APAS-Project (RENA-CT94-0041):
"Long-term Integration of Renewable Energy Sources into the European Energy System, and its Potential Economic and Environmental Impacts" (LTI-Project)

Account of Presently Known Social Costs

Final Report 2.0
Mannheim, June 1996

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Preface

The purpose of this paper is to compile an account of the relevant social costs known today for each fuel cycle technology to achieve a better full cost accounting. The first chapter will briefly outline different facets of the scholarly discussion on externality assessment. In Chapter 2, the results of major empirical studies on external costs of energy are presented and reasons are provided why they vary widely. Some studies are selected to be described in more detail concerning their assumptions, methods, results, and recommendations. However, these differences are almost negligible, as soon as global warming damage estimates are taken into consideration. Therefore, the last chapter is solely devoted to this issue.

Contents

1 Introduction

In the past decade, there have been many empirical attempts to derive estimates of environmental damages induced by the economic activities in a free market economy. The majority of the studies has focused on the energy sector as one of the main contributors to environmental problems. Well-founded arguments to identify, quantify, and monetize the so-called external effects of energy supply and demand, and to internalize them into decision and policy making are provided by economic science. Moreover, the need to incorporate environmental issues into other policy areas – for example by taking account of environmental externalities – has been emphasized as principle for EU action in several official documents of the European Union. These are some of the scientific, political, and legal reasons why *externality studies* have played an increasing role when decision makers try to cope with environmental problems. Yet, even though substantial research efforts have been made in this field, many open questions remain. Politicians have not received one single metric expressing all externalities of electricity generation, as they might have hoped, but monetary values that differ by orders of magnitude. For everyone it is true, that accepting and using the quantitative findings of a particular study on environmental costs implies accepting the goals and values embedded in that study, as the latter are one principal cause for differences in results of externality studies.

2 The Economics of Energy Externalities

The following chapter will in short summarize the economic reasoning behind the debate on energy externalities and damage evaluation. This includes some general definitions of technical terms (Sections 2.1 and 2.2). Section 2.3 looks at selected overall methodological approaches applied so far in the environmental assessment of fuel cycles and compares their advantages and disadvantages.

2.1 The Basic Concepts of External and Social Costs[1]

In neo-classical economic theory, *externalities* are defined as effects arising when the social or economic activities of one group of persons have an impact (either positive or negative) on the welfare or cost of another group while that impact is not fully accounted for in the private decision making of the first group. Applied to fuel cycles "externalities are the costs imposed on society and the environment that are not accounted for by the producers and consumers of energy, i.e. that are not included in the market price. They include physical damage to the natural and built environment as well as impacts on recreation, amenity, aesthetics and other contributors to individual utility" (CEC 1995a, 147). External effects can be either positive or negative depending on the values of the people affected. Negative external effects are often called external costs; accordingly, positive external effects can be called external benefits. Yet, in a slightly different definition, external costs or benefits are monetary equivalents of external effects, which in this case are understood in terms of physical impacts.

From the point of view of many economists, the explanation for the environmental problems of our society can be provided by this concept of externalities which is a component of the neo-classical theory of welfare economics. This concept is fundamentally about seeking opti-

[1] This section is mainly based on Baumol/ Oates (1988), DIW (1995), and Krupnick et al. (1994).

mal, first-best policies for controlling pollution through equating costs of control and their benefits at the margin. Economic efficiency requires the levels of production and consumption of all things that matter directly to be set in the way that the marginal social benefits of those goods and services equal their marginal social costs; the term 'social' is defined as private (or internal) plus external benefits or costs. The result of the existence of externalities is *market failure* and an inefficient allocation of resources in the economy. The answer given by economic theory to the question of how to prevent environmental degradation, in economic terms, of how to correct market failure is internalizing external environmental benefits and costs through various mechanisms, as for instance through taxes or tradable permits.

However, from the perspective of neo-classical welfare economics, the presence of residual environmental damages does not necessarily mean that there is an externality problem. Even if the external costs of an economic activity are internalized correctly, a certain degree of emissions may remain. Assuming perfect information and rational behavior, it represents the level of pollution accepted by economic individuals. Internalization aims at reaching an optimal level of pollution and not its elimination (Krupnick et al. 1994, 11). Therefore, in theory only deviations from optimality should be treated as *relevant external effects.*

The phenomenon of externalities was first described by A.D. *Pigou* (1912, 148ff.) who introduced the distinction between private and social costs. If externalities arise, private costs diverge from social costs (i.e., overall costs). For example, pollutants emitted from factory chimneys cause supplementary costs for the cleaning of clothes as well as for damages to buildings and human health. These costs are not paid for by factory owners. In such cases, social costs are higher than private costs. Since Pigou, the term 'social costs' has been redefined several times in the literature. In contrast to Pigou, *Kapp* (1979) for instance has used the term social costs for the difference between private and total costs, i.e. "for all cost elements of production or consumption handed on to third parties not involved in the specific market transaction" (Hohmeyer/ Ottinger 1994, 1). This notion of social costs is similar to the neo-classical definition of external costs. Yet, it differs with regard to the scope of externalities considered to be relevant. Hohmeyer and Ottinger argue in favor of this "broader" definition of social costs, "as the neo-classical definition of external costs does not allow for important aspects of sustainability" (Hohmeyer/ Ottinger 1994, 1).

Concerning appropriate concepts that might be used to quantify external costs, two approaches have been distinguished in the literature: *abatement costs and damage costs*. Abatement or control costs comprise the money which is to be paid for a certain reduction of pollution, whereas damage costs reflect the value of damages caused by pollution. For economic optimization, the curve of both abatement and damage costs must be known. There is some justification for assuming that marginal damage costs increase with the level of pollution, while marginal abatement costs increase with the level of regulation. At the point of optimality, marginal abatement are equal to marginal damage costs. The concepts of abatement and damage costs are related in a way similar to the concepts of supply and demand: each is the exact counterpart of the other and both are equal at the point of equilibrium. As long as marginal damage costs are higher than marginal abatement costs the further reduction of emissions should be pursued. Moreover, cost-effectiveness is a necessary condition for optimal allocation. This implies that the optimal level of residual emissions and the optimal mix of control technologies must be determined simultaneously. Under optimal allocation, the marginal costs of different control technologies are all equal to marginal damage costs.

Damage costs are often very uncertain or simply unknown. In contrast, abatement costs are easier to assess, because the costs of the underlying technologies are relatively transparent, especially in the case of already traded control technologies. Therefore, marginal abatement costs are often used as a proxy for marginal damage costs. Moreover, due to practical restrictions concerning information, sometimes average abatement costs are gathered. This rather pragmatic approach suffers from a number of weaknesses from a theoretical point of view: *average cost* can hardly be a proxy for marginal costs, while damage and abatement costs may be related only weakly or not at all in reality.

2.2 The Primary Techniques of Valuing Environmental Effects

Ultimately, for an economist the question arises how to assign monetary values to external effects. Valuation of positive and negative environmental effects is important both for investment decisions involving environmental impacts and for the regulation of the environment. At the same time, it is difficult to put monetary values on things such as clean air or a fine view. For commodities that are openly traded we can use market prices. Yet, for items that influence welfare but which do not pass through markets, *prices do not exist*. That does not mean, however, that these items do not induce costs or that economists must not attempt to translate values into monetary terms and compare them to other things that are valued.

The essence of economic valuation of environmental goods is that it seeks to identify the *preference of individuals* for the allocation of resources by quantifying willingness to pay (*WTP*) for improved environmental quality or willingness to accept compensation (*WTA*) for environmental damage. The differences between these two measures are a major source of controversy (see e.g. ....). A range of techniques, which can be based on either one of these measures, has been developed for valuing environmental goods and services. These techniques can be categorized as *direct and indirect methods*. Direct valuation may rely on the market prices of the goods, e.g. to perform the valuation of impacts on crops, timber, or buildings. For damages not related to any real market, e.g. health damages, damages to natural ecosystems such as reduction of biodiversity, estimates of the WTP or WTA can be based on the contingent valuation method (CVM). Preferences of individuals are perceived and gathered by directly asking people how they would respond to hypothetical changes in environmental quality.

When no direct market prices exist for an environmental service, yet, links with other real markets do, the valuation technique can determine the price indirectly. Two major approaches can be distinguished within this second category, the hedonic price method on the one hand, and the travel cost method on the other hand. Both approaches have in common that a value is calculated by trying to find a relationship between the demand for the environmental good under examination and the demand for a complementary good actually traded on a market. The hedonic models look at the actual expenditures that individuals make in avoiding unpleasant environmental impacts. For example, an increase in noise has been demonstrated to reduce the value of properties affected by the change. Travel cost models observe time and money spent by individuals in going to places where a desirable environment may be experienced. In that way, a value might be derived for recreational sites or even for water quality. (Verweis auf Überblicksliteratur)

It should be noted that these monetization techniques imply underlying premises as for instance that economic valuation is anthropocentric – based on human values – and individualistic, i.e. based on personal preferences.[2] Notwithstanding, there is one major advantage of monetary valuation of environmental effects. It allows environmental issues to be *included explicitly in the individual decision making process* in general, and in cost-benefit analysis in particular. From an economic perspective, the internalization of external costs can be achieved

[2] For a more detailed discussion on assumptions, difficulties, and controversies in the field of economic valuation refer e.g. to Markandya/ Richardson (1993) and Rennings (1995).

most efficiently with respect to costs and dynamics by taxes and tradable permits, rather than by command and control instruments. But it is the latter which have predominantly been implemented by German environmental policy in the past decades.

2.3 Top-Down Versus Bottom-Up Methodology, Externality Versus Life-Cycle Analysis

Two general methodological approaches for the assessment of fuel cycle damages can be differentiated, both including the steps of identification, quantification, and monetization of impacts, that is top-down analysis and bottom-up analysis. The latter is also known as the damage function or impact-pathway approach.

Top-down analyses are based on highly aggregated data. Externalities are calculated from estimates of national damages and aggregated emissions of polluting activities. This type of analysis results in estimates of average damage costs only. In contrast, *bottom-up analysis* offers a tool to determine marginal external costs and benefits. The impacts are incremental or marginal impacts due to an additional power plant at a specific site using specified technology, not average impacts due to all existing burdens. The quantification of the physical impacts of the incremental burdens is based on dispersion models, information on the location of receptors, and dose-response functions. Impacts are monetized by the techniques mentioned above.

Each methodology has a justification or an advantage over the other. Economists are quick to point out that, for most decisions, it is the *marginal effects* that matter, as they are required by neo-classical economic theory. Decision makers could only affect energy supply at the margin, for instance by choosing what plant to construct, modify, or shut down (cf. U.S. Congress/ OTA 1994, 55f.). However, the comparison of aggregated external costs of different fuels and energy technologies is an important basis for fundamental issues of energy policy. Since bottom-up analyses are site-specific, their results are not held appropriate for this kind of comparison (cf. Hohmeyer et al. 1996, 23). Arguments in favor or against either one methodology can also be found with respect to dose-response functions. Considering *average effects* of pollution may substantially underestimate the impacts of some pollutants, since additional amounts can have impacts that are dramatically worse due to non-linear dose-response functions. Thus, it should be possible to specify and not to ignore so-called hot spots in a bottom-up analysis (cf. U.S. Congress/ OTA 1994, 55f.). But most dose-response functions used in the marginal damage costs studies are linear in nature due to lacking information and their marginal costs are constant, i.e. the studies cannot make full use of this comparative advantage (cf. Hohmeyer et al. 1996, 23). (further comment)

In contrast to top-down analysis, bottom-up analysis is very intensive with respect to data requirements and the time necessary to perform the analysis. It tends to regard only a subset of impacts and in this way restricts the coverage of the analysis, because it focuses on areas where data are available and impact-pathways can be established. The potential negligence of synergistic effects or missing system-wide links are another weakness of this kind of approach (cf. Hohmeyer et al. 1996, 5f.; S rensen 1995, 6). (further comment) Hence, marginal effects may as well underestimate the impacts of a specific fuel cycle. The resulting figures are in many cases smaller than those obtained with top-down approaches.

The family of appraisal techniques for examining environmental policies and decisions also includes *life-cycle analysis* (LCA). This approach is based on a "careful and holistic accounting of all energy and material flows associated with a system or process" (CEC 1995b, 9f.). S rensen (1994, 28-37; 1995, 21) points out several advantages of LCA and also demonstrates its main analytical steps for different fuel cycles. In contrast to externality analysis it is principally necessary to assess all direct and indirect impacts of a technology. However, "it is not required to monetize impacts, in fact, even non-quantifiable impacts are included whenever possible." Non-monetized and more so non-quantifiable impacts tend to be lost in externality analyses.[3] The problem of precise separation between internal and external costs does likewise not arise in a LCA. Ultimately, one might conclude that externality studies are just one step on the road to full life-cycle assessment (CEC 1995b, 11; S rensen 1994, 37).

3 A Selection of Studies on Social Costs of Energy

In the past two decades, quite a number of studies have attempted to estimate the environmental costs of different energy conversion technologies. Top-down analysis predominates in most of them. Only the more recent studies utilize a bottom-up approach. The studies should have helped policymakers to make choices about the use of current technologies, the level of support appropriate for new or improved technologies, or to decide on the appropriate eco-tax levels. But looking at the resulting monetary estimates, we have to state that *they vary widely*. Most of the differences can be traced back to relatively simple reasons. To give one example: although applying an almost identical methodology, namely the impact-pathway analysis, and similar technologies, the results of some recent American studies (ORNL/ RFF 1994-1995; RCG Hagler, Bailly/ Tellus Institute 1993-1995) are by an order of magnitude smaller than the estimates in comparable European studies (CEC 1995a-f). An essential reason for this phenomenon is the lower *population density* in the U.S. and, as a consequence of that, the lower health damages calculated (Ewers/ Rennings 1995, 9f.). Therefore, site dependence can be crucial for the resulting figures in bottom-up approaches!

3.1 Comparing Studies on a General Basis

Table 1 surveys the external cost studies reviewed in this chapter. The studies are listed by date of publication.

Among the most prominent of past externality studies for the U.S. are those by

- Michael Shuman and Ralph Cavanagh (1982),
- ECO Northwest et al. (1983-87), maybe better known as BPA study,
- Paul Chernick and Emily Caverhill (1989) of PLC, Inc., a consulting firm in Boston, MA,
- Stephen Bernow and colleagues (1990, 1991) of the Tellus Institute, and by
- Richard Ottinger and colleagues (1990) at Pace University.

The Tellus Institute study differs from the others in that it used the control cost method to value damages. It derives all environmental costs estimates from the costs imposed by existing legislation.

[3] For further analysis of these issues refer to Connor-Lajambe, Helene (1996): Taking Account of Non-Monetizable Impacts. Internal discussion paper of the LTI-project.

Table 1: External Cost Studies Reviewed

Study **Publication Date**	**Sponsors/ Editors**	**Authors and** **their Organisations**	**Some Characteristics**
ExternE (1994-1995)	European Commission, DG XII, Science, Research, Development	ETSU, UK/ CEPN and Ecole des Mines, France/ IER, Germany/ Eyre, Energy and Environment and Metroeconomica, UK et al.	impact-pathway analysis, site specific approach; fossil fuel power plants in West Burton, UK and Laufen, Germany; on-going project since 1991
U.S.-DOE (1994-1995)	U.S. Department of Energy (DOE)/ Commission of the European Communities (CEC)	Oak Ridge National Laboratory (ORNL)/ Resources for the Future Inc. (RFF)	impact-pathway analysis; power plants are in the rural Southwest and Southeast of the U.S.; lowest est. of all studies
New York II (1993-1995)	Empire State Electric Energy Research Corp. (ESEERCO)/ New York State Energy Research and Development Authority	Rowe, Robert et al. at RCG/Hagler, Bailly, Inc., Boulder, CO/ Bernow, Stephen et al. at Tellus Institute, Boston, MA	impact-pathway analysis; EXMOD software includes calculations of probability distributions; results refer to resource sites in NY State, in general
Infras/Prognos (1994)	Bundesamt für Konjunkturfragen/ Bundesamt für Energiewirtschaft/ Amt für Bundesbauten	Ott, Walter et al. at INFRAS AG, Zürich/ Masuhr, Klaus et al. at PROGNOS AG, Basel	comparison of damage and abatement costs of global climate change
CSERGE (1992)	UK Department of Trade and Industry (Department of Energy)	Pearce, David/ Bann, Camille/ Georgiou, Steven at The Centre for Social and Economic Reesearch on the Global Environment (CSERGE), London	literature survey; in some respects, an update of the Pace study; building damages by air emissions dominate the estimates – UK specific
Pace University (1990)	New York State Energy Research and Development Authority/ U.S. Department of Energy (DOE)	Ottinger, Richard L. et al. at Pace University Center for Environmental Legal Studies	review of existing literature; one of the most frequently cited, wide-ranging and extensive studies
Tellus Institute (1990, 1991)	several state energy agencies and utility regulatory bodies	Bernow, Stephen/ Marron, Donald et al. at Tellus Institute, Boston, MA	specific to California and the Northeast of the U.S.; literature review; control costing method: differences in applicable state laws result in differences of cost estimates for emissions
Chernick/ Caverhill (1989)	Boston Gas Co.	Chernick, Paul/ Caverhill, Emily at PLC, Inc., Boston, MA	specific to New England and Northeastern U.S.; literature review (e.g. BPA); only two categories of environmenal effects: air emissions (SO_2, NO_x, CO_2, CH_4) and marine oil spills
Friedrich et al. (1989, 1993)	Vereinigung Deutscher Elektrizitätswerke (VDEW), Frankfurt a.M.	Institut für Kernenergetik u. Energiesysteme (IKE), Stuttgart/ Temaplan, Böblingen/Ifo-Institut, München, Germany	specific to the former Federal Republic of Germany; response to and controversy with Hohmeyer on environmental and macroeconomic (not considered in this paper) external cost estimates
Hohmeyer (1988, 1989, 1994)	Commission of the European Communities (CEC)	Fraunhofer-Institut für Systemtechnik und Innovationsforschung (ISI), Karlsruhe, Germany	specific to the former Federal Republic of Germany; non-environmental and macroeconomic costs included,

			e.g. subsidies
BPA (1983-1987)	Bonneville Power Administration (BPA)/ U.S. Department of Energy (DOE)	ECO Northwest, LTD et al./ Nero and Associates, Inc./ Biosystems Analysis, Inc.	specific to the Northwest of the U.S.; six semi-independent studies; not strictly comparable
Shuman/ Cavanagh (1982)	Northwest Conservation Act Coalition	Shuman, Michael/ Cavanagh, Ralph at Natural Resources Defense Council	specific to the Northwest of the U.S.; preservation of uncertainty ranges to render arbitrary choices unnecessary; includes impacts that are rarely quantified (e.g. global warming).

Additional Sources: Lee (1995); U.S. Congress/ OTA (1994)

For Europe, the two German studies of

- Olav Hohmeyer (1988, 1989, 1994) and
- Rainer Friedrich and colleagues (1989, 1993),
- the British study of David Pearce, Camille Bann and Steven Georgiou (1992) at CSERGE in London, and the
- Infras AG and Prognos AG (1994) study were selected here.

Three extensive studies on environmental externalities of energy have recently been completed:

- one for the European Commission (EC 1995), also known as ExternE study,
- one for the U.S. Department of Energy done by ORNL/ RFF (1994-1995), and
- one for different New York State organizations, done by RCG Hagler, Bailly/ Tellus Institute (1993-1995).

They all identify, quantify, and monetize the externalities of the electric power industry fuel cycles using a common methodology, the so-called impact-pathway approach based on marginal damage cost valuations. All three find that the externalities measurable are solely a fraction of a cent per kilowatthour. Ottinger (1995) came to the conclusion that the values adopted in these studies are not only irrelevant for any policy formulation or resource selection decision, but also dangerous, hazardous, distorting and misleading. To overcome this failure and to avoid the misuse of the results, Ottinger even recommends to recalculate the values. To support his position, he points out several examples and reasons for the figures to be that low in the NY II study: important impacts like climate change or ozone-related chronic respiratory illnesses are omitted. In addition, zero values are assumed for many types of effects in view of their presumed insignificance. Finally, several damages are undervalued by choosing the lower end values from the studies reviewed for getting dose-response functions.

In Table 2, the external costs estimates are summarized for each fuel cycle technology considered in the corresponding study in a highly aggregated form. Besides, only the energy source damage estimates relevant in the LTI-project are listed. When looking at the tables presented here, it should be kept in mind that many studies do not present their component external effect results in an *aggregated* form. Since some adders are interrelated and others have not been quantified or monetized due to the lack of information or to impossibility, totals could in fact give the impression that figures are firm, although they omit several important impacts. Interstudy comparison is unfortunately also impeded by the *variety of categorization schemes* of environmental cost components in the studies. Several studies report estimates associated with certain air emissions, for instance CO_2, SO_2, NO_x, others use impact categories, i.e. human health, crops, materials etc.. Yet, the impact categories and subcategories also differ from study to study. If studies used a common framework, it would make it easier to understand similarities and differences. Although studies classify environmental effects quite differently, for most of the studies is true that a single component estimate, a single category, dominates the total estimate.

Lee (1995) distinguished between the group of studies completed since 1994 or so and the group of studies finished in the late eighties and early nineties. In this way, he was able to reveal *three decisive factors for the differences* in damage estimates of fossil fuel cycles: the choice of methodology, the choice of reference technologies, and the consideration of global climate change.

Firstly, the earlier studies of externalities in the energy sector used top-down *approaches*. In contrast, the three recent ones chose the bottom-up analysis. The earlier studies are mainly literature reviews that generally take other studies' estimates of pollutant emissions or impacts as given, and that multiply these estimates by economic values to calculate the damages. The more recent studies use the damage function approach, which begins with an engineering characterization of the emissions, and which then ideally models the pathway from the emission to changes in pollutant concentrations, to impacts, and to damages. In practice, the emissions, concentrations, and impacts, that the literature review studies use, are greater than the estimates that the bottom-up analyses calculate (also cf. Section 2.3 for more details).

Secondly, the up to ten times lower emissions that the more recent studies assume by analyzing best available *technologies* rather than the average existing technologies play an important role as well. This assumption particularly affects the impacts on health associated with SO_2, NO_x, and particulate matter – the health impact category accounting for the highest percentage of damage costs in almost all studies. The most significant difference between the Pace study and the recent studies lies in the estimates of damages from sulfur dioxide on health, materials, and visibility. The SO_2 damage estimate on human health likewise accounts for 75% of Hohmeyer's fossil fuel externality value. The damages to buildings accounted for 64% of Pearce/ Bann/ Georgiou's (1992) externality adder for older technology coal plants, an extremely high – specifically British percentage compared to other studies. However, they result from acidic deposition caused by relatively high SO_2 emissions.

Thirdly, differences are a consequence of the decision made in recent studies that the state of the science is too imprecise to justify a specific estimate of the damage from *climate change*. This decision corresponds to the one made by Friedrich and colleagues (1989). In Ottinger and colleagues (1990: 31), climate change damage accounts for about 25% of the total estimate made for coal. Pearce/ Bann/ Georgiou (1992: 23) estimate climate change damages caused by coal-fired power plants to be in the range of 8 to 33% of the total damage. While Hohmeyer (1988) estimated the damage to be less than 1% of his monetary estimate for fossil fuel damages in his first study, he revised his estimate dramatically later based on new findings in scientific research (cf. Hohmeyer/ Gärtner 1992 and Chapter 4).

Among the fossil fuels, *natural gas* technologies have the lowest externalities. In the natural gas fuel cycle, sulfur emissions are negligible, so that sulfate damages are not important such as for coal and oil. Most of the difference between the earlier and the recent studies of gas fuel cycles is due to two factors: the CO_2 issue, which accounts for 75% of the damages Ottinger and colleagues (1990) calculate for natural gas, and the effects of ozone on health, the remaining 25% of the damages in the Pace study.

Table 2: List of Estimates on Environmental External Costs of Different Energy Sources in 1990 mECU/kWh

	Conventionals			Renewables				
Studies	**Oil**	**Gas**	**Coal**	**Photo-voltaic**	**Solar Energy**	**Wind Energy**	**Hydro-power**	**Biomass**
EC (1994-1995)	11 12	0,7	6 16	*[4]	*	1 2 [5]	2 [6]	*
US-DOE (1994-1995)	0,122 0,162	0,009 0,162	0,408 0,894	*		*	0 0,114[7]	1,30
NY II (1993-1995) [8]	1,11	0,165	0,637 0,690 2,081			0,008		2,41
CSERGE (1992)	77,9	5,32	16,5 70,0[9]		0,981	0,560	0,560	
Pace (1990)[10]	24,8 26,5 37,3 65,4	6,62 9,11 9,93	23,2 27,3 37,3 56,3		0,00 – 3,31	0 – 0,83		0,00 – 5,79
Tellus (1990, 1991)[11]	27,8 30,3 30,8 32,0 34,9 43,6 47,4	13,2 18,6 33,1	35,1 47,5 55,0 78,3					
Chernick/ Caverhill (1989) [12]	31,2 37,3 43,4 50,3	11,1 13,9 16,5 16,5	27,8 33,0 42,5 49,5					
Friedrich et al. (1989, 1993)			2,26 – 2,42	0,309 – 0,463		0,154 – 0,309		
Hohmeyer (1988, 1989, 1994)	6,42 – 34,3 188 – 276[13]			2,48		0,056		
BPA (1983-1987)	0,296	0,859	0,578 – 8,64		0,00 "no significant env effects found"		8,18 – 11,4	-0,117 0,330 5,21[14]
Shuman/ Cavanagh (1982)			0,37– 258 25–35[15]		0,00 – 1,50	0,00 – 1,50		

All of the studies assess the externalities of electricity generation by *renewables* to be relatively low. Somewhat higher values that may occur in hydropower cycles are due to damages

[4] *: Estimates should soon be available.
[5] Wind farms at two locations in the UK: a small farm in an agricultural setting, a very large project on open moorland.
[6] Power locations in Norway and France: one 500 MW extension project, one 20 MW project. Only impact: Visual Amenity.
[7] Retrofit project involving existing dams in Kentucky and diversion project in Washington State.
[8] Estimates shown in this table are for the rural Sterling, NY site and are the central estimates in a probability distribution. Oil distillate comb. turbine; gas combined cycle; coal: gasificat. combined cycle; fluidized bed atmosph.; pulverized steam;
[9] Estimates are for a new and old coal plant, respectively.
[10] Oil: combustion turbine (1% S); boiler (0.5% S; 1% S; 2.2% S); gas: best available control technology; combined cycle; existing steam plant; coal: integrated gas combined cycle (0.45% S); atmospheric fluidized bed combustion (1.1% S); new source performance standards; existing boiler (1.2% S).
[11] Oil: steam (0.75% S, 0.70% S, 1.3% S, 1.0% S, 0.30% S, 1.5% S); combustion turbine; gas: combined cycle; steam; combustion turbine; coal: flue-gas desulfurization; 0.82% S; 2.37% S; 1,83% S.
[12] Oil: existing steam plant (0.5% S; 1% S); combustion turbine (0.3% S); existing steam plant (2.2% S); gas: best available control technology; new source performance standards (NSPS); combined cycle; existing steam plant; coal: integrated gas combined cycle; atmospheric fluidized bed combustion; NSPS; existing boiler (1.2% S).
[13] These estimates include the Hohmeyer/ Gärtner (1992) estimates of global warming effects added in Hohmeyer (1994).
[14] Low, expected, and high values, including only neg. health and pos. visibility effects. Cogeneration plant (size: 12 MW).
[15] Authors give a "reasonable" midpoint range, that is roughly an order of magnitude lower than the upper bounds.

to relatively unique resources. With wind technologies, noise-related externalities reflected in depreciated property values can explain almost half of the total, as in the EC´s high estimate. The earlier studies generally do not consider biomass, the estimates of Pace University are directly taken from ECO Northwest (1986).

The U.S. Congress and the Office of Technology Assessment (OTA) having examined several studies of the environmental costs of electricity conclude that "no clear consensus exists on quantitative estimates, or on methodologies for making those estimates. Both vary widely." For these reasons, cost estimates are difficult to combine or compare; they are variable and uncertain. All studies note that their results contain substantial *uncertainty* and cannot incorporate all relevant categories of externalities. Not all studies include explicit estimates of this uncertainty, but when uncertainty ranges are given, they are sometimes as large as or larger than the estimates themselves. U.S. Congress and OTA go on saying that "many of the differences can be addressed through further research and analysis. Some critical disagreements over methodology, however, mask deeper disputes over values, basic policy goals, and the intended role of environmental cost studies. It is unlikely that these disputes can be resolved by technical analysis or scientific research" (U.S. Congress/ OTA 1994, 2).

3.2 Some Studies in More Detail

In the following, six studies, their achievements and shortcomings, will be examined in more detail. The selected studies are the ExternE study, the European study of the most recent approaches, and those which continue to influence the current thinking and discussion. As already shown, the recent studies are pretty similar in many respects. Ottinger (1995, 1) reproaches them with "failing to value such a significant proportion of externalities", and "undervaluing the externalities for which values are actually calculated, as to render the values adopted irrelevant to any policy formulation or resource selection decisions." Concentrating on the ExternE study, the following sections might partly explain why Ottinger comes to this conclusion. His comprehensive study of 1990 produces the highest cost figures of the studies surveyed here (cf. Table 2). Finally, the debate which was going on in Germany between Hohmeyer (1988, 1989, 1994) and Friedrich and colleagues (1989, 1993) with the multiple mutual reactions might also reflect the international controversy over both, technical questions as well as values and basic policy goals embedded in external cost studies.

3.2.1 European Commission (1995)

The ExternE project was initiated by the European Commission (EC) together with the U.S. Department of Energy (U.S.-DOE) in 1991. It made a claim for becoming "the first systematic approach to the evaluation of external costs of a wide range of different fuel cycles" (EC 1995a: 8). Thus, the *main objective* stated was the development of a methodology rather than the calculation of external costs. Especially research done in Phase I (1991-1993) of the then common EC/U.S.-DOE project focused on this goal. During a second phase (1993-1995), the methodology was applied to all fuel cycle technologies, and the accounting framework was implemented in most of its member states, i.e. at many different reference sites. Recently, the third phase of the ExternE project has started. It is undertaken within the EC's 4th Framework Programme (1995-1998) and concentrates on extensions of the developed accounting framework and dissemination of the results in support of policy issues and decision making.

The ExternE study implements the damage function *(DPA)* or impact pathway approach *(IPA)* to assess fuel cycles. This approach is described as "a step by step method, starting with the *fuel cycle stage* and its *emissions*, and moving through their interactions with the environment to a *physical* measure of *impact* and, where possible, a *monetary valuation* of this" (EC 1995a: 152). Externalities are valued by identifying general pathways for each source of the damage. Another important characteristic of the bottom-up methodology developed is that impacts are expressed on a marginal basis by examining the *incremental effects* of a single reference plant. Consequently, data, analysis, and results are site and technology specific and dependent. The study focuses on one or two actual plants "in an effort to produce specific and defensible results".

Power generation *technologies* of the type chosen for new plants in the EU in 1990 are considered in the conventional fuel cycles. The technologies satisfy the requirements for new plants under the Large Combustion Plant Directive of 1988. Hence, the environmental characteristics of technologies selected differ considerably from some older plants, and therefore the damages calculated are not representative of the mix of generation currently supplying electricity in the EU. There is an additional bias in the assumptions made. For the assessment of renewable energy sources, actually existing plants are examined not taking into account the high technological development potential as the project did for fossil fuels. Moreover, locations are chosen which are regarded as fairly typical of new plants. European fuel sources are used in each case and one single upstream fuel cycle stage, e.g. coal mine or oil field, is taken for analysis.

The rule followed in the ExternE-Project is that fuel cycle stages should be included if it is believed that they might be significant compared to the direct effects of the fuel cycle stages themselves, and that the definition of the system boundaries should explicitly state what has and what has not been included in the analysis. Thus, for *renewable energy* sources, life cycle analysis is carried out, since for them the majority of burdens arises from other (than the generation) stages of the life cycle. Damages of secondary emissions have not been included in the fossil and nuclear implementations. Yet, they are assessed for some of the renewable fuel cycles, because the absence of primary emissions and the low level of other damages implies that they can be a significant fraction of total damages.

Studies based on the impact-pathway approach like the ExternE project stress that the nature and the size of externalities depend on the type of equipment and the locations of activities in the fuel cycle. The component externality *results* are not presented in an aggregated form, since totals could give the impression that figures are complete.

3.2.2 Pace University (1990)

The Pace study was sponsored by the New York State Energy Research and Development Authority and the U.S. Department of Energy. It was completed in 1990.

Externalities are identified and quantified for three coal-fired technologies, two oil-fired technologies with three different sulfur content assumptions, and two natural gas-fired technologies with differing control equipment. Furthermore, values for nuclear, solar, wind, biomass, waste-to-energy systems, demand-side management are estimated. Numerical estimates are taken from a critical review of existing literature, i.e. previous studies, e.g. the one by ECO Northwest (1987) and the one by Chernick/ Caverhill (1989).

Ottinger and colleagues (1990) give as reason for their selection of different fossil-fired resource options that these examples are illustrative of the relative externalities, both existing and new, but are not meant to represent average externalities of these technologies (Ottinger 1991: 357). The Pace University study is based on marginal and average costs. The study explicitly notes several classes of environmental costs excluded from the analysis, generally due to uncertainty or lack of data. For fossil fuels, it excludes greenhouse gases such as methane and N_2O, air toxics (heavy metals), VOCs, ozone precursors, water use, land use, and solid waste disposal, and environmental costs associated with fuel extraction, transportation, and processing.

Due to these exclusions, and considering the locations at which the reviewed studies were performed – their documentation and thoroughness – the monetary values reported above are listed by Ottinger and colleagues as "*rough starting points*"; in several cases (SO_2, NO_x, and particulates), the authors think that the damages „could be much higher“. The term "starting point" is used for the estimates, because the author do not pretend the figures to be cost estimates. However, the *results* show that the externalities of older coal- and oil-fired boilers are dominated by SO_2 and NO_x emissions. For newer technologies, and for gas-fired plants, the externalities are largely dominated by CO_2 emissions. Environmental costs associated with natural gas are somewhat lower, and costs associated with renewable sources (solar, wind, and biomass) and demand-side management are substantially lower.

3.2.3 Hohmeyer (1988, 1989, 1994) and Friedrich and colleagues (1989, 1993)

Hohmeyer's first study (1988) on social costs of energy consumption, which was conducted on behalf of the EC Commission, was one of the first important and systematic attempts to estimate external effects of electricity generation. It was carried out within the economic and administrative framework of the Federal Republic of Germany. The main objective was to compare electricity production based on fossil fuels and that based on renewables (wind energy and photovoltaics). For that reason, Hohmeyer's study produces only a single range of external cost estimates for all fossil fuels. Hohmeyer is fully aware that "external effects of energy systems cannot be adequately quantified or monetarized". He would like his results to be interpreted as "very crude figures" which can be used for "some initial corrective economic policy measures".

Hohmeyer has used a top-down approach of total environmental damages. Based on the review of previous estimates of total damage costs, he breaks these costs down into different energy subsectors. A fixed percentage (28%) of total energy-related emissions and social costs is attributed to electricity conventionally generated from fossil fuels. Hohmeyer covers four main areas of external effects of energy systems: environmental effects, the depletion of natural resources, general economic effects such as employment effects, and direct and indirect public subsidies including expenditure for research and development on energy technologies. Here only the first category is the relevent one, since it is the generally accepted one. The study also discusses and summarizes several categories of external effects which could not be fully monetarized or quantified, for example, the full cost of climate changes (only raising of coastal dams), and the environmental effects of all stages of the fuel cycles. The costs of avoiding the effects of sea level rise caused by global climate change are included with a rather rough, and low estimate.

In response to Hohmeyer (1988), the Association of the German Electricity-Generating Industry asked Friedrich and colleagues to review the Hohmeyer study critically. They criticize Hohmeyer for "rough estimates", incompatible values, and the inclusion of external effects which in their opinion cannot be estimated in a "serious manner", i.e. the costs of climate change. They do not take non-environmental externalities into account, and attribute a smaller part of overall environmental (forest) damages to the generation of electricity than Hohmeyer (1988). Consequently, the estimates of the social costs of electricity turn out to be very low. However, the overall framework and methodology of the two studies are very similar and easy to compare. Other important differing assumptions are that the 1988 estimates of Hohmeyer are based on emissions of 1982 and average available technologies of that year. Friedrich and colleagues (1989) base their emission on new standard technologies of 1990 using much better control equipment. For the valuation of health impacts the two studies use other sources and statistics. Friedrich and his colleagues used the lower figures in general; however, health and forest damages dominate as well in the total estimate. Moreover, effects of the rise of the sea level are not included for reasons of uncertainty.

3.2.4 Bonneville Power Administration (1983-1987) and Shuman and Cavanagh (1982)

Both studies were a consequence of the Pacific Northwest Electric Power Planning and Conservation Act of 1980. Under the provision of this act, Bonneville Power Administration (BPA) and the Northwest Power Planning Council must include the environmental costs and benefits of proposed electricity-generating resources to have a planning basis for choosing the most cost-effective energy options. The Shuman and Cavanagh study was supported by environmental and citizens´ groups (U.S. Congress/ OTA 1994: 28).

The earlier study analyzes environmental impacts of five energy options: coal-fired and nuclear generation, wind power, solar water heating, and household weatherization. Explicit objectives of the study are to compare coal / nuclear and solar / conservation resources and to offer a range of plausible environmental costs for various technologies despite all the uncertainties and the lack of information. Shuman and Cavanagh conclude that total environmental costs from conventional technologies could run as high as 257 mECU/kWH for coal, but argue that reasonable point representations of these broad ranges should be at least 20-30 mills per kWh, a figure that is roughly an order of magnitude lower than the upper bound. These costs are still substantially larger than the 0-1,50 mECU/kWh environmental cost that were calculated for wind power and solar heating. The study´s estimates of solar and wind were done largely in a relative way. For example, the health impacts of solar and wind were estimated by using the estimate for nuclear (excluding radon emissions). This reflects the author´s belief that the primary environmental costs of solar and wind were due to the construction of a large facility and that those risks were similar for nuclear, solar, and wind. Environmental costs estimates of coal include health effects, pollution damages to property and crops and possible damages resulting from climate change. The global warming effects account for more than half of the total costs at the high end of the range (0-154 mECU/kWh). The authors explicitely note impacts which could be identified, but not yet quantified.

4 The Global Warming Issue

4.1 The IPCC Second Assessment Report

At the end of 1995, the Intergovernmental Panel on Climate Change (IPCC) completed the final pieces of its Second Assessment Report.[16] Unlike the First Assessment Report of 1990, when scientists were not able to deduce that humans were influencing the climate, the recent report confirms that there has been an *anthropogenic global warming effect* in the past and that there will be one in the future. The IPCC synthesis report (IPCC 1995: 2.4) states that "global mean surface temperature has increased by about between 0.3 and 0.6°C since the late 19th century, a change that is unlikely to be entirely natural in origin. The balance of evidence, from [that change] and from changes in geographical, seasonal, and vertical patterns of at-

[16] The three Working Groups (WG) of IPCC established in 1988 were charged with assessing the state of scientific knowledge on climate change (WG I), examining its environmental impacts and formulating response strategies (WG II), and with analyzing the socio-economic implications of impacts, adaptation, and mitigation as well as preparing future emissions scenarios (WG III) (Arris 1996).

mospheric temperature, suggests a discernible human influence on global climate." In addition, a 10-25 cm rise in sea level has as well been observed over the past century, and "much of the rise may be related to the increase in global mean temperature." The scenarios analyzed by Working Group I indicate that temperature increases could range from 1°C to 3.5°C by 2100. Including the effects of aerosol concentrations in the model calculations for the first time, the "new best estimate" global mean surface temperature increase is projected to be about 2°C between 1990 and 2100 – 0.5°C less than estimated in the First Assessment Report of IPCC. This reduction is also due to lower emission scenarios, as well as "improvements in the treatment of the carbon cycle" (IPCC 1995a: 5). IPCC admits that besides a temperature increase, a rise of average sea level, and a changed hydrological cycle, human interference with global atmosphere may further result in other "unexpected, large and rapid climate system changes" (IPCC 1995a: 7).

Regardless of both, the magnitude and rate of climate change, it is predicted to affect a huge range of receptors, such as human health, terrestrial and aquatic ecological systems, and socioeconomic systems, e.g., agriculture, forestry, fisheries, and water resources (IPCC 1995b: SPM-3). Yet, indeed asserting the probably serious implications of global warming, the recent extensive *studies on external costs of fuel cycles* funded by the European Commission, the U.S. Department of Energy and New York State have not yet produced new quantitative figures for potential global warming damages. The ExternE study (EC 1995a: 82-85, 161) shrinks back with the explanation, that "estimation of damages is complex, being scenario dependent, very uncertain, and long term. Damages are potentially very large. Estimation of the impacts is rendered difficult by poor understanding of the likely regional variation in climatic change. Quantification is therefore difficult. The most comprehensive assessment of the impacts, for example by the IPCC, are largely qualitative." For that reason, the ExternE project has only reviewed literature so far and reported the found quantitative results in a table of its Summary Report (cf. Table 3). The conclusion in the ExternE report, as well representative of the other studies mentioned, is on the one hand, that "global warming impacts may well be the most serious of the fossil fuel cycles." However, since "these impacts cannot be calculated with any accuracy" and the calculation of these effects raises "serious ethical issues" additionally, no value was recommended, on the other hand (EC 1995a: 161f.).

Looking nevertheless briefly at the values summarized in the first three columns of Table 3 and comparing them with the marginal cost estimates of the more recent studies in Table 2, it can be recorded that the figures would approximately be doubled in the case of the ExternE study. And the environmental cost values of the U.S. studies would turn out to be almost negligible, disregarding which global warming damage estimate we take. The adding of the cost figures of Hohmeyer/ Gärtner (1992) to the respective external cost values of any of the studies of Table 2 or to some extent to energy prices would completely change the results and action.

Table 3: Global Warming Damage Estimates in 1990 mECU/ kWh for a Discount Rate of 0%

	Cline (1992) (shadow values)	Fankhauser (1995) (marginal costs)	Tol (1995)* (marginal costs)	Hohmeyer/ Gärtner (1992) (average costs)
oil	10	6	12	3200
gas	6	4	8	2100
coal	15	10	18	5000
lignite	19	12	22	6200

* Figures are based on a discount rate of 1%.
Source: EC (1995: 163)

The recently published Summary for Policymakers of IPCC Working Group II (IPCC 1995b: SPM-3) seems to support the ExternE point of view. It states that "although ... qualitative estimates can be developed, ... impacts of climate change on any particular system at any particular location are difficult" to quantify. The lack of information on impacts for quite a lot of regions plus the uncertainty of predictions of the regional impacts in general appear to be a decisive restrictive factor for damage calculations. Moreover, "our current understanding of many critical processes is limited; and systems are subject to multiple climatic and non-climatic stresses, the interactions of which are not always linear or additive." How *sensitive and controversial* this topic is *in both, the political and academic arena*, nowadays is likewise reflected by the work and discussions in IPCC Working Group III, charged with assessing the social and economic costs of potential climate change impacts, adaptation, and mitigation. WG III had considered to remove the entire chapter on the social costs of climate change from the report, due at least in part to controversy over the valuation of human lives (Arris 1996: 6)! According to Michael Grubb of the Royal Institute of International Affairs, London, UK interviewed by Environmental Watch Western Europe, there was also substantial disagreement over the text on abatement costs. The U.S. representatives wanted all numbers to be excluded from the text, while Germany, France, and Canada insisted on keeping them in, arguing that "having done five years of research on the issue, if the IPCC couldn't come up with some specific numbers, it was a bit of a waste of time" (Arris 1996: 5). So IPCC WG III (1995c: 15) cites a range of marginal damage estimates from about 5 to 125 U.S. $ (1990 $) per ton of carbon emitted today. Then, it explicitly states that it "does not endorse any particular range of values for the marginal damage of CO_2 emissions" and that the range published does not reflect the full range of uncertainty, either (IPCC 1995c: 15f.). It shows, however, "variations in model scenarios, discount rates, and other assumptions".[17]

4.2 Damage Cost Studies and Sustainability

Having noticed the caution this issue is treated with, the next paragraphs will nonetheless look into *damage cost studies of global climate change* more closely drawing on the articles of Fankhauser and Tol 1995, Mayerhofer and Friedrich 1996 and Pearce and colleagues 1995. The scientific research on greenhouse effect impacts has focused primarily on the $2xCO_2$ scenario – the impacts of an atmospheric CO_2 concentration of twice the preindustrial level. Due to the lack of knowledge and the complexity of processes outlined above, studies usually deal with only a subset of damages, and are often restricted to a description of physical impacts.

[17] Smith/ Ragland/ Trabka (1994) examine this question in a paper. They compare four studies on damage estimates to the United States from global warming using common assumptions about the rate and magnitude of climate change, the rates of return on investments, the discount rates, and the real value of damages. The standardized calculations of Nordhaus (1991), Cline (1992), Fankhauser (1992) and Titus (1992) are within a much smaller range of each other. They differ by a factor of 1,4 instead of a factor of 15.

The best studied impact categories are agricultural impacts and the costs of sea level rise. The estimates of non-market damages, such as human health, risk of human mortality and damage to ecosystems, are regarded as highly speculative and not comprehensive, and thus as a source of major uncertainty in assessing the implications of global climate change for human welfare (IPCC 1995: 7.2). Furthermore, several kinds of impacts have mainly been ignored so far, e.g. migration and tropical diseases, since they could not be adequately quantified. To avoid long-term, rather arbitrary predictions, figures have been derived by imposing the $2xCO_2$ scenario onto a society with today's structure, thus for example excluding the effects of and on population growth.

The aggregate estimates of damages from a 2°–3°C warming tend to be a few percent of world gross domestic product (GDP), with, in general, considerably higher estimates of *damages to developing countries* as a share of their GDP (IPCC 1995: 7.3). To be more explicit, the OECD countries would lose about 1 to 2 percent of GDP, the developing countries 2 to 9 percent. Figures that are fully corrected for differences in purchasing power parity do not deviate significantly. Yet again, there is a considerable range of errors and value judgements in these figures. The literature on social costs of anthropogenic climate change is mainly based on research done on developed countries, then often extrapolated to developing countries. There is no consensus about how to value statistical lives or how to aggregate statistical lives across countries. In this context, IPCC notes that "in virtually all of the literature discussed [in its report]: i) the developing country statistical lives have not been equally valued at the developed country value; and ii) other damages in developing countries are also not equally valued at the developed country value" (IPCC 1995c: 13). However, there is a consensus that vulnerability in most developing countries seriously exceeds that in developed countries.

Hohmeyer and Gärtner (1992) estimated damages of about 220 \$/t of CO_2 (807 \$/tC) in a rough first estimate of orders of magnitude. The essential damage effect (99% of all estimated damages) resulted from a shift in agricultural production due to changed precipitation patterns, higher evaporation, higher frequency of draughts and decreased availability of water for irrigation purposes. In their analysis, the assumed decline in agricultural production caused additional starvation in developing countries in the range of hundreds of millions of people. The growth of world population was included into these considerations, and thus absorbed possible increases in productivity. Acknowledging the complexity of interactions, insufficient knowledge, uncertainties and the long-term nature of the problem, Hohmeyer (1995, 1996) today demands to put the global strategy to prevent major climate changes on a different basis. He argues that the calculation of marginal damage costs is unfeasible in the context of global warming because of the difficulties just mentioned. The determination of the 'optimal level of emissions' in the sense of neo-classical economics requiring the comparison of the marginal damage and abatement costs of additional greenhouse gases emitted (cf. Section 2.1) is just not possible for those reasons. Hohmeyer (1995,1996) shows taking the example of possible losses in agricultural production, that even rough, average damage estimates have to be *based on three "normative ethical" assumptions*, depending on which the present monetary value of a potential future damage can vary by a factor of 10^6-10^8. Those value judgements concern the question of countries to be covered in the examination (United States, Europe, developing countries or the world as a whole), the decision which value of statistical life to take, and the assumption on the value for the discount rate – 0%, 3% or 10%. Accordingly, Hohmeyer sees the danger that economists might "produce arbitrarily high or low monetary damage estimates" which can then be applied to back up whatever political goals and action. So, he regards an international public discussion on this issue as essential. His proposal is to base the global policy on the basic principles of strong sustainability – "only a safe minimum standard for greenhouse gas emissions and a resulting standard price approach seems to be a reasonable approach to man made global warming."

5 Conclusions for the LTI-Project

The cost estimates of environmental external effects of energy supply differ widely due to different methods and assumptions in different studies. For that reason, the resulting figures are difficult to combine or compare; they are variable and uncertain. All studies reviewed here note that their results contain substantial uncertainty and cannot incorporate all relevant categories of externalities. "Many of the differences can be addressed through further research and analysis. Some critical disagreements over methodology, however, mask deeper disputes over values, basic policy goals, and the intended role of environmental cost studies. It is unlikely that these disputes can be resolved by technical analysis or scientific research" (U.S. Congress/ OTA 1994: 2). Thus, accepting and using the quantitative findings of a particular study implies accepting the goals and value judgements embedded in that study or using it in the context of the study´s assumptions.

The more recent studies which utilize a very similar approach and methodology produce rather low damage cost estimates for the fuel cycle technologies. One reason being that they do not include the potential global warming damages because of the size of uncertainties linked with this evaluation. However, these impacts might by far be the most serious ones. Omiting this damage category in monetary estimations has severe consequences for the total of component external costs. The available monetary damage estimates of global climate change, however rough and differing they are, would change the external cost figures calculated in the more recent studies by orders of magnitude. Hence, in the Fair Market Scenario of the LTI-project, we can hardly rely on the aggregated damage costs of the ExternE project.

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