THE POTENTIAL ROLE OF EXTERNAL COST ESTIMATES IN LIBERALIZED ENERGY MARKETS[1]

Dipl.-Volksw. Isabel Kühn

Zentrum für Europäische Wirtschaftsforschung (ZEW),
P.O. Box 10 34 43, D-68034 Mannheim, Germany
Ph.: +49/621/1235-216, Fax: +49/621/1235-226, E-Mail: kuehn@zew.de

1 INTRODUCTION

A wide variety of environmental burdens and resulting impacts relating to our current energy system have been identified over the past decades. Present fuel cycles release flows of problematic substances into all environmental media, that is air, water, and soil. Local and regional pollution through atmospheric dispersion of emissions has for a long time proven to be the main source of negative impacts on human beings as well as on man-made and natural ecosystems. In recent years, the focus is shifting towards the issue of human induced global warming caused by otherwise less problematic gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

The environmental and other effects of the use of energy technologies have been appraised with a variety of analytical techniques and methodologies developed by different academic disciplines. The mainstream economic approach for 'taking the environment into account' is based on the concept of externalities and thus valuation in monetary terms. Stirling (1997, 518) holds that this concept "now seems to be the dominant paradigm in the comparative environmental appraisal of contending energy options." The objective to internalize external costs and benefits was also stated as a crucial pillar of environmental policy design in the Fifth Environmental Action Program of the European Commission in 1992. Therefore, research programs on external costs of energy have played an important role at the European level. ExternE, for instance, is an extensive research project on external costs of fuel cycles, which has been funded by the European Commission since 1991, and lately started into its fourth phase. The project has established expert networks of research institutes from most countries of the European Union for the review, implementation, and dissemination of the externality assessment methodology developed in the course of the project. So the concept of external costs seems to be receiving more attention and acknowledgment in the member states of the EU nowadays.

Apart from projects funded by the European Commission, there have been quite a number of other empirical studies on environmental externalities of energy in the past decade, especially in the United States. There, cost-benefit analyses as well as contingent valuation studies are conducted and used as a regular tool for decision and policy making in all fields of the public sector. But the interest in external cost of energy research has shrunk with the liberalization steps on the electricity markets. This is mainly due to the fact that in the US external cost estimates were merely seen as part of the regulatory approach, that is they were utilized and required in a number of states for resource planning decisions on the investment stage. Yet, of

[1] This paper is based on research funded in part by the APAS as well as the JOULE III program of the European Commission. It was presented at the 4th IAEE / GEE Conference in Berlin on Sept. 9, 1998.

course there are other possibilities to internalize external costs than accounting for them on the utility planning level only.

It is the purpose of this paper to present recent developments in the empirical externality assessment to the IAEE / GEE community. Towards that end, the results of a selection of studies are reviewed. Reasons are supplied why the resulting monetary values vary and why they have to be interpreted and applied with caution (Chapter 2). Anthropogenic climate change is an environmental problem of so far unknown dimensions. A brief, separate overview on the progress in the evaluation of impacts of greenhouse gas emissions will be given in Chapter 3. It will be argued, that the traditional economic appraisal procedure is even more critical, or indeed inappropriate for this kind of environmental problem. Looking at the empirical estimates of external costs from a more pragmatic, or implementation-oriented point of view, some conclusions can still be drawn based on the results of the studies.

2 EXTERNAL COSTS OF ENERGY USE

2.1 Theoretical Background

The economic approach in the tradition of Arthur Pigou to tackling environmental problems is based on the internalization of external costs into market decisions. External costs are defined as the monetary values of negative impacts that are imposed on society or parts of it by activities of an individual or a group and that are not reflected in the market prices, and therefore not in the individual decision-making processes either. The market failure to reflect the costs to society in the market prices results in a misallocation of goods and services in the economy, according to neo-classical welfare economics. Preventing or correcting this misallocation ideally involves understanding the monetary values of the external effects, and then finding mechanisms for integrating those values into the decisions.

Underlying philosophical premises and biases of the concept of external costs as well as the strength and weaknesses of the different techniques of monetary valuation have been extensively discussed in the theoretical literature.[2] This discussion is beyond the scope of this paper. However, I want to point out once again, that the preferences of individual consumers are at the focal point of the welfare economic paradigm, that is values of environmental goods or services are measured by the aggregation of consumer preferences. People's willingness to pay (WTP) for improved environmental quality or willingness to accept (WTA) compensation for environmental degradation is considered as the adequate valuation tool reflecting these preferences. It is for example often criticized that the revealed WTP or WTA is strongly related to the individual's level of information and also depends on the ability to pay. The former can result in an under- or overestimation of the respective environmental problem from a scientific perspective, the latter means that the measures intrinsically discriminate against the preferences of low-income people.
The main advantage of the economic technique is to provide only one and a common criterion through which different objectives are trade off, that is prices. That should facilitate comparison between different energy technologies. On the other hand, there is a significant literature which argues that monetary values fail to address the multidimensional nature of environmental issues, and reduce their complexity to one unit (e.g. Bernow et al. 1996; Endres 1995;

[2] Refer e.g. to Freeman (1993), Hoevenagel (1991), Krutilla/ Fisher (1975), Markandya/ Richardson (1993), or Pearce (1993).

Stirling 1997). The question is raised whether it is appropriate to use a single measure ('monetary commensurability') instead of more explicit political decision making procedures (e.g. O'Connor 1997; O'Hara 1996). Important aspects inherent in policy questions on the environment like uncertainty, irreducibility, distributional and temporal concerns, and the diversity of ethical positions can only be reflected insufficiently in one monetary value. A more detailed discussion of this substantial topic cannot be given here, either.

Irrespective of the philosophical foundation of the appraisal procedure, it is well-understood that the theoretical ideal of monetizing externalities and thus determining the 'optimal' price is impossible to achieve in empirical studies. There are a range of difficulties, which are partly the consequence of an information and data problem and partly of fundamental limits of scientific findings.

2.2 Empirical Studies

Empirical studies on external costs of energy usually focus on the quantification of priority impacts instead of giving a detailed account of all effects and damages to third parties associated with a system or process. They typically analyze impacts of air pollution on human health, on building materials, on commercial crops, forests, and unmanaged ecosystems, as well as impacts of smell, noise, and visual amenity. Thus, most of the research concentrates on atmospheric dispersion. The effluent releases to surface and groundwater, and the effects related to solid wastes have been studied less. Only rough calculations and methods seem to be available for selected water and soil pathways.
The valuation of global warming impacts has proven particularly difficult due to their long-term, partly irreducible, uncertain and intergenerational nature. Therefore, in spite of asserting that global warming impacts may well be the most serious consequence of the current energy systems, many externality studies do not include any quantitative figure for potential global warming damages in their results. Rather the range of damage cost estimates found in the literature is given to demonstrate their variability.
On the whole, all studies note that their results contain substantial uncertainty. The resulting monetary values vary over a wide range of values, yielding different rank orderings for the various electricity generating options.[3]

There is no standardized categorization of impacts or a standardized methodology for identification, quantification, and monetization of the damages.[4] Although studies classify environmental effects quite differently, for most of the studies it is true that a single component estimate, a single category, dominates the total value. The health impact category accounts for the highest percentage of damage costs for the fossil fuel cycles in all studies (known to the author) but a British one by Pearce, Bann and Georgiou (1992). Here the damage to buildings from acidic deposition represents 64 per cent of the externality adder calculated for older coal technology. This statement is not taking into account damage estimates of global warming.

Top-Down Analyses

[3] For a more detailed overview on externality studies you are referred to US Congress/ OTA (1994), Kühn (1996), Lee (1996), and Stirling (1997). In this essay only the more recent studies are under examination.
[4] If studies used a common framework, it would make it easier to understand similarities and differences, for experts and non-experts alike. For life-cycle analyses (LCA) an organization, the Society for Environmental Toxicology and Chemistry (SETAC), has been charged with standardizing LCA internationally. To the knowledge of the author, no such effort has been made for the assessment of environmental externalities – even though the ExternE methodology has been spread pretty widely.

In Table 1 and Table 2, the external costs estimates of selected studies are summarized in an aggregated form for different fuel cycle technologies. Of the earlier studies, just one is included. The Pace University study by Ottinger and colleagues (1990) was sponsored by the New York State Energy Research and Development Authority and the US Department of Energy. Even if their comprehensive study of 1990 produces rather high cost figures in comparison to most other studies, the monetary values reported are assessed as "rough starting points" by the authors; in several cases (SO_2, NO_x, and particulates), the authors argue that the damages "could be much higher". The study explicitly notes several categories of environmental costs excluded from the analysis, generally due to uncertainty or lack of data.
As most of the earlier studies, the Pace University study can be classified as a top-down analysis. The studies on the external costs of energy carried out in the eighties and early nineties are primarily literature reviews, which base their damage calculations on estimates of national damages and aggregated emissions of polluting activities. This type of approach rather results in estimates of average damage costs. Yet, Ottinger et al. (1990) stress that their technological examples cover both existing and new technologies, but are not meant to represent average externalities of the technologies. In sum, the externalities of older coal- and oil-fired power plants are predominantly caused by SO_2 and NO_x emissions, whereas impacts of CO_2 emissions have a larger share of the total cost estimate for newer technologies and for gas-fired plants (according to the Pace University study). External environmental costs associated with natural gas and biomass are quite low, and costs associated with other renewable energy sources (wind and solar) and demand side management (DSM)[5] are substantially lower than the estimated external costs of fossil fuels (Ottinger et al. 1990).

Table 1: *Estimates on external costs of fossil-fuel based energy technologies in 1995 mECU/kWh from selected studies.*

	Oil	Gas	Coal
Ottinger et al. (1990)	30 – 79	8.0 – 12	28 – 68
RCG/ Tellus (1995)	1.3	0.21	0.78 – 2.5
ORNL/ RFF (1994)	0.16 – 0.19	0.012 – 0.19	0.50 – 1.1
CEC (1995)	13 – 16	0.85	7.3 – 19
CEC (1998) – Nat. Impl.	26 – 110	5 – 35	18 – 150

Notes:
All numbers are rounded to two significant digits.
The studies often refrain from presenting their component external cost results in an aggregated form, since some impacts are interrelated and others have not been quantified or monetized due to a lack of information or to impossibility. Totals could in fact give the impression that figures are firm, although they omit several important impacts.
Ranges in the Ottinger et al. (1990) study derive from the analysis of various existing and then new technologies with different control equipment and of different sulphur contents of the fuel. The results of the other studies listed are plant, i.e. site and technology specific. Ranges given do not represent uncertainty ranges, but the respective upper and lower values of various plant specific calculations.

Bottom-Up Analyses

Three extensive studies have been completed in the mid-nineties:

- one for the Commission of the European Communities (CEC 1995a-f), also known as ExternE project (Phase II),
- one for the US Department of Energy (ORNL/ RFF 1994a-h), and

[5] The cost figures for solar and DSM are not given in the tables, as these options are not part of the other studies.

- one for different New York state organizations carried out by RCG/Hagler, Bailly and Tellus Institute between 1992 and 1995 (RCG/ Tellus 1993-1995), also called NYII study.

They all use a common methodology, the so-called damage function or impact-pathway approach which begins with an engineering characterization of the emissions and burdens of a certain fuel cycle. Then it ideally models the pathway from the emissions to changes in pollutant concentrations with the help of (air) dispersion models. The physical impacts on receptors are quantified with (linear) dose-response functions based on epidemiological studies. Finally, monetary values for the quantified impacts are derived from economic valuation studies. In contrast to top-down approaches, the bottom-up analysis first offers a tool to determine marginal external costs and benefits, as they are required by neo-classical economic theory. The damages assessed are incremental impacts due to an additional power plant at a specific site using a specified technology. This approach is very data-intensive. Many pieces of information are necessary just to cover the biophysical dimensions of the impact-pathways.

Krupnick and Burtraw (1996) point to a relatively clear consensus on the general method for the air-human health pathways, the damage category emphasized most by all teams. Particularly, the impacts of primary and somewhat less of secondary air emissions on different human health endpoints are clearly examined best, physically and economically, and dominate the cost estimates of the three studies. The external costs in Phase II of the European study are in the order of 10 mECU/kWh for oil and coal and 1 mECU/kWh for natural gas. The by one to two orders of magnitude lower health damages calculated in the two American studies can partly be traced to the lower population density in the United States (cf. Lee 1996). But the difference is for example also due to the sophistication of air dispersion and chemistry modeling what will be briefly outlined in the following paragraph.

As a major part of the New York Electricity Externality Study (NYII) as well as of ExternE Phase II, computer models for assessing external costs of energy use through the impact-pathway methodologies of the two projects have been developed. EXMOD has been developed at the Tellus Institute in Boston for New York State regulatory agencies and utilities to permit them the estimation of environmental externalities for new and relicensed electric resource options. EcoSense has been elaborated by the Institute for Energy Economics and Rational Use of Energy (IER) at the University of Stuttgart. Meanwhile, the model has supported the impact assessment of many research institutions in Europe.

The modeling of air dispersion is one major difference between EXMOD and EcoSense.

- In EcoSense, the local range (< 50 km) atmospheric transport model – the US EPA Industrial Source Complex Short Term model (ISCST2) – calculates hourly concentrations of the primary pollutants SO_2, NO_x and particulates at the center of 10x10 km^2 grid cells for one year. Annual and seasonal mean values are obtained by temporal averaging of the model results.
- The regional range (> 50 km) model of EcoSense – the Harwell Trajectory model-like Windrose Trajectory Lagrangian plume model – considers both primary particulate emissions as well as the annual average concentration and dry and wet deposition of secondary acid species caused by SO_2 and NO_x emissions across Europe, i.e. over several thousands of kilometers. The grid cells are 100x100 km^2 in the regional range (cf. CEC 1995b for more details).

EXMOD models air dispersion from any location in New York State to receptor cells of various extents throughout fourteen northeastern states of the US and some Canadian provinces. The local range (< 50 km) atmospheric transport model is the Long Term version (ISCLT2) of the Industrial Source Complex model applied in EcoSense (RCG/ Tellus 1994b). For that issue, there seems to be no major difference therefore. Likewise in the ORNL/ RFF study a ver-

sion of this US EPA model is chosen (ORNL/ RFF 1994b). The Long Term version calculates changes in annual (instead of hourly) average ambient concentrations of emissions, and needs less data input. However, the distinction comes through the regional air dispersion models.
For long-range changes (> 50 km) in annual average concentrations of primary and secondary pollutants and in wet and dry deposition rates, the Sector average Limited Mixing Mesoscale Model (SLIM3) is applied and combined with optimized model parameters from another study. The model does not have a high input data requirement and was specifically developed for the NYII project. After the first few tens of kilometers of transport, emissions from a power plant stack are distributed uniformly in the vertical dimension between the top of the mixed layer and the ground. The model has the advantage of computing concentrations consistent with those calculated by ISC2LT. Yet, this pattern can be questioned for regional atmospheric dispersion. In addition, the application of SLIM3 should not be extended beyond a few hundred kilometers from the source (RCG/ Tellus 1994b for more details). The ORNL/ RFF study does not even include secondary pollutants in the externality appraisal. Moreover, for distances beyond 80 km, the ISCLT model is utilized as basis for a statistical calibration approach for primary pollutants (ORNL/ RFF 1994b). Against this background and with the information that the long range damages and thus the impacts of secondary pollutants usually account for far more than 80 per cent of the total damage costs estimated with EcoSense, differences in the external cost values presented in the tables can be explained better and are not astonishing.

There is a high correspondence between the three externality studies as regards priority impact pathways identified and the exposure-response functions (ERFs) implemented. ERFs are assumed to be linear and generally no thresholds are applied. Often the same epidemiological studies, all performed in the United States, are referred to, for instance in the case of acute mortality, restricted activity days, asthma attacks, respiratory symptoms, and chronic bronchitis. Aside from chronic bronchitis, no chronic illnesses could be included in the assessment.
All three studies follow the value of statistical life (VOSL) approach for the monetization of mortality impacts. The central VOSL estimate applied is in the same order of magnitude, that is about 3 millions ECU (CEC 1995a-f; ORNL/ RFF 1994a-h; RCG/ Tellus 1995).

In the two American studies, differences between external cost estimates of fossil and renewable energy sources are comparatively small. While damages caused by indirect emissions during fuel production and the manufacture of the equipment have not been included for fossil fuel cycles, they are assessed for some of the renewable energy fuel cycles, as the majority of burdens arises from other than the conversion stages of the fuel cycle. The absence of direct emissions and the low level of other damages imply that the indirect emissions can be a significant fraction of (low) total damage estimates. In this regard the energy use of biomass is an exception. Since the biofuels are mostly converted by conventional combustion technologies, biomass produces external effects similar to those of fossil fuels with respect to the 'classical' atmospheric emissions. On the other hand, biofuels have substantial advantages as far as CO_2 is concerned since the carbon dioxide emitted was taken in from the atmosphere during growth. The time constant of this cycle is short compared to the temporal dimension of climate change. Noise, visual effects, and impacts on recreation are the major impacts of hydropower and wind farms. The impacts of renewable energy sources tend to be local in nature.

Table 2: *Estimates on external costs of renewable energy technologies in 1990 mECU/kWh from selected studies.*

	Photovoltaics	Wind Energy	Hydropower	Biomass

	Photovoltaics	Wind Energy	Hydropower	Biomass
Ottinger et al. (1990)	–	0 – 0.97	–	0 – 7.0
RCG/ Tellus (1995)	–	0.012	–	2.9
ORNL/ RFF (1994)	*	*	0 – 0.13	1.6
CEC (1995)	*	1.2 – 2.4	2.4	*
CEC (1998), Nat. Impl.	1.4 – 3.3	0.5 – 2.6	0.04 – 6	1 – 29

Notes:
–: This energy source is not analyzed in the study.
*: Results were not available.
All numbers are rounded to two significant digits.
Again, the ranges of all studies listed except the one Ottinger et al. reflect estimates from different locations and technologies.

To sum up, the impacts identified in the three studies do not present a complete list of external environmental effects. Only the priority impacts are assessed, many of which cannot be quantified or monetized. As important damage categories, especially of the fossil fuel cycles, like impacts of climate change, impacts on ecosystems or ozone-related and aerosol-related impacts on public health are omitted, the total component external costs must be pretty low. Solely the available ranges for monetary damage estimates of global climate change could alter the external cost figures produced in the studies by orders of magnitude (cf. CEC 1998 and Chapter 3). What was just said in particular holds for the American studies.

The last project to be examined here in brief is the National Implementation Project of ExternE Phase III which was running all of 1996 and 1997 (cf. CEC 1998). It has covered more than 60 representative cases, for 15 European countries and 12 fuel cycles; the cases also comprise the update of earlier externality assessments conducted in Phase II. The update became necessary, since some fundamental assumptions in the ExternE accounting framework have been changed during further work on the methodology in Phase III. The changes have been integrated into EcoSense, so that a fairly consistent implementation was ensured across all countries through the use of the EcoSense 2.0 version, at least for impacts of atmospheric pollutants.
Methodological modifications and shifts of the latest ExternE Phase include

- the integration of new damage subcategories, and
- new ERFs for some 'old' human health endpoints, as for example acute mortality and hospital admissions. Recently completed CEC-sponsored epidemiological studies in 12 European urban areas have given new evidence to base the ERFs of ExternE on European instead of American reference studies. Thus, the similarity between the ERFs of EcoSense and EXMOD described above has been very much reduced.
- Within the ExternE accounting framework, the valuation of acute and chronic mortality is crucial for the final results since these impacts generally constitute more than two thirds of the damage cost estimates. The ERF for chronic mortality linked to particulate emissions is still obtained from only one American study, however.
- Moreover, the interpretation of this study has changed[6], with the additional consequence of a basic shift in the concept for valuing mortality. Values of Life Years Lost (VLYL) are defined in addition to the Value of Statistical Life (VOSL). The way how the VLYL were computed from the VOSL is not at all satisfying yet. Passing from a valuation based on the number of premature deaths at full value of life to one based on years of life lost the cost of acute mortality due to air pollution is reduced by 1-2 orders of magnitude. Costs of chronic mortality were not included so far, but are now.

[6] Among the experts, there seems to be a consensus that the epidemiological evidence justifies the shift.

- Since there are no adequate models for ozone formation processes, a rough method for not excluding ozone damages was developed. It is based on average European unit pollution values, though.
- Finally, an expert group of the ExternE team was charged with improving the assessment of global warming damages (Eyre et al. 1997). The group tried to take account of some shortcomings highlighted and criticism expressed by the Working Group III of the International Panel on Climate Change and others on earlier social cost studies. They produced their own estimates based on two climate change models, namely OpenFramework and FUND, and did many sensitivity analyses. Both models arrive at values of roughly 170 US$ per ton of carbon in the base case, that is the IPCC IS92a scenario, with equity weighted regional damages over the period 1990-2100, and at 1% discount rate. Even though the group stresses the very large uncertainty of their findings and determine a broad range of values, external costs estimates for global warming impacts are applied to the case studies of ExternE Phase III (cf. CEC 1998) (in contrast to earlier studies). An inner uncertainty range was chosen.

As there are so many methodological modifications and altered assumptions, results are not comparable anymore with ExternE Phase II results (CEC 1995a-f).

The National Implementation studies of the most recent ExternE phase (CEC 1998) arrive at very similar cost ranges and the same orders of magnitude for the different energy sources as Ottinger and colleagues. One could conclude from these studies, that the level of external cost values for the coal and oil fuel cycles is not irrelevant for any policy formulation or resource selection decision. Yet, the results have been derived by different methodologies and many distinct assumptions. Actually, they are not comparable.

Apart from the methodological differences, the bottom-up approaches reveal that the magnitude of the damage cost estimates also very much depend on

- the population density in the regional plume of the emissions. The sensitivity analyses carried out in a study on external costs of different biomass fuel cycles co-ordinated at ZEW demonstrate this site specificity of the damage figures for traditional air pollutants (The BioCosts Research Group 1998).
- the choice of the reference technology. The emission figures of best available technologies operating with improved control equipment rather than a mix of existing technologies are much lower, so are not surprisingly their external cost estimates. For instance, the coal power plant studied for Belgium has no FGD or DeSOx. Therefore, it has high emissions per kWh. It accounts for the upper value of the coal fuel cycle estimates given in Table 1 for CEC (1998).

One can conclude, that in particular earlier and the most recent European studies indicate that external costs of fossil technologies are significant compared to energy prices, and that well located renewable energy technologies provide sustainable energy options.

3 GLOBAL WARMING

Scientific research on the impacts of the greenhouse effect has focused primarily on a scenario which assumes a doubling of pre-industrial CO_2-equivalent concentrations in the atmosphere. This so-called benchmark scenario indicates that the increase of the global mean surface temperature could range from 1°C to 3.5°C between 1990 and 2100, with a 'best estimate' of about 2°C (IPCC 1996a). Due to the lack of knowledge and the complexity of processes,

studies usually deal with only a subset of impacts, and are often restricted to a description of physical impacts. The best studied impact categories are agricultural impacts and the costs of the sea level rise. The estimates of non-market damage, such as human health, risk of human mortality and damage to ecosystems, are regarded as highly speculative and incomplete, and thus as a source of major uncertainty in assessing the implications of global climate change for human welfare. Furthermore, several kinds of impacts have been virtually ignored so far, e.g. migration and tropical diseases, since they could not be adequately quantified (IPCC 1996c).
The aggregate estimates of damages from a 2-3°C warming tend to be a few per cent of the world gross domestic product (GDP), with, in general, considerably higher estimates of damages to developing countries as a share of their GDP (IPCC 1996c). Nordhaus (1991, 933), Cline (1992, 131), Fankhauser (1995, 55) and Tol (1995, 4) estimate the damages caused by a warming of 2.5°C at 1 to 1.5 per cent of US-GDP. On the basis that CO_2-equivalent doubling will produce a warming of 4°C rather than 2.5°C, Titus (1992) estimates that damages to be 2.5% of GDP. Estimates for other OECD countries are generally in about the same order of magnitude (Fankhauser 1995; Tol 1995). The literature on external 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 ... the developing country statistical lives have not been equally valued at the developed country value nor are other damages in developing countries equally valued at the developed country value" (IPCC 1996c, 10). However, there is a consensus that vulnerability in most developing countries seriously exceeds that in developed countries.

The standard economic approach to analyzing global warming relies on cost-benefit analysis, the traditional economic technique for evaluation of projects and public policy issues. Pearce (1993, 56) describes it as "an appraisal procedure that evolved from concerns with mainly localized and certainly marginal changes to the state of the economy." Cost-benefit analysis attempts to equate the marginal damage of greenhouse gas emissions to the marginal cost of reducing them, thus to weigh the costs and benefits of climate change or alternative control strategies in terms of a common monetary unit. The ultimate goal is to determine the optimal level of greenhouse gas reduction, i.e. efficient strategies to reduce the cost of climate change. But both, estimates of the costs of mitigation options and estimates of potential physical damages due to climate change vary widely. The efforts to get closer to this unattainable and in my opinion inappropriate goal are only slightly successful, also since the calculation of damage costs from global warming involve substantial value judgments (cf. Kühn/ Groscurth 1998 for an overview). The valuation of intra- and intergenerational effects raises "serious ethical issues". It is unlikely that these disputes can be resolved by technical analysis or scientific research" (US Congress/ OTA 1994, 2).

IPCC WG III (1996c, 11) cites a range of marginal damage estimates from about 5 to 125 US$ (1990) per ton of carbon emitted today which is based on the studies just mentioned. Then, IPCC 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, 11). The range reflects, however, "variations in model scenarios, discount rates, and other assumptions". This issue is further illustrated by Azar and Sterner (1996), who show that, using the Nordhaus model, values up to 590 US$ per ton of carbon can be derived by dismissing discounting, assuming longer retention of CO_2 in the atmosphere, and weighting damage by income. Considering three major assumptions, that is whether or not to include effects in developing countries, which VOSL to take, and whether or not to discount human casualties, can lead to damage costs varying by 6 orders of magnitude

(Hohmeyer 1996). Any value in between the extremes may be justified. Discounting of the monetary values of environmental and health impacts is controversial. Arguments for and against a zero discount rate have been part of a wider, and unresolved, debate concerning intergenerational equity and sustainability.

Nevertheless, even though "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" (IPCC 1996b) it has to be concluded that global warming poses a major risk to the opportunity of future generations to live comfortably and in peace. Furthermore, "the literature indicates that significant 'no regrets' opportunities are available in most countries and that the risk of aggregate net damage due to climate change, consideration of risk aversion, and application of the precautionary principle, provide rationales for actions beyond no regrets." (IPCC 1996c, 1). Thus, it is proposed to base global energy policies on the basic principles of strong sustainability. Where impacts are very long lasting and potentially catastrophic, direct application of physical sustainability constraints may prove a more effective approach to policy formation (cf. also Eyre 1997).
In other words, environmental damage should not be regarded as being compensated for by economic benefits, but should be considered separately. The respective strategies will also decrease damage from conventional pollutants substantially.

4 CONCLUSIONS

The process of measuring external effects can play a role in informing the debate about how to deal with environmental issues in electricity markets. 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. Nevertheless, it is important to realize that conventional cost calculations governing individual decision-making may leave out substantial portions of the total costs to society and may, thus, be misleading.
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.

Relatively little effort has been directed to understanding how the estimates should be used to improve electricity resource planning or system operation, neither in the context of the regulatory environment nor in the restructured electricity industry (Burtraw/ Krupnick 1996; Eyre 1997). Different conceptions of internalization of environmental damages are possible. In a narrow sense it refers to the goal of Pareto-efficiency in resource allocation, i.e. to the practice of optimization. An option, that from an efficiency perspective dominates, is the first-best instrument for internalizing environmental externalities – a broad based set of emissions fees or tradable emission permits. In a broader sense internalization refers to political processes and institutions for resolving conflicts over environmental concerns (O'Connor 1997, 455f.). Moreover, monetary valuation of impacts may be important to inform constraint setting, but other analytical techniques are also needed.

Finally, it is noted that there is no fundamental contradiction between deregulated energy markets and consideration of environmental issues in decision and policy making, from a theoretical point of view. Economic instruments like taxes and tradable permits for example fit a more competition-oriented regulatory framework well.

5 REFERENCES

Azar, C., Sterner, T. (1996): Discounting and Distributional Considerations in the Context of Global Warming. Ecological Economics 19, 169-184

Bernow, S., Biewald, B., Dougherty, W., White, D. (1996): Counting the Costs: Scientific Uncertainty and Valuation Perspective in EXMOD. In: Hohmeyer, O., Ottinger, R.L., Rennings, K. (Eds.) (1996), 200-231

The BioCosts Research Group (1998): Total Costs and Benefits of Biomass in Selected Regions of the European Union (BioCosts). Draft Final Report to the European Commission under Contract JOR3-CT95-0006

Burtraw, D., Krupnick, A.J. (1996): The Second-Best Use of Social Cost Estimates. Discussion Paper 96-29, Resources for the Future (RFF), Washington DC

CEC – Commission of the European Communities, DG XII, Science, Research and Development (Ed.) (1995a-f): ExternE. Externalities of Energy, Vol. 1-6. Office for Official Publications of the European Communities, Brussels Luxembourg

CEC – Commission of the European Communities, DG XII, Science, Research and Development (Ed.) (1998): ExternE Phase III. National Implementation Studies On Externalities of Energy. *Forthcoming* (results are already publicly available on http://ExternE.jrc.es/)

Cline, W.R. (1992): The Economics of Global Warming. Institute for International Economics, Washington DC

Endres, A. (1995): Die externen Kosten der Energiewirtschaft – Methodologische Probleme ihrer monetären Bewertung. Zeitschrift für Energiewirtschaft (ZfE) 4/95, 305-313

Eyre, N. (1997): External Costs. What do they mean for energy policy ? Energy Policy 25, 85-95

Eyre, N., Downing, T., Hoekstra, R., Rennings, K., Tol, R.S.J. (1997): ExternE. Global Warming Damages. Final Report to the CEC for the JOULE-Project JOR3-CT95-0002. Brussels

Fankhauser, S. (1995): Valuing Climate Change. The Economics of the Greenhouse. Earthscan Publications Ltd, London

Freeman, A.M. III (1993): The Measurement of Environmental and Resource Values. Theory and Methods. Resources for the Future, Washington DC

Hoevenagel, R. (1991): A Comparison of Economic Valuation Techniques. Discussion Paper of the Institute for Environmental Studies, Free University Amsterdam

Hohmeyer, O. (1996): Social Costs of Climate Change. Strong Sustainability and Social Costs. In: Hohmeyer, O., Ottinger, R.L., Rennings, K. (Eds.) (1996), 61-83

Hohmeyer, O., Ottinger, R.L., Rennings, K. (Eds.) (1996): Social Costs and Sustainability. Valuation and Implementation in the Energy and Transport Sector. Proceedings of an International Conference held at Ladenburg, Germany, May 27-30, 1995. Springer, Berlin Heidelberg New York

IPCC – Intergovernmental Panel on Climate Change (1996a): Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the IPCC. Cambridge University Press, Cambridge

IPCC – Intergovernmental Panel on Climate Change (1996b):

IPCC – Intergovernmental Panel on Climate Change (1996c): Climate Change 1995. Economic and Social Dimensions of Climate Change. Contribution of Working Group III to the Second Assessment Report of the IPCC. Cambridge University Press, Cambridge

Krupnick, A.J., Burtraw, D. (1996): The Social Costs of Electricity. Do the Numbers Add Up ? Discussion Paper 96-30, Resources for the Future (RFF), Washington DC

Krutilla, J.V., Fisher, A.C. (1975): The Economics of Natural Environments. Studies in the Valuation of Commodity and Amenity Resources. The Johns Hopkins University Press, Baltimore

Kühn, I. (1996): Account of Presently Known Social Costs. Discussion Paper for the CEC APAS-Project 'Long-Term Integration of Renewable Energy Sources into the European Energy System, and its Potential Economic and Environmental Impacts (LTI)'. Zentrum für Europäische Wirtschaftsforschung GmbH (ZEW), Mannheim

Kühn, I., Groscurth, H.-M. (1998): Global Warming, Sustainability and the Energy Use of Biomass. Discussion Paper for the CEC JOULE-Project 'Total Costs and Benefits of Biomass in Selected Regions of the European Union (BioCosts)'. Zentrum für Europäische Wirtschaftsforschung GmbH (ZEW), Mannheim

Lee, R. (1996): Externalities Studies: Why Are the Numbers Different? In: Hohmeyer, O., Ottinger, R.L., Rennings, K. (Eds.) (1996), 13-28

Markandya, A., Richardson, J. (Ed.) (1993): The Earthscan Reader in Environmental Economics. Earthscan Publications Ltd, London

Nordhaus, W.D. (1991): To Slow or Not to Slow. The Economics of the Greenhouse Effect. The Economic Journal 101, 920-937

O'Connor, M. (1997): The Internalization of Environmental Costs: Implementing the Polluter Pays Principle in the European Union. International Journal of Environment and Pollution 7 (Special Issue), 450-482

O'Hara, S. (1996): The Challenges of Valuation: Ecological Economics Between Matter and Meaning. Paper presented at the 4th Biannual Conference of the International Society for Ecological Economics (ISEE) held in Boston, August 4-8, 1996

ORNL/ RFF – Oak Ridge National Laboratory, Resources for the Future Inc. (1994a-h): External Costs and Benefits of Fuel Cycles. A Study by the US Department of Energy and the Commission of the European Communities. Reports 1-8. McGraw-Hill/Utility Data Institute, Washington DC

Ottinger, R.L., Wooley, D.R., Robinson, N.A., Hodas, D.R., Babb, S.E. (1990): Environmental Costs of Electricity. Pace University Center for Environmental Legal Studies. Oceana Publications, New York London Rome

Pearce, D. (1993): Economic Values and the Natural World. Earthscan Publications Ltd, London

Pearce, D., Bann, C., Georgiou, S. (1992): The Social Costs of Fuel Cycles. Report to the UK Department of Trade and Industry. Centre for Social and Economic Research on the Global Environment (CSERGE), London

RCG/ Tellus – RCG/Hagler, Bailly, Inc., Tellus Institute (1993-1995): New York State Environmental Externalities Cost Study. Research Report EP 91-50. Prepared for the Empire State Electric Energy Research Corporation. Reports 1-4. Albany New York

Stirling, A. (1997): Limits to the Value of External Costs. Energy Policy 25, 517-540

Titus (1992)

Tol, R.S.J. (1995): The Damage Costs of Climate Change. Toward More Comprehensive Calculations. Environmental and Resource Economics 5, 353-374

US Congress/ OTA – Office of Technology Assessment (1994): Studies of the Environmental Costs of Electricity. Background Paper. OTA-ETI-134. US Government Printing Office, Washington DC