differs from person to person, from moment to moment. Only about 40% of the noise nuisance reaction can be described directly by means of the equivalent sound level (Leq). If psycho-social factors are also meant to be taken into account, the CVM is appropriate. For the 5 dB(A)-classes from 50 dB(A) to >75 dB(A) (see the valuation chapter 2.4), the number of people exposed along each of the specific route segments has to be calculated using an Excel-based computer model.

For road emissions daytime and nighttime noise emission levels per hour (L) in dB(A) are calculated for each route segment following the German traffic noise protection ordinance 16.BImSchV 1990 (BMV, 1990).

$$L = Leq\ (metre)\ (DTV/h\ ;\ \%\ of\ trucks) + Dv + Dsurf + Dslop + Dwall \qquad (1)$$

$$Leq\ (25) = 37.3 + 10\ lg\ (DTV/h\ (1+0.082*p))\ dB(A) \qquad (2)$$

The basis of the calculation is the equivalent sound level (Leq) measured at a distance of 25m from the emission source. It provides an average burden value per hour for day and night. The Leq (25) is a function of the Average Daily Traffic per hour (DTV/h) and the percentage of trucks (p). The following route-specific information is taken into account in the form of adders to the standardizised Leq (25):

- Speed, traffic situation (Dv)

- Road surface (Dsurf)
- Slope of the segment (Dslop)
- Noise reduction facilities (screens, walls, etc.) (Dwall)

The dispersion formula given in the German ordinance provides dB(A) values which reduce the emission level L by the amount of Ddist.

$$Ddist = 15.8 - 10 * lg (d) - 0.0142 (d)0.9, \quad d = \text{distance in metre} \qquad (3)$$

Free dispersion is assumed. One exception: tunnels reduce noise emissions to the level of zero. For Switzerland we have bottom-up data including information about the location of road tunnels. For the other countries involved in our route no tunnels are assumed.

The influence of the geographical and meteorological situation is not included, because no data is available. In Switzerland in particular an underestimation of external noise costs may be the consequence, because in valleys noise nuisance is partly four times higher than average.

Building up a matrix for various distances, we get a range of 10m strips along the route which are polluted with certain noise levels and can be clustered in the necessary decibel-classes. The metres exposed of each dB(A)-class are multiplied by the segment-related persons per metre value, which was derived from population density (pers/km²) data.

Concerning rail traffic the main assumption made is that passenger trains run only in the daytime (06.00 to 22.00), freight trains only at night (22.00 to 06.00). According to 16. BImSchVO §3 Anlage 2 (BMV, 1990) we calculate for each train technology and route segment a noise emission level per hour (L) in dB(A).

$$L = Leq \text{ (trains/h ; \% of disc-braked waggons)} + Dvl + Dwall \text{ (+ Dtrack)} \qquad (4)$$

$$Leq (25)= 51+10*lg (n*(5-0.04*p)) \text{ dB(A)} \qquad (5)$$

The basis of the calculation is the equivalent sound level (Leq), which provides an average burden value per hour for day and night at a distance of 25m from the middle of the track. The Leq is a function of the number of trains/h (n) and the percentage of disc-braked waggons (p) (of the total train). Route-specific information can be taken into account in the form of adder to the standardizised Leq (25):

- speed and length of the train (Dvl)
- noise reduction facilities (screens, walls, etc.) (Dwall)
- track surface (Dtrack) (no data available).

Regarding these route-specific characteristics, we get an emission level for each segment divided by class of train. Following the German ordinance, we add these up the technology-specific sound levels to a total emission level for each segment:

$$Ltotal=10 \, lg (100.1*L1 + 100.1*L2 + 100.1*L3 + 100.1*L4), \qquad (6)$$

where L1 is the highest (e.g. the goods train) and L4 the lowest sound level.

We assume for road and rail transport that roads and railway tracks run exactly parallel. Hence the above mentioned characteristics of dispersion also apply to rail traffic.

In this paper aircraft noise cannot seriously be taken into account due to problems with the specification of the duration and the location of the sound around the airports concerned. Besides, the method for measuring aircraft noise takes peak sound levels into account and differs from the road/rail method (continuous noise sources).

3.5 Accidents

From the literature on economics, we know that the accident costs which are relevant for the pricing of infrastructure use can be defined as the difference between marginal social and marginal private accident costs, which is called marginal external accident costs. Due to our empirical bottom-up approach the calculation starts by counting the number of accidents on our route in 1995 for each mode divided according to passenger and goods transport. These accidents are valued with the recommended monetary values minus the part which is covered by insurances.

Formally we can express the total external accident costs (AC) for each transport mode as follows:

$$AC = \sum_{j=1}^{2} \sum_{n=1}^{3} v^{n} * (1 - c^{n}) * A_{j}^{n} \tag{7}$$

Index ***j*** represents the distinction between passenger and goods transport (for road traffic: car accidents or truck accidents). Index ***n*** indicates the severity of the accident. We differentiate between fatalities, serious and minor injuries from accidents. Variable ***A*** represents the number of persons (for each severity class) involved in the accidents. ***v*** represents the recommended monetary values for each severity class, while ***c*** indicates the percentage by which the valuation function is reduced due to the already internalised accident costs borne by the health insurance companies and employers´ liability insurance associations.

This approach is independent of the traffic volume (vehicle km travelled), thus, marginal costs in dependence of the traffic flow cannot be calculated. However, Jansson indicates that for interurban traffic the accident rate is more or less independent of the traffic flow (PETS, 1997). In other cases, if no real data is available, a risk approach has to be applied including the probabilities that accidents of every severity occur (for an example see Mayeres *et al*,1996).

With regard to road traffic a difficulty arises when we try to distinguish between accidents related to cars and trucks. From the German Statistical Office (1995) we know the number of one-vehicle and two (or more)-vehicle accidents. It is the latter ones that are critical. The assumption was made that all accidents involving trucks are subsumed under the category "truck accidents" even if cars are also involved.

On our route there were no train or plane crashes causing fatalities or injured persons in 1995 (German Bundesbahn, 1997; German Lufthansa, 1997). Thus, for these transport modes the external accident costs are zero. One could argue that in this case a risk approach seems to be appropriate. However, due to the lack of probability data for each transport mode on our route, the application of a risk-based method would not be serious.

4 Results for the Route Frankfurt - Milan

Due to limited space, not all the specific calculation steps and results for the route Frankfurt - Milan can be presented in this paper. Therefore, we will concentrate on results which allow a modal comparison for passenger and goods transport. In the QUITS final report the results from each step of the process of identification, quantification and valuation of external effects are documented separately to make the assumptions transparent and to provide all relevant information for decision-makers (see Weinreich *et al*, 1998).

Concerning road traffic, our route has a length of 634.8 km including the motorway A5 from Frankfurt to Basel (310.1 km), the A2 from Basel to Como (282.7 km) crossing the St. Gotthard pass, and the A8/9 from Como to Milan (42 km). An average occupancy factor for the whole route for long-distance traffic is assumed which is usually higher than the average factor including short and long distances. For cars, an average occupancy factor of 1.81 passengers per vehicle is assumed, the corresponding figure for trucks is 8.77 tonnes per vehicle.

Concerning rail traffic, the input data for the calculation of emissions and external costs was gathered from the responsible railway companies, for the route Frankfurt-Milan primarily from the German railway company (German Bundesbahn 1997). Four passenger train technologies are included, highspeed (ICE for Germany and partly for Switzerland, and one Cisalpino/day from Zurich to Milan), Intercity/Eurocity (IC/EC), Interregio, D- , and Night-trains (IR/D/N), and local trains. 183.8 passengers per train is the average occupancy of all four train technologies. For goods transport only one full load train technology (1,600 tonnes train) powered by electricity is analysed to represent this very inhomogeneous transport mode. The total route is 715 km long and is made up of 343 km in Germany (D), 326 km in Switzerland (CH), and 46 km in Italy (I).

With regard to air traffic, the average length of the flight is 535 km. Seven types of airplanes (B737, MD80, AVRA, A322, A300, A310, and A321) cover more than 98 % of all flights so that the calculations are limited to these types. In 1995 the average number of passengers per airplane was 84.3.

Table 6: Comparison of the emissions per trip from different transport modes, direction Frankfurt - Milan (one way), passengers and goods in 1995

Passengers	**g/passenger-km**			**Goods**	**g/tonne-km**	
	road	**rail**	**air**		**road**	**rail**
CO_2	105.78	33.11	181.25	CO_2	73.24	13.335
CO	2.59	0.01	0.39	**CO**	0.23	0.004
HC	0.15	0.00	0.06	**HC**	0.11	0.001
NO_x	0.69	0.04	0.60	NO_x	0.72	0.017
SO_2	0.02	0.06	0.03	SO_2	0.04	0.023

Concerning the emissions and external costs of one trip, only passenger-related or tonne-related figures are comparable, i.e. ECU/passenger or ECU/tonne and ECU/passenger-km or ECU/tonne-km. Table 6 presents the emissions per trip from different transport modes.

The external costs due to air pollutants, global warming, noise, and accidents will be compared in Table 7 for passenger traffic and in Table 8 for goods transport summarizing the results for each transport mode.

Table 7: Specific external costs of passenger road, rail and air traffic per trip, direction Frankfurt - Milan, 1995

	Air pollutants	Global warming	Noise	Accident	Total external costs
	ECU/1000 pkm				
ROAD-PASSENGER					
Frankfurt - Basel (D)	14.77	5.11	4.37	13.16	**37.41**
Basel - Como (CH)	12.98	5.17	1.82	31.63	**51.60**
Como - Milan (I)	34.25	5.60	7.35	27.48	**74.68**
Frankfurt - Milan	**15.63**	**5.16**	**3.83**	**19.64**	**44.26**
RAIL-PASSENGER					
Frankfurt - Basel (D)	2.95	2.82	2.79	0	**8.56**
Basel - Como (CH)	0.18	0.09	0.52	0	**0.79**
Como - Milan (I)	4.62	2.81	0.31	0	**7.74**
Frankfurt - Milan	**1.71**	**1.54**	**1.62**	**0**	**4.87**
AIR-PASSENGER					
Frankfurt - Milan	**9.60**	**8.55**	**3.76***	**0**	**21.91**

For air pollutants, the figures given are calculated with the YOLL concept. For global warming, the results are based on the high value of 170 ECU/tonne of carbon. The asterisk (*) indicates a value from IWW/Infras (1995) for Germany, as noise from air traffic is not quantified in the QUITS project.

Regarding the Swiss route sections, the difference between road and rail traffic is enormous, because the electricity for the railway system is mostly generated without fossil fuels, which has a strong impact on both air pollutants externalities and global warming. For noise the differences between the national route sections seems to be too high; this can be explained by the limited population data available and the exclusion of valley effects. The inclusion of tunnel segments is another reason for the low Swiss noise results.

Table 8: Specific external costs of road and rail freight traffic per trip, direction Frankfurt - Milan, 1995

	Air pollutants	Global warming	Noise	Accident	Total external costs
	ECU/1000 tkm				
ROAD-GOODS					
Frankfurt - Basel (D)	14.26	3.23	8.79	2.44	**28.72**
Basel - Como (CH)	18.81	3.84	3.98	5.03	**31.66**
Como - Milan (I)	19.28	3.78	15.55	8.87	**47.48**
Frankfurt - Milan	**15.74**	**3.42**	**7.96**	**3.50**	**30.62**
RAIL-GOODS					
Frankfurt - Basel (D)	0.90	0.86	1.97	0	**3.73**
Basel - Como (CH)	0.06	0.03	0.53	0	**0.62**
Como - Milan (I)	1.80	1.09	1.20	0	**4.09**
Frankfurt - Milan	**0.68**	**0.62**	**1.50**	**0**	**2.80**

For air pollutants the figures given are calculated with the YOLL concept. For global warming, the results are based on the high value of 170 ECU/tonne of carbon.

The comparison of the specific external costs also indicates that the results are route-specific. The Italian figures in particular, which refer to a very short route section of 46 km in length, cannot be seen as averages for the whole country.

Concerning the external environmental and health costs due to air pollutants, the results for cars are aggregated figures that take into account the vehicle-mix of each country involved. An approximation based on the specific emission factors is made for all major car technologies. These figures are presented in Table 9.

Table 9: Specific external environmental and health costs due to air pollutants from different car technologies per trip, direction Frankfurt-Milan, 1995,

ROAD-PASSENGER	Germany	Switzerland	Italy	Total FM
	ECU / 1000 pkm			
petrol with catalytic converter	9.1	6.2	8.6	**8.1**
petrol conventional	47.4	35.6	42.7	**42.5**
diesel	13.0	20.2	23.8	**14.6**

5 Conclusions

Finally, we are able to draw the following conclusions from the externality analysis:

- First steps towards a consistent methodology of the valuation of transport-specific air pollutants have been made.
- The application of the integrated model for the calculation of road-specific external costs is a first step towards the complex analysis of the dispersion of air pollutants, the identification and quantification of impacts, as well as the valuation of these impacts.
- Concerning the comparison of transport modes, external costs of passenger road traffic are about 9 times as high as those from rail traffic and about twice as high as those from air traffic. Even if we exclude accident costs which dominate the external costs of car traffic from the comparison, road traffic results for the whole route are about 5 times as high as those from rail traffic. For goods transport, it can be concluded that the external costs of road traffic are about 11 times as high as those from rail traffic.
- For the valuation of external costs of global warming, new estimates were used which were derived from the current ExternE study of the European Commission. The global warming damages estimated in this study are significantly higher than calculations in earlier studies. However, they are lower than estimates derived from an avoidance cost approach, which was used in some recent top-down studies (e.g. IWW/Infras 1995).
- For noise impacts it can be concluded that there are great differences between the national route sections due to different population densities along the route. Besides, the inclusion of tunnel segments (noise dispersion is set to 0) is a reason for the low Swiss noise results.
- The bottom-up approach for the route-specific external cost analysis produces plausible results. In comparison to top-down approaches the results are about twice as high for

passenger road transport with regard to external environmental and health costs due to air pollutants. 99.2 % of the external costs of road traffic are due to health damages caused by air pollutants, only 0.8 % are caused by impacts on crops, forests and material. This can be explained by the high mortality impacts of air pollutants in the current EcoSense version.

- With regard to impacts of air pollutants, some sensitivity analyses were made. This is particularly important in order to show the sensitivity of results to the use of alternative concepts for valuing health risks (YOLL vs. VSL approach). It can be concluded that the total external costs as well as the specific ones double when the VSL concept is applied.

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