ERGEBNISSE VON TA-PROJEKTEN – NEUE TA-PROJEKTE

Estimation of External Costs Using the Impact-Pathway-Approach

Results from the ExternE project series

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In recent years there has been much progress in the analysis of environmental damage costs, thanks to several major projects evaluating the external costs of energy in Europe, especially a series of projects financed by the European Commission, DG Research, called ExternE: The external costs of electricity production. This major study series was undertaken over the past 10 years with the participation of researchers from 12 EU Member States.* The project was designed to quantify the socio-environmental costs of different forms of electricity production (fossil, nuclear and renewable) for the EU region. The report of the 1998 - 2000 phase is just published (Friedrich and Bickel 2001), and the latest phase – continuing until 2003 – has just started. This paper presents an overview of the methodology and the results.

Introduction

The production and application of technologies, for example for energy conversion or transport of passengers and goods, cause considerable damage to human health, flora and fauna, ecosystems and materials. These impacts are mostly externalities, i.e. not reflected in the prices of goods. This damage however should be considered in the framework of technology assessments and when taking decisions that have an impact on the amount of emissions to the air. A direct way to do this is the quantification of the damage and the subsequent transformation into monetary units based on the "willingness-to-pay-approach". The resulting external costs can then be internalised via taxes or charges, used for cost-benefit-analyses or as an indicator for environmental damage within green accounting.

In most former studies, a top-down approach was used, i.e. total damage estimated for a country was divided by the activity leading to the externality (e.g. emission of NO_x) to allocate damage to sources. However this approach fails to take into account the fact that damage is to a large extent location-specific. For example, the health damage caused by the emission of NO_x at a given site depends on the population distribution, on wind speed and direction and on the background concentration of other pollutants, that react with the emitted NO_x in the atmosphere. The transport of pollutants across national boundaries was also neglected. Furthermore, this approach gives average figures, but not marginal ones as required.

It follows from the above that basic research in this area was needed to develop a methodology that made much better use of the available science. From its beginnings, the ExternE study went beyond the earlier studies in several respects. These are:

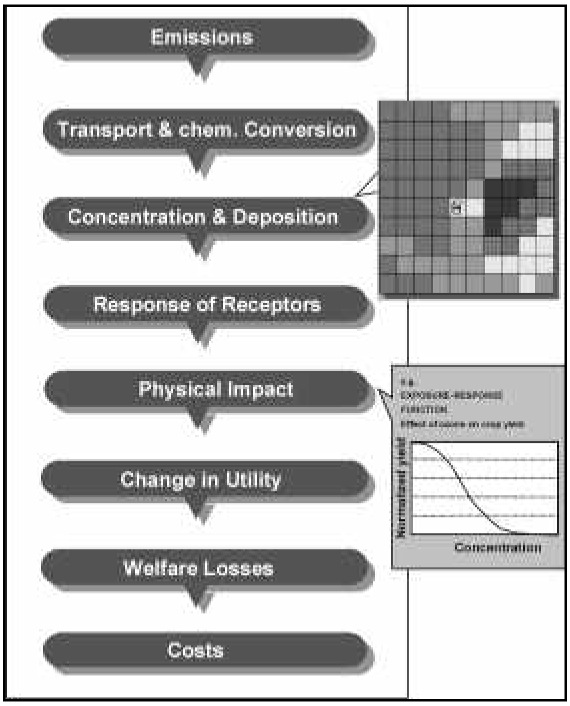
a) A more thorough characterisation of the technologies and their discharges into the environment on a site specific basis. Clearly the environmental impacts of electric power generation will vary according to the technology adopted. These need to be made much more precise than has been done in the past before valuations can be carried out. Furthermore, the impacts will vary according to where the plant is located. On a priori grounds, site specific differences should be important. The EU-study has aimed to find out how important these differences are by evaluating the damages from plants with the same technology but with different locations.
b) A consideration of all major stages of a life cycle rather than just a process like e.g. electric power generation or the operation of a vehicle. Significant environmental impacts occur during mining of fuels, their transportation and the eventual disposal of wastes. These need to be evaluated as carefully as those of the generating stage
c) Modelling the dispersion and transformation of pollutants over their full range. Ear-

lier work relied mainly on short distance dispersion models for the majority of the air pollution impacts. However, these were inadequate, as reference to the concern over trans-boundary air pollution in Europe clearly shows. Chemical reaction of pollutants in the atmosphere also needs to be accounted for.

d) Engaging in a more extensive, critical review and use of the ecology, health sciences, and economics literature than previous studies. Many ecological, epidemiological and valuation studies have come out in the last ten years which needed integration within a framework whereby they could be better used for policy analysis.

e) Estimating externalities by accounting for existing market, regulatory, insurance and other conditions that internalise some damages so that they are not externalities. ExternE makes an attempt to analyse when, and to what extent, external effects have been internalised.

Fig. 1: The Impact Pathway Approach



The Impact Pathway Approach

The ExternE Project has adopted the "impact pathway" approach for the assessment of the external impacts and associated costs resulting from the supply and use of energy. The phrase "impact pathway" simply relates to the sequence of events linking a "burden" to an "impact" and subsequent valuation. The methodology therefore proceeds sequentially through the pathway, as shown in Fig. 1. The chain of causal relationships starts from the emission of a burden through transport and chemical conversion in the environment to the impacts on various receptors, such as human beings, crops, building materials or ecosystems. Based on exposure-response functions physical impacts are calculated. Finally the resulting welfare losses are transferred into monetary values based on the concepts of welfare economics. The impact pathway approach provides a logical and transparent way of quantifying externalities. A detailed discussion of the methodology and the models used is given in (European Commission 1999a). The most recent recommendations can be found in (Friedrich and Bickel 2001).

Within the series of ExternE projects the EcoSense model has been developed, representing the implementation of the impact pathway approach in an integrated computer tool (see e.g. Krewitt et al. 1995). EcoSense provides harmonised air quality and impact assessment models together with a comprehensive set of relevant input data for the whole of Europe, allowing a site specific bottom-up impact analysis. In ExternE, EcoSense has been used to calculate external costs from electricity generation and transport of passengers and goods in a large number of case studies in all EU countries.

Three types of air quality models are included in EcoSense:

- the Windrose Trajectory Model (WTM), a user-configurable trajectory model based on the Windrose approach of the Harwell Trajectory Model developed at Harwell Laboratory, UK (Derwent et al. 1988). It includes air chemistry processes and covers the whole continent of Europe;
- the Source Receptor Ozone Model (SROM), for estimating ozone concentration by using source-receptor matrices. These were derived from results of the EMEP Ozone Model for different reduction scenarios (Simpson et al. 1997). The model is based on the EMEP iteration

model developed by David Simpson (Simpson and Eliassen 1997);

- the Industrial Source Complex Model (ISC) (Brode and Wang 1992) for point emission sources, or the ROADPOL model (Vossiniotis et al. 1996) for line emission sources. Both are Gaussian plume models used for transport modelling of primary air pollutants on a local scale.

Dose-effect models have been compiled and critically reviewed by expert groups within the ExternE project, based on the state-of-the-art studies in the field of health effects, impacts on plants and on building materials. A detailed discussion of the effect mechanisms, underlying assumptions etc. is given in (European Commission 1999a).

shadow price for reaching the Kyoto reduction targets in the European Union is used as a second best option, as long as reliable damage cost estimates are not available.

Exemplary Results: Estimation of Marginal Costs

Electricity Production

Table 1 presents the results of applying the impact pathway approach to different types of power plants in Germany (see Friedrich and Krewitt 1997). In addition to the damage cost estimates, avoidance costs are given for impacts on ecosystems and global warming, where damage cost estimates show large uncertainty ranges. The costs for ecosystems are based on the political aim (as stated in European Commission 1997) of reducing the area in the EU, where critical loads are exceeded, by 50 %. For global warming a shadow price for reaching the Kyoto reduction targets is used.

Table 1: Quantifiable marginal external costs of electricity production in Germany*

	Coal	*Lignite*	*Gas*	*Nuclear*	*PV*	*Wind*	*Hydro*
Damage costs							
Noise	0	0	0	0	0	0.005	0
Health	0.73	0.99	0.34	0.17	0.45	0.072	0.051
Material	0.015	0.020	0.007	0.002	0.012	0.002	0.001
Crops	0.0000	0.0000	0.0000	0.0008	0.0000	0.0007	0.0002
Total	0.75	1.01	0.35	0.17	0.46	0.08	0.05
Avoidance costs							
Ecosystems	0.20	0.78	0.04	0.05	0.04	0.04	0.03
Global Warming	1.60	2.00	0.73	0.03	0.33	0.04	0.03

* Numbers in Eurocent/kWh; median estimates; CO_2 emissions are valued with avoidance costs of 19 Euro/t CO_2.

The final step in the analysis is the economic valuation of the damages quantified. According to the underlying economic theory, monetary valuation is based on individual preferences. As far as available, market prices are used (e.g. for crop losses and material degradation). For health impacts such market prices do not exist. Therefore, monetary values for avoiding or reducing the risk of mortality and morbidity are derived from individual preferences revealed by market behaviour or by contingent valuation surveys.

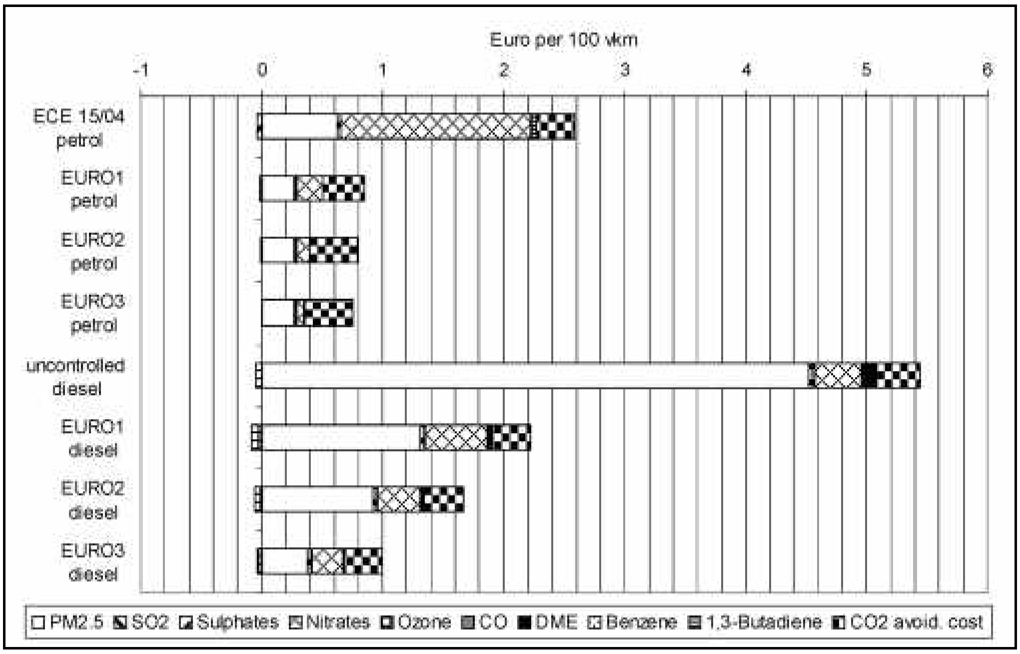
The uncertainties involved in estimating damage costs of global warming caused by the emission of CO_2, methane and nitrous oxide are still very large. For this reason the use of a

Road Transport

A comparison of damage costs for different car technologies (see Friedrich and Bickel 2001) shows that diesel cars cause much higher damages than petrol cars due to their high primary particle emissions. This is illustrated in Figure 2 for the case of Stuttgart, but the picture is similar for other locations. The introduction of EURO I, EURO II, and EURO III emission standards reduces the damage costs per vehicle kilometre by 63 %, 74 % and 86 % respectively compared to an uncontrolled diesel car. The reduction of damage costs caused by petrol cars by 77 % from ECE 15/04 to EURO I is considerable.

where costs due to passenger transport in the city centre of Stuttgart are presented. In Stuttgart, rail vehicles for passenger transport are operated electrically only, that means there are no direct emissions from vehicle use. Of the remaining processes, fuel (electricity) production causes the highest share of costs. For vehi-

Fig. 2: Damage costs for different car technologies in Stuttgart*

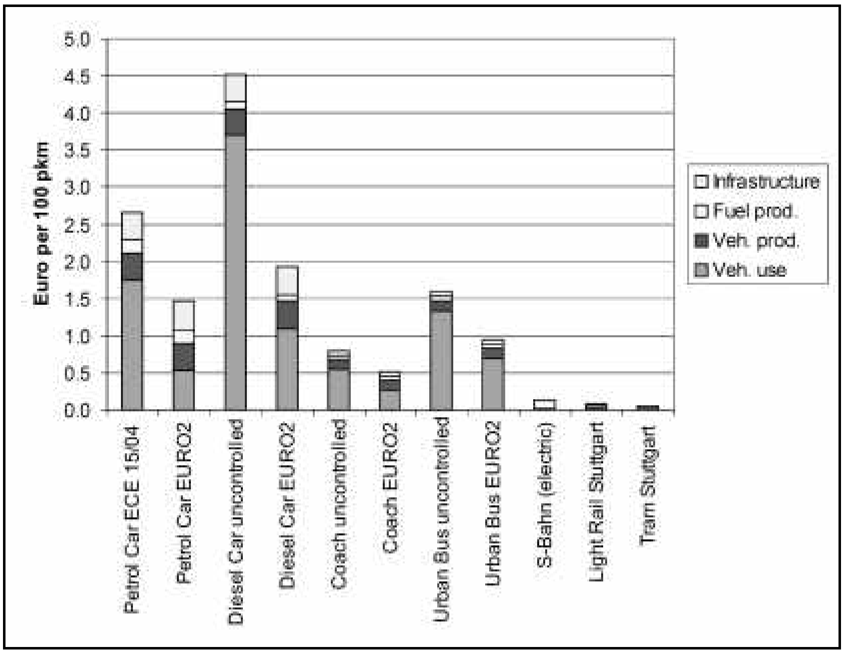


* In Euro per 100 vkm (vehicle-km), median estimates; CO_2 emissions are valued with avoidance costs of 19 Euro/t CO_2.

The reductions due to the introduction of EURO II and EURO III are smaller, because particle emissions are only marginally reduced, although they dominate the damages in the urban environment. Fig. 2 shows some negative costs (i.e. benefits) due to reduced ozone impacts. In the current background emission situation in Germany (as in some other countries), an additional unit of NO emitted leads to a reduction of ozone in some densely populated areas and thus a decrease in ozone damages. However NO emissions are far from being beneficial when taking into account the damage costs due to nitrates, which outweigh the ozone benefits by far.

For comparisons between vehicle types and modes it is important to include up- and downstream processes. This is illustrated in Fig. 3, cles with internal combustion engines, vehicle operation plays a very important role in the urban environment. The only exception is the petrol car complying with EURO II, where infrastructure use causes the highest cost per passenger kilometre (pkm). Costs per pkm due to vehicle production, fuel production and infrastructure use are much lower for busses and coaches than for cars. When looking at the total costs per pkm, the electric rail vehicles by far cause the smallest damage costs due to air pollution. They are followed by the coaches; this is mainly due to the high load factor of coaches. The load factor of buses for inner urban public transport is much lower. So the ranking in terms of increasing damage costs for modern road passenger vehicles is modern urban bus, EURO II petrol car and EURO II diesel car.

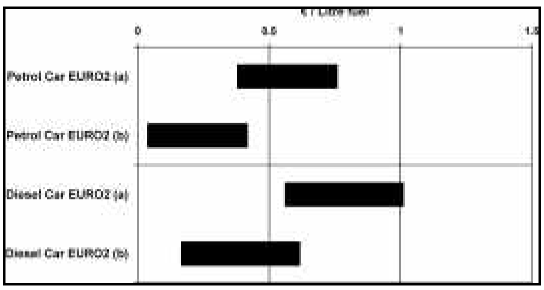
Fig. 3: Comparison of air pollution costs due to urban passenger transport in Stuttgart*



* Median estimates; CO_2 emissions are valued with avoidance costs of 19 €/t CO_2 (pkm = passenger kilometre).

Figure 4 presents the quantifiable range of external costs due to air pollution, accidents and noise in Stuttgart for a petrol and a diesel car complying with the EURO II emission standard. For reasons of illustration the costs are expressed per litre of fuel. The upper bar ("a)") shows the range resulting from low and high estimates for air pollution (ExternE estimates), accidents and noise (both based on Bickel and Friedrich 1995). The lower bar ("b)") in addition includes the balance of infrastructure costs and tax payments (vehicle tax, fuel duty including Ecotax 2001). Results indicate, that external costs caused by cars are not fully reflected in current prices.

Fig. 4: Range of external costs due to a) air pollution, accidents and noise, b) as „a)" plus infrastructure costs minus tax revenues

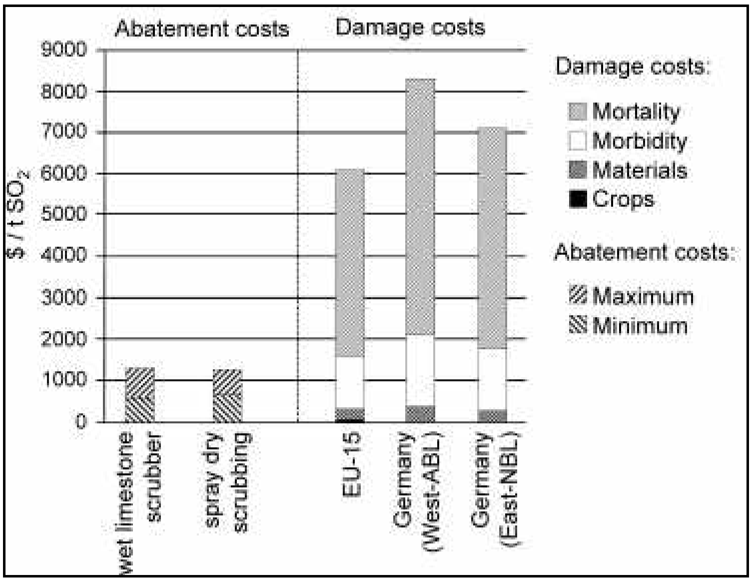


* Incl. „Eco Tax" per January 2001

Exemplary Results: Cost-Benefit-Analysis

As an example for the use of the method for cost-benefit analysis, Figure 5 shows a comparison of the cost of desulphurisation plants attached to large coal fired power plants in Europe in € per tonne of SO_2 avoided and the avoided damage costs due to the reduced emissions. The benefit clearly outweighs the costs. This even remains valid, if e.g. the mortality impacts would be neglected. So, even if the damage cost estimates are varied within the uncertainty range, the conclusion would not change.

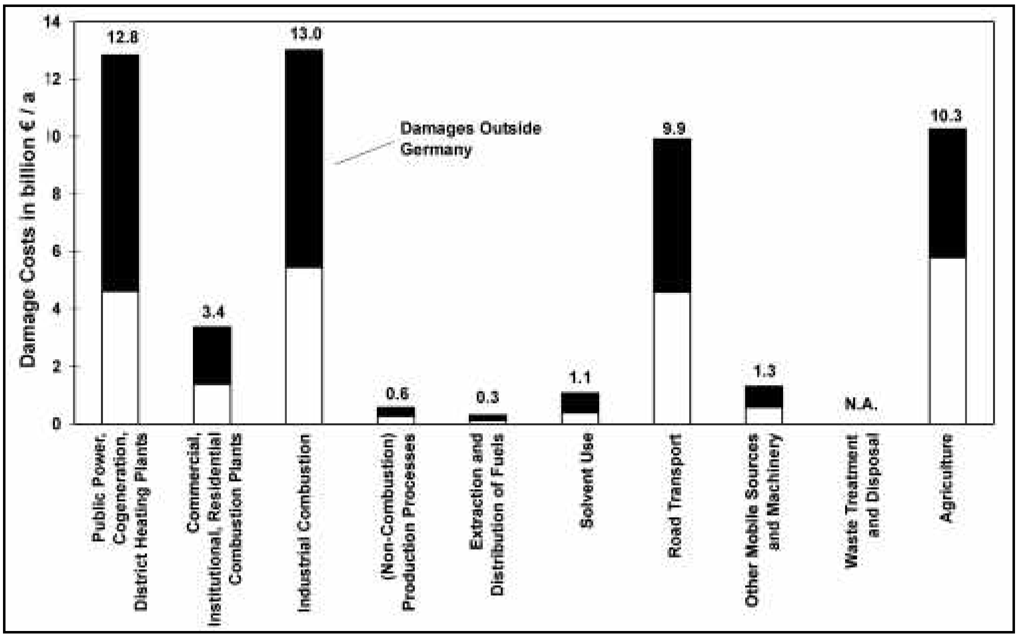
Fig. 5: Comparison of costs and benefits of coal fired power plant desulphurisation



Exemplary Results: Green accounting

The total damage caused by air pollution is needed for green accounting, i.e. for assessing the state of the environment and for exploring whether damage from air pollution is increasing or decreasing. The use of the impact pathway approach for this task has the advantage, that the damage can be allocated to the activities responsible for this damage. Figure 6 shows as an example the damage caused by the emission of selected pollutants of the different source sectors in Germany (European Commission 1998). The damage estimates include effects on human health, crops, and building material. The considered substances are concentrations of SO_2, secondary particles, and ozone and deposition of nitrogen, sulphur, and acidic components. Power plants, industrial combustion, road transport and agriculture are the sectors responsible for the highest damage. Damage inside as well as outside Germany is shown, the exported damage is

Fig. 6: Damage Costs inside and outside Germany caused by NO_X, SO_2, NMVOC, and NH_3 emissions of the country's economic sectors in 1990



higher than the damage in Germany. Similarly, the import from other countries into Germany can be quantified.

Uncertainties and Gaps

The methodology is sometimes criticised by mentioning the uncertainties involved. And indeed uncertainties are large. Before discussing these, one has however to distinguish these uncertainties from deviations of current results compared to earlier results as well from ExternE itself as from other publications. Firstly there has been a substantial methodological development in the last ten years, e.g. from a top-down to a site-dependent bottom-up approach or with regard to the monetary valuation of health effects. So comparisons should include an analysis of whether the chosen methods are appropriate and state of the art and whether the studies are complete. Secondly, new knowledge e.g. about health impacts of course changes the results. For example the emerging knowledge that fine particles can cause chronic diseases resulting in a reduction of life expectancy changed the results considerably. An assessment always reflects current knowledge. That an assessment changes with new knowledge – and also may change due to a change in people's preferences – is natural and not a methodological problem.

With regard to uncertainties, firstly input data and model uncertainties have to be addressed. These can be analysed by using statistical methods. Results show a factor of ca. 2 to 4 as one-geometric standard deviation intervals around the median estimate (see Rabl and Sparado, 1999). The largest uncertainties lie in the exposure-response function for health impacts and the value of a life year lost – current research is directed towards reducing these uncertainties, which reflect our limited knowledge.

Secondly, certain basic assumptions have to be made like e.g. the discount rate, the valuation of damage in different parts of the world, the treatment of risks with large impacts or the treatment of gaps. Here, a sensitivity analysis should be and is carried out demonstrating the impact of different choices on the results. The full range of results including statistical uncertainties and sensitivities could span a range from a factor of 2 up to 7 around the median value, for global warming impacts even more. Decisions then would sometimes necessitate a choice of the decision maker about the assumption to be used for the decision. This would still lead to a decision process that is transparent and, if the same assumptions are used throughout different decisions, these would be consistent with each other. If uncertainties are too large, as currently still is the case for global warming impacts, shadow values could be used as a second best option. Shadow values are inferred from reduction targets or constraints for emissions and estimate the opportunity costs of environmentally harmful activities assuming that a specified reduction target is socially desired.

Despite these uncertainties, the use of the methods described here is seen to be useful, as

- the knowledge of a possible range of the external costs is obviously a better aid for policy decisions than the alternative – having no quantitative information at all;
- the relative importance of different impact pathways is identified (e.g. has benzene in street canyons a higher impact on human health as fine particles?);
- the important parameters or key drivers, that cause high external costs, are identified;
- the decision making process will become more transparent and comprehensible; a rational discussion of the underlying assumptions and political aims is facilitated;
- areas for priority research will be identified.

It is however remarkable, that despite these uncertainties certain conclusions respectively decisions are robust, i.e. do not change over the whole range of possible external costs values. An example is the efficiency of desulphurisation plants (as shown in Fig. 5). Furthermore, it can be shown, that the order of e.g. electricity production technologies with respect to decreasing external costs does not change if assumptions are varied.

It should also be noted, that gaps can be closed and uncertainties reduced by performing further research (e.g. further contingent valuation studies and epidemiological studies).

Conclusion

The impact pathway approach developed within the ExternE project series funded by the European Commission (EC) is a means to estimate damage costs, that can be used as decision aid in

- identifying the most suitable form of eco-political instruments like ecotaxes,
- performing cost benefit analysis for assessing measures or strategies for environmental protection
- identifying environmental aims (e.g. air pollution thresholds, where marginal damage costs match marginal avoidance costs),
- accounting for changes of the state of the environment (green accounting),
- comparing the social costs of different technologies, thereby regarding internal costs as well as environmental and health impacts.

The user has to be aware, that uncertainties exist and certain assumptions have to be made – the method gives valuable support for decision making and a range of results, but does not replace the decision making process. Still, the method is capable of reducing the bandwidth of possible outcomes of decisions. Furthermore, a general application of the method would lead to decisions, that are more transparent and more consistent with each other.

The method has already been extensively used to support decisions concerning a number of air quality directives of the European Commission (e.g. the draft ozone directive, the national emissions ceiling directive, the draft directive on non-hazardous waste incineration, air quality guidelines on CO and benzene), the UN/ECE multi-pollutant, multi-effect protocol and a number of national activities. The methodology is constantly further developed. In the current ExternE project *"NewExt" (New elements for the assessment of external costs from energy technologies)* a survey is made in three countries in Europe to broaden the empirical basis for monetary valuation of risks reducing life expectancy due to air pollution. Furthermore, impact pathways for various pollutants in water and soil are developed. In a number of other EC projects the methodology is extended to applications for industrial activities and for transport activities including a detailed analysis of noise impacts, accidents and congestion. Furthermore, in a project with the acronym GREENSENSE the use of the method for green accounting is further developed.

Note

* The main organisations were the University of Stuttgart (Germany), the Association for Research and Development of Industrial Methods and Processes (ARMINES, Sophia Antipolis, France), the Foundation Eni – Enrico Mattei (FEEM, Venice, Italy), The Flemish Institute for Technological Research (VITO, Mol, Belgium), The Risø National Laboratory (Roskilde, Denmark), AEA Technology (Didcot, United Kingdom) and the Centre for Energy, Environment and Technological Research (CIEMAT, Madrid, Spain). The Commission contributed € 10 million (European Commission 1995 a-f, 1999 a-d).

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Nanotechnologie aus der Perspektive der Innovations- und Technikanalyse

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Schon kurz nach dem Wechsel vom 20. in das 21. Jahrhundert bestätigt sich, dass es sich bei der Nanotechnologie um eine Schlüsseltechnologie des neuen Jahrhunderts handelt. Insofern wundert es nicht, dass der internationale technologische Wettlauf um erfolgversprechende Märkte längst begonnen hat. In diesem Kontext ist es sinnvoll, bereits frühzeitig auch der Frage nachzugehen, welche Technikfolgen die Nanotechnologie auf verschiedene Bereiche unserer Gesellschaft und auch des Standortes Deutschland mit sich bringen kann. Das Bundesministerium für Bildung und Forschung (BMBF) hatte das VDI-Technologiezentrum Zukünftige Technologien damit beauftragt, eine empirisch gestützte Vorstudie zur Innovations- und Technikanalyse (ITA) im Bereich Nanotechnologie für diesen Bereich auszuarbeiten. Neben Fragen zur technischen und ökonomischen Dimension der Nanotechnologie wurden solche zu ökologischen, gesundheitlichen, individuellen und sozialen sowie zu politischen Aspekten berücksichtigt. In