New Elements for the Assessment of External Costs from Energy Technologies

New Ext

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LIST OF ABBREVIATIONS

CalTOX™	Californian Multimedia Total Exposure Model
CCGT	Combined cycle gas turbine
CH_4	Methane
CL	Critical load(s)
CO_2	Carbon dioxide
CO_{2equiv}	Carbon dioxide equivalent
CORINAIR	Core inventory air
CRF	Concentration-response function
DENOX	NO_x removal system
DIEM	Dissemination and Discussion of the ExternE Methodology and Results
DRF	Dose-response function
EC	European Commission
ECU	European currency unit (precursor of EURO up to 1998)
EMEP	Co-operative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe
ENSAD	Energy-related Severe Accident Database
ENSMP	Ecole Nationale Supérieure des Mines de Paris (Ecole des Mines)
EPA	Environmental Protection Agency
ERF	Exposure-response function
EU	European Union
EU-15	European Union of Jan 1, 1995 – April 30, 2004 with 15 member states
EUSES	European Union System for the Evaluation of Substances
ExternE	Externalities of Energy
ExternE-Pol	Externalities of Energy: Extension of Accounting Framework and Policy Applications
FEEM	Fondazione Eni Enrico Mattei
FGD	Flue Gas Desulfurization
FUND	Climate Framework for Uncertainty, Negotiation and Distribution
GHG	Greenhouse gases
GIS	Geographic information systems
GREENSENSE	An applied integrated environmental impact assessment framework for the European Union
GW_eyr	Gigawatt year of electricity
ha	Hectare
HYDRO1K	Geographical elevation derivative database
IAEA	International Atomic Energy Agency
IER	Institut für Energiewirtschaft und Rationelle Energieanwendung
IOM	Institute of Occupational Medicine
IPCC	Intergovernmental Panel on Climate Change
IQ	Intelligence Quotient
JOULE	Non-nuclear energy research programme of the European Commission implemented under the Fourth Framework Programme (1994-1998)
kWh	Kilowatt hour
kWh_e	Kilowatt hour of electricity
LOAEL	Lowest observed adverse effect level

LPG	Liquefied petroleum gas
LTRAP	Long-Range Transboundary Air Pollution
MW	Megawatt
N	Size of the survey sample (population)
n/a	Not applicable
nd	No data available
NEC	European Directive 2001/81/EC on National Emission Ceilings of 2001
NEC+	Proposal of the EC to the European Directive 2001/81/EC on National Emission Ceilings of 1999
NEEDS	New Energy Externalities Developments for Sustainability
NewExt	New Elements for the Assessment of External Costs from Energy Technologies
NH_3	Ammonia
NMVOC	Non-methane volatile organic compounds
N_2O	Nitrous oxide
NOAEL	No observed adverse effect level
NO_x	Nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
PM_{10}	Particulate matter with diameter < 10 µm
PRO	UN-ECE Gothenburg Protocol of LTRAP Convention of 1999
PSA	Probabilistic safety assessment
PSI	Paul Scherrer Institute
REF	Reference Scenario (without emission reduction programs)
SCR	Selective catalytic reduction
s.e.	Standard Error
SO_2	Sulphur dioxide
UK	United Kingdom
UN-ECE	United Nations Economic Commission for Europe
US	United States of America
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UWM	Uniform World Model
VH	Vlier-humaan multi-media exposure model
VITO	Vlaamse Instelling voor Technologisch Onderzoek
VOLY	Value of Life Year
VSL	Value of a Statistical Life
WATSON	Water and Soil environmental fate, exposure and impact assessment model of noxious substances for Europe
WHO	World Health Organization
WTA	Willingness to accept
WTM	Windrose Trajectory Model
WTP	Willingness to pay
WTP_i^L	Lower bound of the willingness to pay interval of respondent i (bid value accepted by the respondent)
WTP_i^U	Upper bound of the willingness to pay interval of respondent i (bid value rejected by the respondent)

I OBJECTIVES

The supply and use of energy imposes risks and causes damage to a wide range of receptors, including human health, natural ecosystems (flora and fauna) and the built environment. Such damages are to a large extent external costs, as they are not accounted for in the factor costs and thus in the decisions of electricity producers. The existence of external effects in the energy sector (but also other industrial activities) may cause welfare losses and a non-optimal allocation of resources

Within the ExternE projects funded under the JOULE Programme during the 1990s, a detailed bottom-up 'impact pathway' (or damage function) approach was developed to quantify external costs from energy conversion resulting from impacts on human health, crop losses, material damage and global warming. The ExternE external costs accounting framework is widely accepted and has been successfully used to support decision making in the field of energy and environmental policy.

However, there are also areas for which a need for further research was identified in previous ExternE phases. Major uncertainties result from uncertainties in the monetary valuation of mortality effects and from the omission of impacts on ecosystems due to global warming and acidification and eutrophication of ecosystems. The formerly existing accounting framework was also criticised for not taking into account the contamination of water and soil. Due to accumulation processes of persistent substances there is a significant potential for long-term effects that were not addressed in previous work. Another source for criticism is the unbalanced treatment of severe accidents, as the current framework is very much focused on accidents in the nuclear fuel chain, while neglecting severe accidents from other energy sources. NewExt as the follow-up of former ExternE phases has therefore focussed on the improvement of the existing framework in four key areas, which are considered as most relevant for the assessment of external costs, and which are expected to be primarily affected by new scientific findings. Thus, the main objective of the project has been to improve the assessment of externalities by providing new methodological elements for integration into the existing external costs accounting framework that reflect the most important new developments in the assessment of external costs.

II METHODOLOGY

To achieve this objective, the update of methodologies focussed on four different areas that are examined each in specific work packages. The project provides

- **an improved methodology for the monetary valuation of mortality impacts from air pollution**

  The monetary valuation of mortality impacts has been identified as the dominant parameter in the assessment of external costs from energy conversion. In the last phase of ExternE it was suggested that the most appropriate methodology for the valuation of mortality impacts is the new approach of 'Value of Life Year Lost' (VOLY) for the valuation of mortality impacts. Since no studies directly focussing on the VOLY have yet been conducted in Europe, such a study has been carried out within the project to provide an empirical basis for this most important single parameter in the accounting framework.

- **valuation of environmental impacts based on preferences revealed in (1) political negotiations (global warming, acidification and eutrophication) and (2) public referenda (global warming).**

  The impact pathway requires estimating the impacts in physical terms and then to value these impacts based on the preferences of the 'common man'. This approach has been successfully applied to e.g. human health impacts, but in other areas this approach cannot be fully applied because data on valuation is missing (acidification and eutrophication of ecosystems) or estimation of all physical impacts is limited (global warming). It is estimated that for those areas a full implementation of the impact pathway approach would require large efforts both in terms of physical science and monetary valuations, efforts that go way beyond ExternE.

  Therefore for these cases, a *second best approach* may be better then having no data, or partial data. In NewExt it has been explored to which extend approaches that elicit *implicit* values in policy decisions can be useful to monetise the impacts of global warming, acidification and eutrophication. Traditional approaches to estimate 'shadow prices' per ton of pollutant cannot be used here because they account for the total impacts and are not additive to ExternE estimates for e.g. public health and because they are not site-specific. Therefore a new approach has been elaborated that uses data on costs and benefits used in the preparation and negotiation of the UN-ECE LRTAP protocol of 1999 and the EU NEC-directive of 2001. This data has been reinterpreted to estimate an *implicit* WTP (willingness to pay) per hectare of ecosystem no longer above critical loads. These values can be further used in combination with estimates of how emissions affect the ecosystems in terms of their exceedance of critical loads.

Second, a similar reasoning has been applied to control of CO_2 emissions. The implicit WTP for meeting the emission limits from the Kyoto protocol is dependent on the policy choices related to the instruments how to achieve these targets.

Third, an innovative approach was developed by deriving an implicit WTP for controlling CO_2 emissions from people's voting behaviour in referenda related to energy questions in Switzerland.

- **a methodology for the assessment of effects from multi-media (air/water/soil) impact pathways**

  The strong focus of ExternE on airborne pollutants has been criticised, as it neglects the significant environmental impacts from the contamination of water and soil resulting from an energy system's full life cycle. In particular, the human exposure to heavy metals and some important organic substances (e.g. dioxins), which accumulate in water and soil compartments and lead to a significant exposure via the food chain, was not well represented. The project identified priority impact pathways and developed methodologies for the quantification of relevant externalities whose results were compared for validation. The multimedia impacts of toxic metals emitted by power plants turn out not to make a significant contribution to the damage costs.

- **a methodology and a related database for the assessment of externalities from major accidents in non-nuclear fuel chains**

  In previous ExternE work, emphasis was placed on the quantification and valuation of impacts from beyond design basis accidents in the nuclear fuel cycle. However, other fuel chains also show a significant potential for severe accidents (e.g. oil fires or large spills, gas explosions, dam failures). The project reviewed and extended existing database systems on major accidents related to energy conversion activities. Furthermore, for hydro power an approach using elements of Probabilistic Safety Assessment (PSA) was defined and some of its components were elaborated on a limited-scope basis. In a second step, a methodology was developed to estimate external costs from major accidents, thus advancing comparability with the results earlier obtained for beyond design basis accidents in the nuclear fuel chain. This work allows for the first time a consistent and comprehensive assessment of externalities from major accidents in non-nuclear fuel chains.

Of course, these four new methodological elements should be compatible with the existing external costs accounting framework. While it has not been the objective of the project to provide a broad review of current external cost estimates by taking into account the new methodology, some testing of the methodology is required to demonstrate its feasibility. The new methodology has been applied to calculate external costs for a set of reference power plants in Germany, Belgium, France and the United Kingdom, for which technical data have been available from previous ExternE work. The question how these new numbers may affect the major policy conclusions of previous work was addressed. One additional essential factor at this stage was the consideration of some parallel new insights, developments and changes that occurred in the scientific field of external costs in parallel to the NewExt project, e. g. changes of applicable dose-response functions.

This project produced a set of new methodological 'building blocks' for integration into the existing EU external costs accounting framework, rather than a 'stand alone' methodology for the assessment of externalities. The communication and dissemination of the new methodological elements to the current users of the existing accounting framework and the relevant scientific community and the guidance on the use of the new methodological elements have been achieved by carrying out a number of workshops and by setting up a webpage (www.externe.info) within the supporting concerted action DIEM (Dissemination and discussion of the ExternE methodology and results).

III MAIN RESULTS

According to the structure of the NewExt project, the methodological work on the four work packages has each lead to specific new insights and results. Based on all this work, but also on further updates of baseline data, dose-response functions and the EcoSense software, new calculations have been made for the basic fuel cycles, so that a comparison with the results of the National Implementation phase of ExternE can be done.

i) MONETARY VALUATION OF INCREASED MORTALITY FROM AIR POLLUTION

- **Context**

This work had as its objective the derivation of unit values to account in monetary terms for the incidence of premature death estimated to result from air pollution in Europe. Values were derived from three surveys undertaken simultaneously in UK, France and Italy, using a common survey instrument.

The impact-pathway approach to the estimation of environmental external costs adopted in the ExternE Research Project requires – for its completion – the monetisation of the impact end-points identified by the modelling of pollution effects arising from energy and transport fuel-cycles. In the case of air pollution, the epidemiological literature presented in previous phases of ExternE has signalled that exposure to a number of pollutants, including particulates, nitrates, sulphates and ozone, (e.g. European Commission, 1999), can lead to cases of immediate (acute) or delayed (chronic) premature death within a given population. There is therefore the need for a unit value to represent each estimated source of premature death in the final estimation of environmental external costs.

The search for appropriate unit values has until now relied on the available literature. However, the values that currently exist are generally not believed to express accurately the willingness-to-pay (WTP) that individuals might express, e.g. for the introduction of a new air quality regulation. More specifically, existing values are derived often in the context of the work-place (wage-risk studies) that estimate the willingness to accept (WTA) a higher wage rate in accordance with a greater risk of accidental death. Alternatively, attention has been given to the valuation of fatal transport accidents, the frequency of which might be expected to change with e.g. the introduction of new transport infrastructure. Both the road and workplace examples of contexts differ from the context of air pollution and so may be expected to result in different WTP values. The principal differences are:

- the length of life-time lost on average through the impact,
- the state of health of the individual impacted,
- the size of the risk change,
- context specificity,
- immediacy of the impact.

These reasons provide the principal justification for the present study that derives unit values more appropriate and reliable to EU air quality policy analysis. This report presents the evidence from a survey-based (contingent valuation) study undertaken to address the issues highlighted above in the existing ExternE practice.

- **Methodology**

The survey instrument adopted in our study has been used in studies in US and Canada and results are reported in Alberini et al. (2001). It was decided by the ExternE team that it would be prudent in the first instance to adopt an existing survey instrument. Reasons included the facts that:

- development costs could be minimized;
- in the course of its implementation in North America it had already been the subject of peer group review and represented the state-of-the-art;
- it allowed comparability with the North American results.

The survey instrument adopted by the country teams in UK, France and Italy was developed using extensive face-to-face interviews in the USA, and was pre-tested in the USA, Japan and in Canada. Nevertheless, the three country teams each conducted a series of focus groups and/or one-to-one testing in order to adapt the instrument for the national contexts. Additionally, the French country team tested a series of variants to the questionnaire on samples of about 50 each. These variants tested: the commodity expressed as a public good; the use of an open question without bid values, and the change expressed as an increase in life expectancy.

The survey instrument is designed to elicit WTP for mortality risk reductions to be incurred over 10 years (effective immediately) and for reductions in the probability of dying between age 70 and 80. The instrument has been developed in order to tackle problems - in particular - insensitivity to the scope of the commodity that have been found in previous studies i.e. the WTP do not vary for different sized risk changes in proportion to the size of the risk changes as would broadly be expected. In Italy and the UK, the risk reductions to be valued by the respondents were those used in Wave 1 of the Canada and US studies. Specifically, people were asked to value an immediate 5 in 1000 risk reduction, an immediate 1 in 1000 risk reduction, and a reduction of 5 in 1000 to be experienced at age 70, in that order. (Wave 2 in the North American studies reversed the order of the immediate risk changes). The France study also implemented the Wave 2 design, whereby the 1 in 1000 risk reduction was valued first.

The survey instrument is self-administered and computerised, thereby removing any interviewer biases. The components of the survey are described in the order that they appear in a series of computer screens. The use of a series of tele-visual screens allows the graphics to be made clearer and more adaptable to the individual than would be possible with printed questionnaires. Comprehension is also improved by reinforcing the written text with voiceovers, so that respondents will both see and hear questions. This has shown to be particularly important in the case of older respondents. Table 1 reports the sample sizes, which are of the order of about 300 in each of the three European countries. Table 2 then summarises the key descriptive statistics of the survey respondents.

Table 1: Sample size and experiment design for the EU 3-country study

	UK	Italy	France
N	330	292	299
Locale of the Study	Bath	Venice, Genoa, Milan and Turin	Strasbourg
Experimental Design	Wave 1	Wave 1	Wave 1 and wave 2

Table 2: Descriptive Statistics of the Respondents

	UK	Italy	France
Average age	58	57	55
Age group 40-49	20%	28%	33%
Age group 50-59	34%	33%	29%
Age group 60-69	33%	23%	26%
Age group 70 and older	11%	14%	10%
Male	49%	48%	47%
Income in € (Mean)	40,096	40,115	32,186
Education (years of schooling)	14	13	11

- **Results**

In deriving our WTP estimates, we assume that WTP follows the Weibull distribution with scale parameter σ and shape θ, and estimate these parameters using the method of maximum likelihood. The log likelihood function of the WTP data is:

(1) $$\log L = \sum_{i=1}^{n} \log\left[\exp\left(-\left(\frac{WTP_i^L}{\sigma}\right)^{\theta}\right) - \exp\left(-\left(\frac{WTP_i^U}{\sigma}\right)^{\theta}\right)\right],$$

where WTP_i^L and WTP_i^U are the lower and upper bound of the interval around the WTP amount of respondent i, where the upper and lower bounds are given by the bid values which the respondent either accepts or rejects. Equation (1) describes an interval-data model. The Weibull distribution was adopted because (amongst other reasons) WTP for a risk reduction should be non-negative. Other distributions, such as the lognormal, exponential and log-logistic are suitable for non-negative variates, and so we compared the fit of the Weibull with that of these distributions. The fit of the Weibull was always better. The Weibull and the other distributions generally agree in terms of their estimates of median WTP, but may produce very different figures for mean WTP. With WTP, experience suggests that mean WTP tends to be two or even three times as large as median WTP. We therefore regard median WTP as a conservative, but robust and more reliable, estimate. For this reason, we report median WTP figures for the 5 in 1000 risk reduction in Table 3 below. We use the WTP values for the 5 in 1000 risk reduction as our central values because previous testing in the North American context suggests that answers to the first question asked tend to be more reliable. It is also likely to be an easier size of risk change to effectively comprehend.

Table 3. Median WTP for the 5 in 1000 risk reduction beginning now. Annual WTP in €.

	UK	Italy	France*
Median WTP (standard error)	386 (37)	724 (86)	479 (75)

*We used both wave 1 and wave 2 observations for the France study because of the small sample size.

The value of a statistical life (VSL) implied by these figures is € 772,000 for the UK, € 1,448,000 for Italy, and € 958,520 for France.

We then pooled the data from the three European countries to increase the sample size and to be able to provide recommendation for VSL figures to use for policy purposes in the EU. Three regressions, with different independent variables, were run on the pooled data to explain the 5 in 1000 risk reductions; results are reported in Table 4, below.

These results imply that mean WTP for the 5 in 1000 risk reduction from the three European countries is € 1129 per year (s.e. € 132.5), while median WTP per year is pegged at € 526 (s.e. € 39.5). The implied VSLs are € 2.258 million and € 1.052 million, respectively.

Column (A) shows that income is significantly associated with WTP, a result that is consistent with expectations. Column (B) includes country dummy variables to account for the different sampling frames at the different locales where the survey was administered. Holding household income the same, the French and the Italian respondents hold WTP values that are greater than their UK counterparts. In this specification, the coefficient of income is larger in magnitude than, but is within 10% of, its counterpart in specification (A).

Column (C) suggests that WTP declines only for the oldest respondents in the sample, who hold WTP amounts that are approximately 25% lower than those of the other respondents, all else the same. However, the coefficient on the dummy for a respondent who is 70 or older is not significant at the conventional levels; the French results suggest that such an age effect may be due to lower income during retirement. As in earlier studies, males have slightly lower WTP and so do people with higher levels of education. Persons who have been hospitalized for cardiovascular or respiratory illnesses over the last 5 years hold WTP amounts that are over twice as large as those of all others. The presence of cancer and chronic illnesses, however, does not influence WTP.

Table 4. Pooled data interval-data regressions for WTP. 5 in 1000 risk reduction.[a]

	(A)	(B)	(C)	(D)
Intercept	6.4648** (0.126)	6.0057** (0.148)	6.7208** (0.342)	5.8024** (0.386)
Household income (thou. Euro)	0.0089** (0.0029)	0.0097** (0.0029)	0.0098** (0.0031)	0.0098** (0.0031)
Age 50-59 (dummy)			-0.0702 (0.196)	0.0245 (0.190)
Age 60-69 (dummy)			0.0391 (0.207)	0.2056 (0.204)
Age 70 or older (dummy)			-0.2144 (0.263)	-0.0748 (0.256)
Male (dummy)			-0.1831 (0.147)	-0.1842 (0.142)
Education			-0.0217 (0.023)	0.0072 (0.024)
Chronic respiratory or cardiovascular illness (dummy)			0.0409 (0.157)	0.076 (0.152)
ER or emergency room visit (dummy)			0.7445** (0.292)	0.5944* (0.282)
Has or had had cancer (dummy)			0.4399 (0.326)	0.4397 (0.315)
France dummy		0.8405** (0.205)		0.8636** (0.214)
Italy dummy		0.6556** (0.160)		0.6705** (0.162)
Shape parameter (θ)	0.7014 (0.042)	0.7276 (0.043)		0.7400 (0.044)

[a] Only wave 1 is used for the data from the French study.
* = significant at the 5% level; ** = significant at the 1% level.

- **Interpretation for Value of a life year lost (VOLY)**

Discussion of the appropriate WTP metric for the air pollution context elsewhere[1] has concluded that the epidemiological evidence dictated that the VOLY be adopted. Since we do not have direct estimates of VOLY – our survey generates VSLs – we rely upon a conversion relationship between changes in probabilities of death and changes to life expectancy. This relationship is established in Rabl (2002), According to Rabl's calculations, the extension in life expectancy ranges from 0.64 to 2.02 months, depending on the person's age and gender, and averages 1.23 months (37 days) for our sample.[2] To find out the value of a life-expectancy extension of a month, we divide a respondent's WTP by that respondent's life expectancy extension. A Weibull double-bounded model pegs mean WTP at €1052 (s.e. 128.4) per year for each month of additional life expectancy. Median WTP is €465 (s.e. 33.3) for a month of life expectancy gains. Because in our survey the payments would be made every year for ten years, the total WTP figures for a life expectancy gain of one month are €10,520 and €4650 respectively. The implied values of a statistical life-year (VSLY) are €125,250 and €55,800, respectively. Given the uncertainties, this might safely be rounded to €50,000.

The VOLY of € 50,000 is derived from an annual payment made over a ten-year period and as such does not require further discounting since we assume that the respondents have implicitly done this when giving their answer. Since available empirical evidence suggests that a typical time period of latency to elapse in the case of chronic air pollution-induced mortality is 5-7 years we may adopt this value for chronic mortality impacts, whilst noting that the life years lost (gained) after the time of death are not accounted for in this unit value. If, however, we assume that the VOLY of €50,000 is equivalent to the VOLY derived from life-table analysis, (following Hurley and Miller, (2004), and Friedrich and Bickel (eds) p92, (2001)), discounted at 3%, then the equivalent undiscounted VOLY is (50,000/0.67) = €74,627[3]. For calculating new results, this value is rounded to €75,000. This can be interpreted as a value for acute mortality as long as it is assumed that no other factors (e.g. a victim's health condition at time of death) affect WTP for these end-points.

An upper bound value is taken as that resulting from the mean WTP value of the 1:1000 immediate risk change. These give a VSL of € 3,310,000 and a VOLY (discounted) of € 151,110. A lower bound estimate could be derived from the results of the French questionnaire that uses a direct estimate of an equivalent change of life expectancy of € 200. This converts to a VOLY of € 18,250. That is considerably less because of concerns about the quality of life during that extra period and because the gain (about 40 days on average) is too short for the respondents to consider it significant and worth undertaking the medical

[1] See NewExt Technical Report for EC DG Research.

[2] A change in the probability of surviving the next 10 years changes the probabilities of surviving all future periods, conditional on being alive today. The sum of these future probabilities of surviving is a person's remaining lifetime. Rabl's calculations are based on an exponential hazard function, $h(t)=\alpha*\exp(\beta t)$, where t is current age, and α and β are equal to 5.09*E-5 and 0.093 for European Union males, respectively, and 1.72E-5 and 0.101, respectively, for European Union females.

treatment for ten years; also, this value is very uncertain because it is based upon a much smaller sample size of 50.

- **Outstanding Issues and Future Work**

The project team finds that these values are comparable to the central value used by DG Environment, and provide a much-needed empirical validation for current practice in policy analysis. The testing by the country teams does, however, provide some evidence for the argument that we cannot regard these results as the last word on this subject. The three elements of the survey instrument that have been most challenging are outlined in the paragraphs below.

- Even given the pictorial representation of the risk changes in the survey instrument and the reinforcing voice-overs, there was some evidence that the small size of the risk changes involved still proved to be difficult for the respondent to be able to provide meaningful values. The internal scoping tests showed that though the values for the smaller risk change are lower than the larger risk change, they are not proportional, or close to proportional, as one might expect. Work was undertaken in the French variants of the survey instrument to address this problem by substituting the risk change for the equivalent length of life expectancy, though here the perception of the quality of the change in life expectancy needs to be addressed more carefully. The issue of the appropriate metric, though, remains outstanding for valuing premature death in the air pollution context since the epidemiology seems to dictate the use of values for the change in life expectancy and more future effort in valuing this directly in Europe is clearly required.
- There remains a question mark over the effectiveness of using an abstract commodity to be valued. On one hand it is recognized by Krupnick et al. (2000) – and is demonstrated by the French variants – that supplying a public good context is likely to attract a number of biases relating to free rider effects or altruistic motives. On the other hand, in the absence of a recognizable or familiar commodity there is a tendency to think of health products or services for which individuals have been shown to have different preferences (biased in relation to the real context with which we are concerned).
- There is a problem with the acceptance of the scenario because many respondents tend to doubt the efficacy of a treatment that they have to pay themselves because it is not recognized for reimbursement by the social security system common in Europe, in particular France (the questionnaire had been developed for the USA where the health insurance system is totally different).
- It remains to be seen whether there is robust evidence of starting point bias being introduced by the use of dichotomous choice in the survey instrument. Preliminary

[3] Note that under this approach a zero discount rate would result in acute and chronic VOLYs being the same.

analysis presented in the French report has found this to be the case. The importance of the starting point bias in contingent valuation has been demonstrated in many studies, in particular Green et al (1998).

These issues suggest the need for further research in establishing unit values for air pollution-related deaths in the ExternE context. Nevertheless, the values that we derive in this report represent significant progress in this quest.

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ii) VALUATION OF ENVIRONMENTAL IMPACTS BASED ON PREFERENCES REVEALED IN POLITICAL NEGOTIATIONS AND PUBLIC REFERENDA

- **Context**

The impact pathway requires estimating the impacts in physical terms and then to value these impacts based on the preferences of the common man. This approach has been successfully applied to e.g. human health impacts, but in other areas this approach cannot be fully applied, because data on valuation is missing (acidification and eutrophication of ecosystems) or estimation of all physical impacts is limited (global warming).

Therefore and for these cases, a second best approach may be better then having no data, or partial data. Therefore, in NewExt, it has been explored too which extend approaches that elicit implicit values in policy decisions can be useful to monetise the impacts of acidification and eutrophication and global warming.

In addition, an innovative approach was developed by deriving an implicit WTP for controlling CO_2 emissions from people's voting behaviour in referenda related to energy questions in Switzerland.

ii) A. Revealed preferences in policy negotiations related to impacts of acidification and eutrophication on ecosystems

- **Method**

In this work package we explore the possibilities to value the impacts of airborne emission of SO_2, NO_X and NH_3 on acidification and eutrophication of ecosystems, using the implicit values of policy makers, i.e. to use the abatement costs of emissions reductions, policy makers are willing to pay as a proxy for the revealed willingness to pay of European society for the improvements in ecosystems health.

Earlier studies have used abatement costs as 'shadow prices' for the total impacts on human health, agriculture and ecosystems, expressed as € per ton pollutant. We follow a more sophisticated approach, which aims at figures that are more in line with the impact pathway approach of ExternE and that are additive to the ExternE estimates for impacts on human health, agriculture and building materials. Therefore, the analysis combines the *impact pathway approach* to estimate impacts in physical terms (step 1), which are then valued following a careful analysis of international agreements of emission reductions in Europe (step 2).

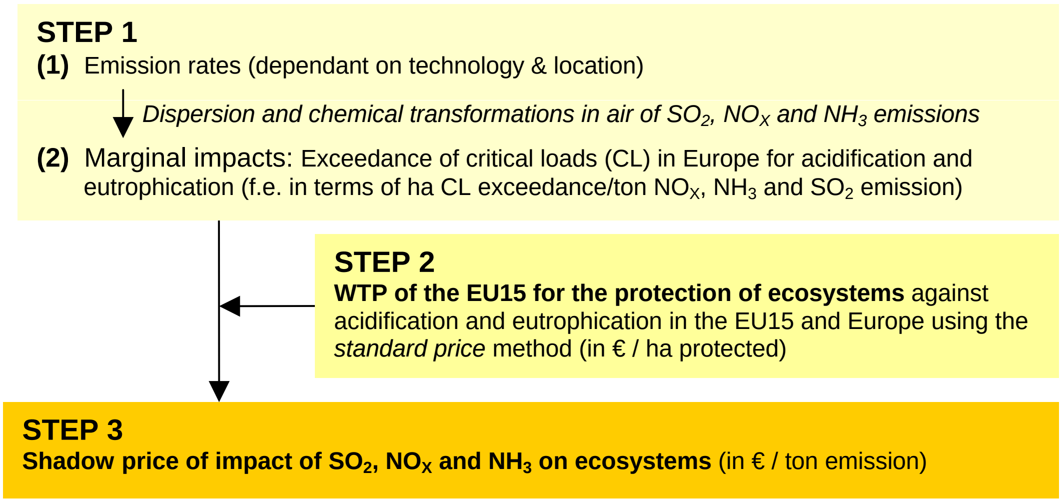

Figure 1: Steps in the analysis to determine the shadow price for impacts of acidification and eutrophication on ecosystems.

In step 1 country specific marginal impacts of SO_2, NO_X and NH_3 emissions on ecosystems protected form acidification and eutrophication are quantified in "hectares of ecosystems with exceedance of critical loads/year". These impacts are then valued in monetary terms by the "EU-15" willingness-to-pay (WTP) per hectare of ecosystem protected against acidification and eutrophication (in €/ha*year) from step 2, as revealed in the international agreements of emission reductions in Europe. On this basis, we can estimate the shadow price (representing the damage cost or external cost) per ton of emissions (step 3). Figure 1 shows the different steps.

- **Calculation of the WTP for the improvement of the European ecosystems health**

To determine this WTP, we have analysed the different international agreements for emissions reductions of NO_X, SO_2 and NH_3 and the information on the related costs and benefits as used in the decision making process. These costs are a proxy for the benefits that policy makers attribute to these reductions as we assume that policy makers act as rational decision makers who carefully balance (their perception of) abatement costs of emission reductions with (their perception of) the benefits of these emissions. Our analysis is based on the different emission reduction scenarios used in the preparation of the UN-ECE Gothenburg Protocol on LTRAP (1999) and the European Directive 2001/81/EC on National Emission Ceilings (NEC) (2001). In Figure 2, the stepwise application of step 2 is explained schematically.

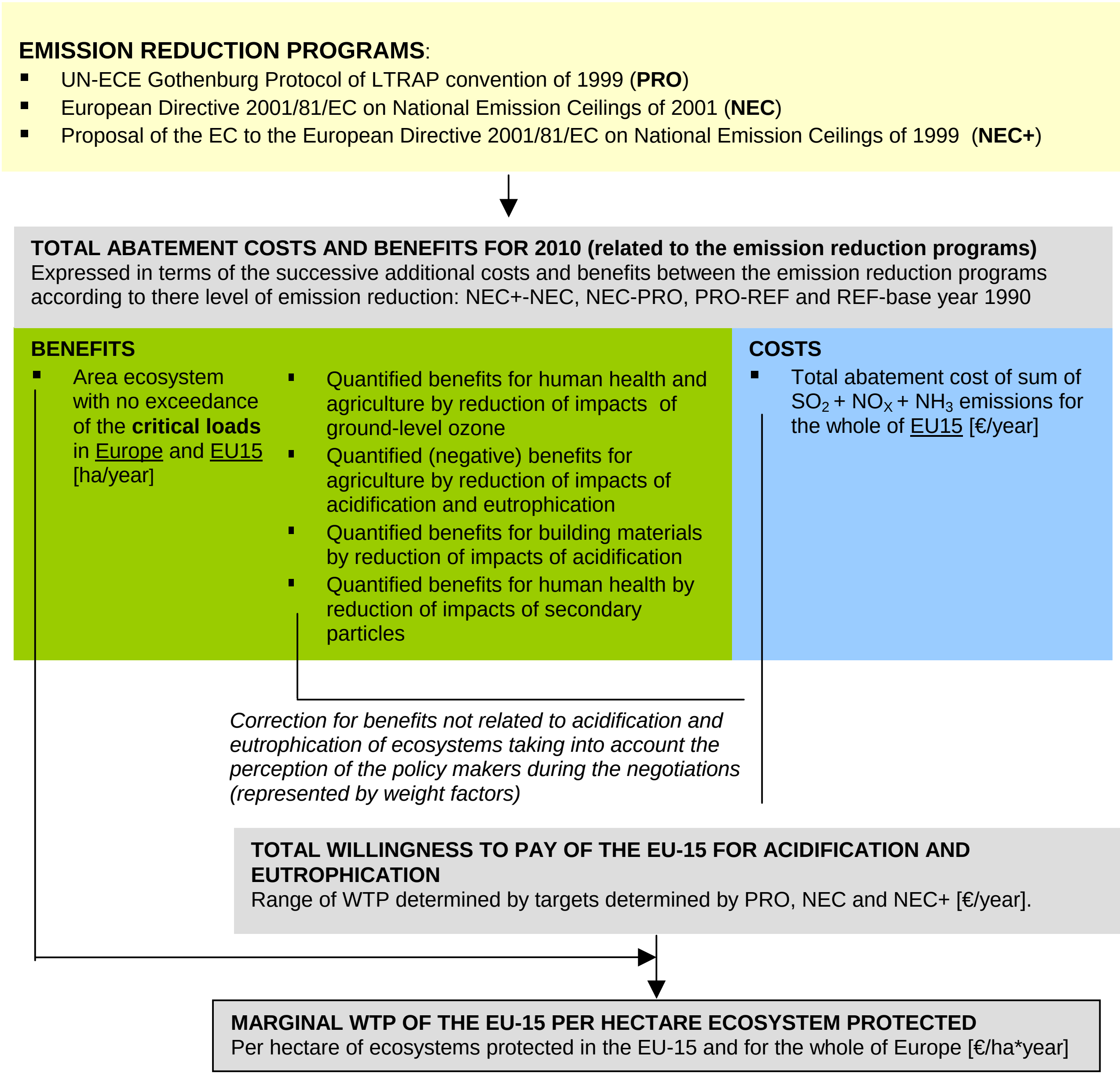

Figure 2: Detail of the stepwise application of step 2 of the analysis

The WTP for improvement of ecosystem health has been determined, based on the abatement costs to be made by the EU-15 and with effects on the hectares ecosystem protected on EU-15 and on European level.

Our best estimate for the WTP per hectare ecosystem protected against acidification and eutrophication has been estimated to range from 60 to 350 €/ha with a best estimate around **100 €/ha*year**, to be applied to all ecosystems protected in Europe (EU-15 + rest of Europe). If we limit the analysis to the ecosystems within the EU-15, this results in a value around 300 €/ha*year.

- **Major parameters and assumptions**

The major parameters and assumptions related to **ecological indicators** are:

- We assume that exceedance of critical loads (CL) is a good indicator for the marginal impacts on ecosystems.
- Our approach demands the expression of CL in terms of hectares because the goals during the negotiations have been defined as such. It would be useful however to extract a WTP in terms of accumulated exceedance of CL and, where available, to use dynamic models.
- We add up exceedance of critical loads for different types of ecosystems, and we add up impacts of acidification and eutrophication.
- Regional differences in critical loads within Europe are not accounted for.

The major parameters and assumptions related to **other impact categories** are:

- Our approach takes into account that the emission reduction programs will generate benefits related to ozone, agriculture and building materials, and that decision makers have taken this into account for their balancing of total costs and benefits.
- We assume that the benefits from the emission reduction programs on health impacts from secondary particles (aerosols) was not reflected in the targets set:
    1. this assumption is based on the analysis of the official text of the Gothenburg protocol and the legal text of the NEC directive.
    2. these benefits got a high uncertainty rating in cost-benefit analyses executed for the Gothenburg Protocol and the initial proposal on the NEC directive.
    3. if public health played a decisive role, and if the numbers were taken into account, policy makers should have decided on tighter emission standards.

The major parameters and assumptions related to **costs indicators** are:

- We assume that the costs as estimated by the technical-economic models are a good indicator for the WTP.
- We do not use marginal costs of single measures but the average costs of a marginal policy package.

The major generic assumptions and those related to **selection of scenarios** are:

- We assume that policy makers of the EU have the same WTP for improving ecosystems health in all Europe, including both EU-15 and non-EU Europe.
- We only look at the issue from an overall European and EU-15 perspective, which does not reflect differences in WTP between countries.

Some may argue that decisions are not based on balancing costs and benefits. This remark is valid as long as it refers to an explicit balancing. However, we are interested in the implicit preferences, as revealed in the decisions taken.

- **Shadow prices for impacts on ecosystems from emissions of SO_2, NO_X and NH_3**

In the last step of the analysis, step 3, we estimate the shadow prices (damage or external costs) for acidification and eutrophication per ton emitted.

We need to integrate our estimate on the marginal WTP in the impact pathway approach in order to calculate the shadow prices. Therefore, the marginal impacts in *physical terms* need to be calculated, i.e. number of hectares of ecosystems for which the critical loads have been exceeded per additional ton of SO_2, NO_X and NH_3 emitted. At this moment, steps have been undertaken to quantify the physical impacts of SO_2 and NO_X on ecosystems on EU level but it is too early to integrate them into the NewExt project, as up to date critical load data has not been available.

Once the shadow prices are calculated, this data can be used to compare energy technologies and fuel cycles, used in the EU. The figures are additive to the ExternE figures, but are best separated, as they reflect another approach.

Although detailed results based on the most recent critical loads data are not yet available, first evidence[4] suggests that, on average for EU-15, these impacts are unlikely to make a major contribution to the total damage cost for power plants in many countries, but may be significant for power plant sites in or near countries or regions with low impacts on human health and relative high impacts on ecosystems (e. g. in Scandinavian countries).

It has to be noted that the figures cannot be used in cost-benefit analysis or policy advice related to the Gothenborg protocol or the NEC directive, as they are based on these policies.

ii) B. Preferences revealed in policy negotiations related to global warming

- **Context and objectives**

Externalities estimated based on the impact pathway approach in ExternE resulted in a best estimate ranging from 0.1 - 16 €/ton of CO_{2equiv}. (Tol and Downing, 2000) However, it remains unclear to which extent these data give a complete picture of the total impact, as a wide number of impacts are not included and for those that are included, uncertainties are large, both for quantification of effects as for the valuation.

Given the uncertainties and incompleteness inherent to these estimates, one can argue that the balancing of costs and benefits in negotiations over targets and/or policy measures may offer a complementary view on how society values the benefits of the first steps in CO_2 control.

4 First estimates are based on critical load data from literature but that are outdated and do not match with the newer UN-ECE dataset used for the support of the Gothenburg Protocol and the NEC Directive (Hettelingh, private communication).

Therefore, in NewExt two approaches based on revealed preferences have been explored. The first is to estimate revealed preferences based on policy targets. A second approach is based on public preferences as revealed in referenda related to energy questions in Switzerland. The latter is discussed in chapter ii.C.

- **A shadow price for CO_2 emissions in Europe**

To estimate the revealed preferences, similar information and data are required as for revealed WTP to limit impacts from acidification on ecosystems, and similar steps in the analysis are required.

The main target at EU level is the Kyoto protocol of 1997, which has been ratified by the EU and its member states in 2002. The European Climate Change Program of 2000 elaborates a roadmap to translate this target into proposals.

The Kyoto protocol defines the target for the EU to reduce greenhouse gas emissions by 8 % by 2008-2012 compared to 1990 emissions, for the EU-15 as a whole. The protocol itself however does not indicate how the target should be achieved. The EU has developed differentiated targets for each member country in order to share equitably the economic burden of climate protection. It reflects that costs and the capacities to carry the costs may differ, as well as society's willingness to take early action. Second, a combination of measures at European and national level is required, including flexible mechanisms like emission trading that will start in 2005. This will allow for a cost efficient reduction of CO_2-emissions for big industrial energy users. In addition, additional measures and targets will be required, e.g. for transportation and household sectors, both at European and national level.

The discussion mainly focused on one GHG, i.e. CO_2. Towards the preparation of the Kyoto protocol, the potential for CO_2 emission reduction in the EU and their costs were well documented. Therefore, it is fair to say that in preparing and implementing Kyoto agreement, these costs were balanced against the benefits. The main benefit of the first steps towards CO_2 control is not only a reduction in damages from global warming, but they also contribute to build a world-wide strategy to combat global warming. In this context, the benefits of meeting the Kyoto target may have a multiplicator effect, as will the costs of not meeting the target.

In the policy process leading to the adaptation of the European Climate Change Program and the proposal for a directive on CO_2 trading mechanism, several studies on the costs of meeting these targets were executed, mostly using energy-economic models. The latest studies for the EU suggest that under a full flexibility EU-wide allocation of least cost sectoral objectives, the marginal abatement cost will be 20 euro per ton. These estimates are based both on top-down and bottom up approaches. A recent review showed that this estimate is in the middle of the wider range of estimates, both from studies and from starting or experimental CO_2-trading schemes (Downing and Wattkiss, 2003). If however each member state will try to fulfil its objectives on its own, the marginal cost for Belgium will increase up to 90 Euro per ton CO_2 (Blok et al., 2001). On the other hand, allowing some kind of trading outside the EU may lower the compliance costs to perhaps 5€ per ton. Consequently, most studies take a figure close to this 20 € per ton of CO_2 as the marginal abatement costs and a proxy for the society's willingness to pay, for Europe. This number is also well below the penalty set in the emission trading scheme (40 € per ton of CO_2 for the first 3 years.), which can be seen as an upper limit for this shadow price.

A number of countries accepted stricter emission reduction targets and took earlier unilateral actions to limit CO_2 emissions. E. g. from analysis of policy targets for the Netherlands and national costs estimates, a shadow price of 50 € per ton of CO_2 equivalent is proposed (Davidson et al., 2002).

Thus, one can argue that the WTP in some countries may be higher. Although the marginal abatement costs for reaching the objectives are available per country, these cannot be taken as a proxy for society's WTP per country, unless more evidence to support such values is available; Although it may be argued that the real WTP will be lower because policy makers are aware of benefits in other areas like energy saving or air pollution, there are no data to correct for this potential effect.

- **Application of shadow prices for CO_2 and greenhouse gases**

An assessment of the costs for achieving Kyoto targets can be interpreted as a proxy for society's willingness-to-pay for early action against global warming. For assessing technologies and fuel cycles in the mid-long term, the best estimate is between 5-20 €/ton of CO_2, with the higher range reflecting the costs if emissions are controlled within Europe. By extension, it can be applied to all greenhouse gases. For application in NewExt case studies, a value of €19 / t CO_{2equiv}. has been selected.

This shadow price for CO_2, based on the marginal abatement costs to meet the Kyoto target, reflects the CO_2-efficiency of energy technologies or fuel cycles. Those that are more efficient will be given credit for this benefit, which allow European society and economies to save costs for meeting the Kyoto target.

When applying this range, some remarks have to be considered. First, it needs to be evaluated on a case-by-case base whether this figure is applicable and whether some kind of CO_2-externality has already been internalized. Within the sectors subject to the emission trading regime (e.g. electricity generation), a price incentive that reflects CO_2-efficiency will be installed from 2005 onwards. The average electricity price for consumers however, may or may not contain a price signal that reflects overall CO_2-efficiency. When comparing technologies on a full fuel cycle base, emissions outside the EU are unlikely subject to price incentives that reflect CO_2-efficiency.

Second, depending on the context, sector or country specific marginal abatement costs may be better then the European marginal abatement cost. This is the case if the shadow price needs to reflect the contribution of that technology or fuel cycle to a specific target at national or sectoral level. This will be especially the case for decisions with a short time impact, and limited to a specific sector or country. The same reasoning goes for shadow prices for other greenhouse gases. On the other hand, if the objective is to reflect some overall shadow price for making (small) progress towards controlling greenhouse gases, the overall marginal European marginal abatement cost for CO_2 is a better proxy, and can be applied to all greenhouse gases. This will especially be the case for decisions with a longer time horizon, and a cross sector or crossborder impact.

ii) C. Public preferences related to global warming revealed in referenda

Decision making in Switzerland differs essentially from decision making in other countries due to strong components of "direct democracy". In many cases, key Swiss policy issues are decided by a national referendum. There have been a number of Swiss national referenda related to the subjects "energy" and "environment". Some included decisions about prices/taxes. Referenda can be viewed as large surveys, which at the same time constitute political decisions.

Within NewExt, results of referenda on energy taxes held in year 2000 have been analyzed. Under plausible assumptions about the underlying WTP distribution, the average willingness of the Swiss population to pay energy taxes per kWh can be estimated. The referenda originally refer to taxes on non-renewable energy consumption in order to favour renewable energy. The change from fossil fuels to renewable energy affects mainly direct CO_2 emissions but not necessarily other pollutant emissions (e.g. NO_x or PM_{10} emission factors for biomass are comparable to those for fossil fuels). Therefore it is plausible to account the WTP per kWh fully to CO_2 as far as emissions are concerned.

The resulting estimates are about 6 to 9 €/ton CO_2 for the geometric mean and about 14 to 22 €/ton CO_2 for the arithmetic mean. The estimate is of the same order of magnitude as the one derived above.

ii) D. Conclusions

The evaluation has shown that under certain assumptions the costs of achieving the well specified targets for acidification, eutrophication and global warming can be used to develop shadow prices for pollutants or specific impacts from pollutants. These shadow prices can be used to reflect these effects for comparison of technologies and fuel cycles.

The analysis shows that a simple analysis may not be correct, i.e. abatement costs for SO_2 and NO_X need to be corrected for other impacts and incentives to internalise CO_2 shadow prices need to be checked carefully. Furthermore, if the EU would decide to strive for more stringent aims than expressed in the Kyoto protocol, this would of course lead to an increase in the marginal abatement costs to be used for assessment.

The figures can be used for comparison of technologies and fuel cycles, similar to e.g. life cycle impact assessment tools, like Eco-Indicator. They cannot be used to evaluate environmental policy objectives related to the thresholds or objectives, that have been used to derive them.

The evaluation has also shown that under certain assumptions, results of referenda related to energy questions can be interpreted as revealed preferences to tackle environmental problems. A first exercise for Switzerland shows that individual preferences to control CO_2 emissions may be of the same order of magnitude as marginal abatement costs for the EU.

ii) E. Recommendations for further research

It is recommended that further studies should focus on up to date data for marginal impacts of emissions on critical loads, in order to have up to date data.

It is recommended that the current data and interpretation schemes are kept up to date with the policy developments related to long-range transboundary pollution and especially climate change.

It is recommended that the approach to extract revealed preferences from referenda is further explored, so that the results of such referenda can be used in a broader policy context.

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iii) ASSESSMENT OF ENVIRONMENTAL IMPACTS AND RESULTING EXTERNALITIES FROM MULTI-MEDIA (AIR/WATER/SOIL) IMPACT PATHWAYS

The goal of this work package was to develop models for the assessment of external costs from priority impact pathways via soil and water, and to apply them to the emission of toxic substances emitted by power plants. Of particular concern are the toxic metals As, Cd, Cr, Hg, Ni and Pb, as well as certain organic pollutants, in particular dioxins. The output of this model is the damage per kg of pollutant, as a function of the site and conditions (for emissions to air: stack height, exhaust temperature and velocity) of the source. The emissions, per kWh, of toxic metals by coal and oil fired power plants are estimated to obtain the resulting contributions to the cost per kWh.

At the start of this work several existing models for the calculation of doses have been considered in detail, in particular EUSES (1997), CalTOX (McKone & Enoch 2002), the model of EPA (1998) for waste incineration, the model of IAEA (2001) for radionuclides, and the Vlier-humaan (VH) multi-media exposure model of VITO. None of these models can be used directly for the calculation of external costs because they do not quantify the total impact of an emitted pollutant but only the impact in a limited region, over a limited time horizon or on a limited population (the most exposed subgroup). Since the external cost should take into account the total impact (expectation value rather than worst case estimate) over all time, all space and the entire population, these models could not be used without major changes..

Therefore the decision was made to develop two new models, based on elements of the above models. The first one, called “uniform world model” (UWM) is based mostly on USEPA, with some supplemental data of IAEA; in its present version it focuses on toxic metals (As, Cd, Cr, Hg, Ni, and Pb) because these are the most troubling emissions of the energy sector. The second model, called WATSON, is an extension of the existing EcoSense model (ExternE 1998) by the integrated WATer and SOil environmental fate, exposure and impact assessment model of noxious substances for Europe (Bachmann 2004). It is a multi-zonal model that links the regional air quality model of EcoSense to a soil and water multi-media model of the Mackay level III/IV type (Mackay 2001).

In addition, the VH model of VITO has allowed us to carry out certain sensitivity studies to get a sense of the reliability of the results of UWM and WATSON.

Finally, to obtain damage cost estimates, one also needs the dose-response functions (DRF) or concentration-response functions (CRF), as well as unit costs of the corresponding end points for the monetary valuation. Here a crucial limitation lies in the paucity of available information. For most substances and non-cancer impacts the only available information covers thresholds, typically the NOAEL (no observed adverse effect level) or LOAEL (lowest observed adverse effect level). Knowing thresholds is not sufficient for quantifying impacts; it only provides an answer to the question whether or not there is a risk. The principal exceptions are carcinogens and the classical air pollutants, for which explicit dose-response functions are known (often on the assumption of linearity). We have found suitable DRFs (WHO 1988-2001, http://www.epa.gov/iriswebp/iris/index.html) for cancers due to As, Cd, Cr, and Ni, as well as for IQ decrement due to Pb (Schwartz 1994), but so far we have not been able to quantify the damage cost due to Hg.

- **The "Uniform World Model" (UWM)**

The starting point for the UWM is the observation that for incremental impacts due to small (compared to background levels) changes in emissions the dose-response function (DRF) can be linearized and, if the parameters of the equations are time-independent, the corresponding total damage can be calculated with equilibrium models (steady state) even though the environment is never in equilibrium. The necessary equations and parameters for the assessment of As, Cd, Cr, Hg, Ni and Pb are obtained from USEPA. The model is a generalization to multimedia of the "uniform world model" for air pollution of Curtiss & Rabl (1996) and Spadaro (1999); it provides typical results for a region rather than for a specific site. Nonetheless it can distinguish, by means of simple correction factors, different kinds of sources such as power plants, industrial boilers and cars.

It accounts for the pathways in Figure 3. We do not consider dermal contact because that pathway has been found to be entirely negligible for these metals. Like the underlying model of EPA we do not consider ground water, assuming that on average inflow and outflow of the pollutant to this compartment are equal. In the same spirit we assume that all drinking water is taken from surface water rather than groundwater. The resulting drinking water dose is an upper bound because it does not account for removal processes during the passage to and from groundwater.

We do not yet have all the elements for calculating the dose due to ingestion of seafood, potentially large because of bioconcentration and because most fish comes from the ocean rather than freshwater. One would need compartment models of all the oceans, coupled with data on fish production. Even if the concentration increment in the sea is very small, the collective dose from seafood could be significant if the removal processes (sedimentation) are slow and the analysis has no cutoff in time. The problem of long time constants also haunts the assessment of pathways that pass through soil. Neither EPA nor IAEA consider the impacts beyond the lifetime of the emitting installation, typically a few decades. Being concerned with total impacts, we present two sets of results: one for the totality of the collective dose, and one for the collective dose incurred during the first 100 years. To allow valuation of the costs beyond the first generation with a lower intergenerational discount rate, we also indicate what fraction of the dose is incurred during the first 30 years after an emission.

The model is fully documented in the paper by Spadaro and Rabl (2003), see also www.arirabl.com. The model has been used for calculating doses, impacts and damage costs due to emission of the most toxic metals: As, Cd, Cr, Hg, Ni and Pb. The paper also presents detailed sensitivity studies and comparisons with measured data and with the CalTOX model.

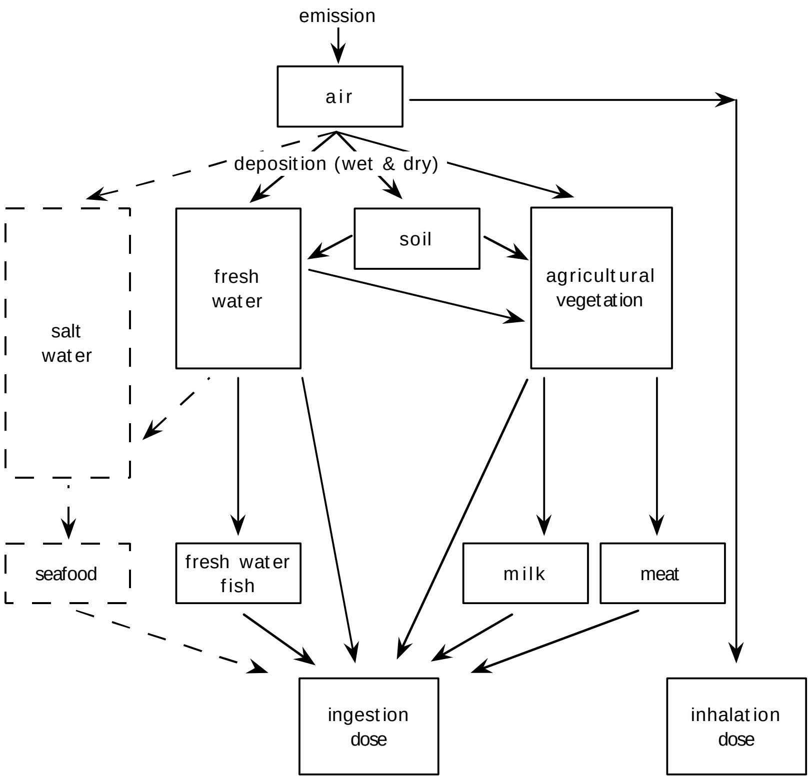

Figure 3: Pathways taken into account by UWM for health impacts of air pollutants. Direct emissions to soil or water are a special case where the analysis begins at the respective "soil" and "water" boxes. In the present version seafood is not yet included.

- **The WATSON model**

The integrated WATer and SOil environmental fate, exposure and impact assessment model of Noxious substances (WATSON) for Europe (Bachmann 2004) can be considered an extension of the software tool EcoSense proposed within the ExternE project (ExternE 1998). In order to allow for a bottom-up impact assessment approach that is in agreement with the impact pathway approach of ExternE, the media soil and water need also to be modelled in a rather spatially resolved way for the whole of Europe.

Especially due to the data demand, the multimedia modelling approach introduced by Mackay has been followed here (Mackay 2001) which is well suited to quantitatively assess average concentrations at the regional scale resulting from highly dispersed and diffused sources (Cowan et al. 1995). It is based on a mass balance that is formulated as a set of linear first order ordinary differential equations. With the help of these models, usually the steady-state solution is computed which assesses the situation when no mass change in any compartment modelled occurs due to continuous release of a substance over longer time periods. The time period until such a steady-state is reached actually depends on the nature of the substance (i.e. the related inputs and outputs with respect to the scope of the model). Therefore, WATSON offers the opportunity not only to calculate a substance's environmental concentration in water and soil as a steady-state concentration (which may serve as an indicator for sustainability if compared to a societal target value) but also dynamically with variable time steps. In addition, the time to reach a specified percentage of the steady-state concentration can be computed in order to get an impression of what time scales we have to deal with under a certain emission scenario. The processes that are covered by WATSON can be divided into different types (Table 5).

Table 5: Process types and related processes in WATSON

Process type	Processes
Transformation	Degradation; decay
Exchange	
- inter-regional	River discharge; circulation of large lakes[a]
- intra-regional	Matrix leaching and *preferential flow;* soil erosion and Hortonian overland flow; sedimentation, resuspension and *sediment burial*; ice melt of glaciers; diffusive exchange between water and sediments
Direct and diffuse input	Dry and wet atmospheric deposition; direct releases into water and soil

[a] if a lake is fully contained in a region it is already assumed to be fully mixed or homogeneous as part of a freshwater compartment according to multimedia modelling practice.

The environmental fate model consists of an existing single-medium air quality model (the Windrose Trajectory Model WTM (Trukenmüller and Friedrich 1995) of the EcoSense software of ExternE) linked to a water and soil multimedia type of model ('air model' and 'water and soil model' bars in Figure 4). The multimedia soil and water environmental fate model divides Europe into about 3400 so called base regions according to the HYDRO1k GIS dataset for basins (USGS 1996). At present no seawater compartment and corresponding sediment are included. Inhalation and ingestion exposure via different exposure pathways are at present considered (Figure 4). Different from inhalation, the exposure via food does not only need to take into account the environmental concentration and the transfer into plants and/or animals but also the trade of the food that contains a substance which causes an adverse effect. For this it is assumed that the food items are equally distributed over the whole area covered by WATSON weighted by the stocks or the produced amounts of livestock and crops, respectively. This approach of course is a generalization of the real path of food products or, on the other hand, of the actual exposure scenario.

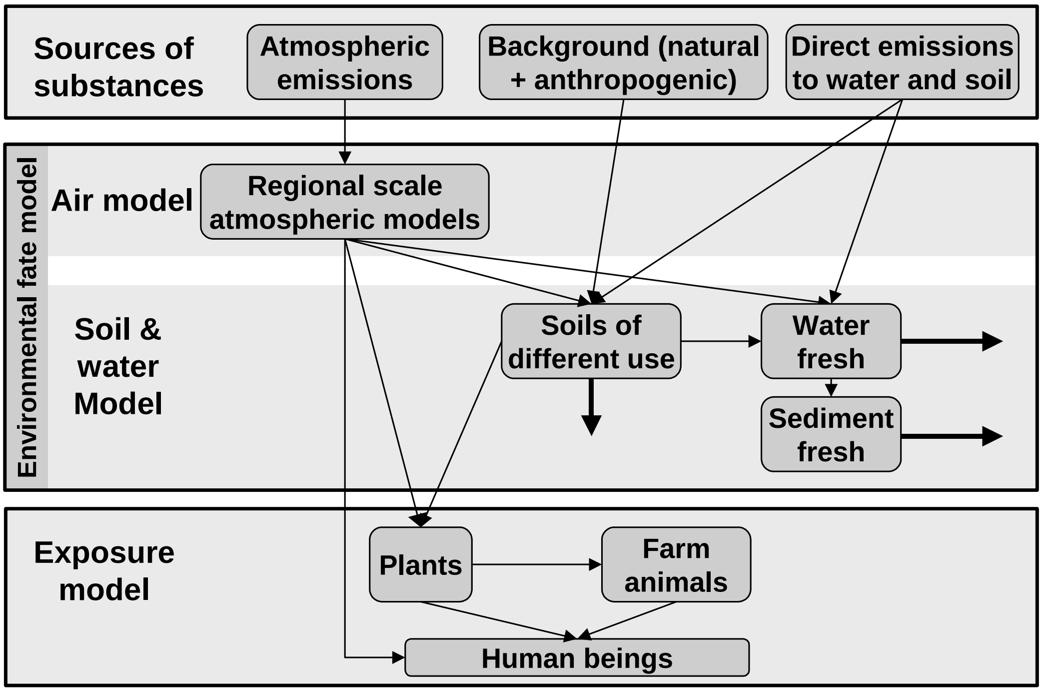

Figure 4: Conceptual structure of the multimedia model including exposure (arrows denote a substance's environmental pathway; bold arrows denote transport beyond the model's scope)

Comparing the WATSON results to those yielded by the UWM is not readily done especially due to the different exposure pathways considered. With both models, however, exposure via cereals seem to dominate the exposure via ingestion whereas (short-term) inhalation exposure only contributes to a few percent to the overall intake fraction (Bachmann et al. 2004), which is a measure of the overall portion of an emission that a population will be exposed to when integrating over infinity (Bennett et al. 2002).

It can be concluded that when ingestion exposure especially of persistent pollutants is considerable very long time horizons need to be taken into account during the impact and/or damage assessment.

- **The VLIER-HUMAAN (VH) model**

Even though the VH model is by concept totally different from the Uniform World Model as well as from the EcoSense-WATSON model, it can provide certain checks. In particular it has been used for a comparison between VH and UWM because parameter values can be more easily adopted from a single-zone model (UWM) than from a rather highly spatially resolved model (EcoSense-WATSON). We have been able to check the ratios of ingestion to inhalation for Cr, Ni and Pb; for Ni it is very consistent between VH and UWM and for Pb reasonably consistent, given the uncertainties. For Cr the agreement is less good, possibly because of differences in the detailed chemical form of the Cr. Furthermore, we have compared some of the key parameters, such as bioconcentration factors.

- **The cost per kg and per kWh**

We have provided estimates for the damage cost, in €/kg, of As, Cd, Cr, Ni and Pb; they are summarized in Table 6. Multiplying them by the emissions data in g/kWh$_e$, one obtains the damage cost per kWh$_e$; they turn out to make a negligible contribution to the external costs of coal and oil fired power plants. The highest share of these is the damage by lead; this amounts to 0.013 €-cent per kWh$_e$ for oil-fired and 0.009 €-cent per kWh$_e$ for coal-fired electric utility plants. For the other heavy metals damage costs are in the range of 10^{-5} to 10^{-8} € per kWh$_e$.

The uncertainties are large, about an order of magnitude in either direction. In general the damage costs yielded by the UWM and EcoSense-WATSON are compatible within the uncertainties. Therefore, we recommend taking both estimates for sensitivity considerations. The assessment of lead and arsenic via ingestion, however, are considered especially uncertain.

Table 6: Damage cost per kg of pollutant

€/kg	UWM	EcoSense-WATSON	Recommended
Arsenic	80		80
of which inhalation	*46.4*	*111*	
Cadmium	19	59	39
Chromium	14 [a]- 23 [b]	44 [a]-71 [b]	29 [a]- 34 [b]
Lead	1633	n/a	1600
Nickel	2.6	5.0	4
Formaldehyde	0.12 [c]		0.12

[a] coal-fired power plants
[b] oil-fired power plants
[c] Inhalation only, CRF of ExternE (2000)

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iv) EXTERNAL COSTS FROM MAJOR ACCIDENTS IN NON-NUCLEAR FUEL CHAINS

- **Background**

The main objectives of this present work package were: (a) to carry out comparative assessment of severe accidents in the energy sector, focusing on non-nuclear energy chains; (b) to assess the external costs associated with severe accidents within the various energy chains. Lack of estimates of external costs of non-nuclear accidents had previously been identified as one of the limitations of the state-of-the-art of externality assessment. The results obtained can support policy decisions and serve as an essential input to the evaluation of sustainability of specific energy systems.

In 1998 ENSAD (Energy-related Severe Accident Database), a comprehensive database on severe accidents with emphasis on the energy sector, was established by the Paul Scherrer Institute (PSI). The historical experience represented in this database was supplemented by probabilistic analyses for the nuclear energy, to carry out a detailed comparison of severe accident risks in the energy sector (Hirschberg et al., 1998). The database allows us to carry out comprehensive analyses of accident risks, which are not limited to power plants but cover full energy chains, including exploration, extraction, processing, storage, transports and waste management. The ENSAD database and the analysis have now been much extended, not only in terms of the data coverage but also the scope of data applications. For the full coverage of work performed we refer to (Burgherr et al., 2004).

- **Database extensions and current status**

The extensions of the ENSAD database and of the scope of analysis have taken place on various levels:

- Information from a variety of commercial and non-commercial data sources was added. Examples include specialized databases covering oil spills as well as dam accidents.
- The time period covered has been extended to reflect the historical experience to the year 2000 (previously it was 1996).
- Small accidents were also addressed though these accidents were not in the original scope of the study.
- Based on PSI's engagement in the China Energy Technology Program of the Alliance for Global Sustainability, it has been possible to gain access to previously restricted information on accidents in China (Hirschberg et al., 2003a; Hirschberg et al., 2003b); records on Chinese accidents were practically unavailable in the past.

- Within the externality assessment valuation of the relevant end-points (such as death and injury, evacuation of population, costs of oil spills) was carried out and the degree of internalisation was addressed.

In ENSAD an accident is considered as severe if any of the following seven criteria is satisfied: (1) At least 5 fatalities or (2) at least 10 injured or (3) at least 200 evacuees or (4) extensive ban on consumption of food or (5) releases of hydrocarbons exceeding 10,000 tons or (6) enforced clean-up of land and water over an area of at least 25 km^2 or (7) economic loss of at least 5 million (in $US\$_{2000}$).

ENSAD contains currently 18,400 accidents. Man-made accidents comprise 12,943 or 70.3% of the total, whereas natural disasters amount to 5,457. A total of 6,404 energy-related accidents corresponds to 34.8% of all accidents or 49.5% of man-made accidents. Among the energy-related accidents 3,117 (48.7%) are severe, of which 2,078 have 5 or more fatalities. Non-energy-related accidents and natural disasters are of second priority within ENSAD. Consequently, the corresponding data are likely to be less complete and of lower quality than the ones provided for the energy-related accidents. Figure 5 shows the number of fatalities world-wide in different types of accidents over a period of more than 30 years.

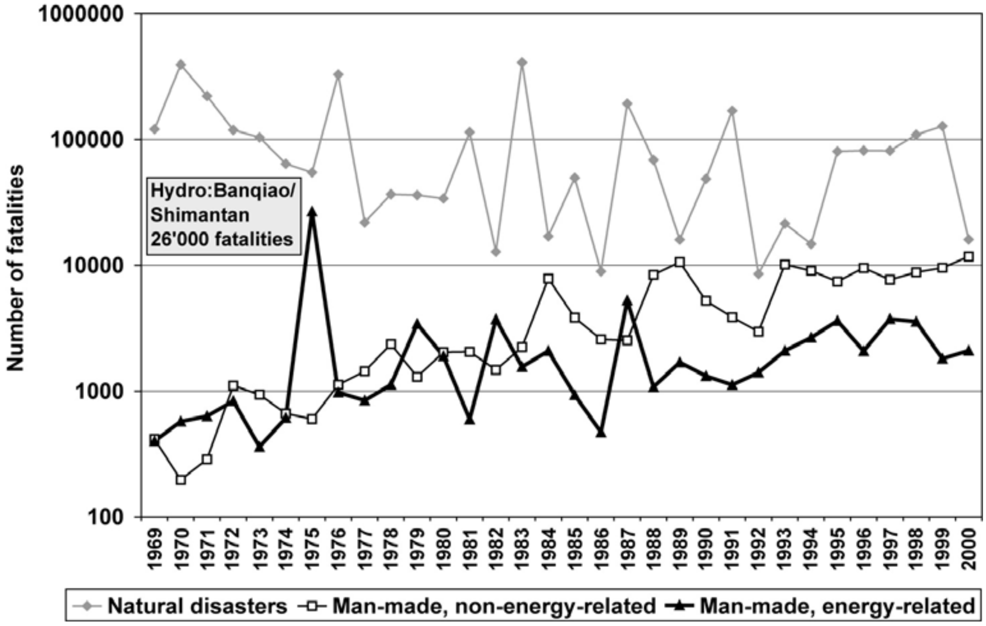

Figure 5: Number of fatalities in severe (≥ 5 fatalities) accidents that occurred in natural disasters and man-made accidents in the period 1969 to 2000.

- **Damage indicators and frequency-consequence curves**

Selected aggregated accident indicators were generated and compared. The approach used accounts for contributions from all stages of the fuel cycles that were analyzed. The comparison of different energy chains was based on normalized indicators combining consequences (e.g. number of fatalities) and product (e.g. electricity generation), and on the estimated accident-related external costs for selected technologies. Figure 6 shows results in terms of affected people per GW_eyr, differentiating between OECD and non-OECD countries[5]. It should be noted that the statistical basis for the indicators for individual energy chains may radically differ. For example, there are 1,221 severe accidents with fatalities in the coal chain and only one in the nuclear chain (Chernobyl).

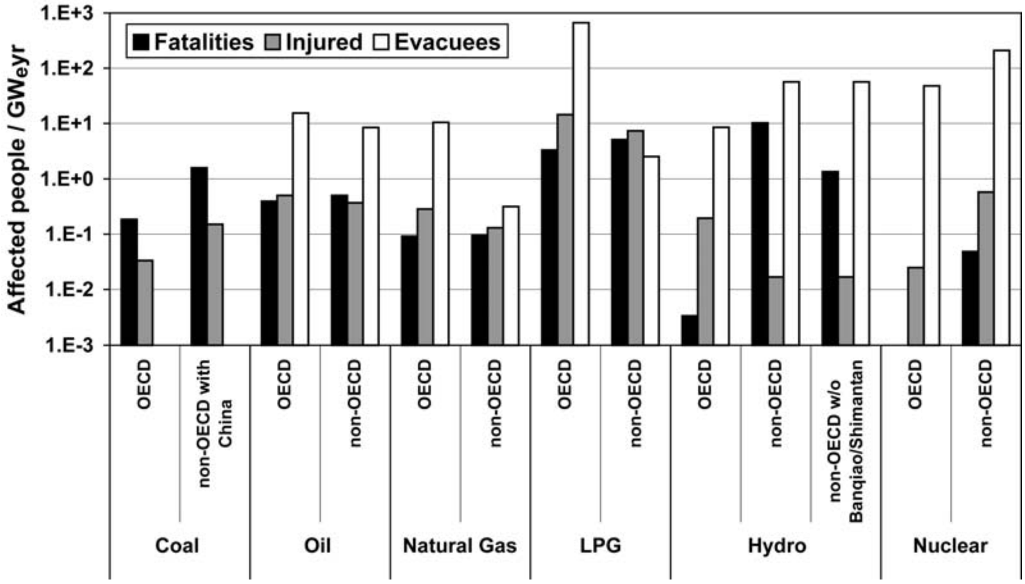

Figure 6: Aggregated damage rates, based on historical experience of severe accidents in OECD and non-OECD countries for the period 1969-2000. The indicators were estimated with partial reallocation of damages to OECD countries taking into account imports of fossil energy carriers from non-OECD countries. Note that only immediate fatalities are shown; latent fatalities will be commented on below.

The frequency-consequence curves for OECD and non-OECD countries are provided in Figures 7 and 8, respectively. Fossil-fuel energy chains in non-OECD countries display a similar ranking as for OECD countries, except for the Chinese coal chain that exhibits significantly higher accident frequencies than in other non-OECD countries. However, the vast majority of severe coal accidents in China result in less than 100 fatalities. Accident frequencies of the oil and hydro chains are also much lower than for the (Chinese) coal chain, but maximum numbers of fatalities within the oil and hydro chains are respectively one and two orders of magnitude higher than for coal and natural gas chains.

5 Corresponding results were also obtained for EU-15. With the exception of hydro power, they show no major differences compared to those for OECD-countries. As the latter have a broader statistical basis they are also considered to be representative for EU-15. Specifically for hydro power there were no severe accidents in EU-15 during the period of observation. This also further strengthens the need for implementation of a simplified probabilistic approach for hydro. A framework for this has been outlined in this work package.

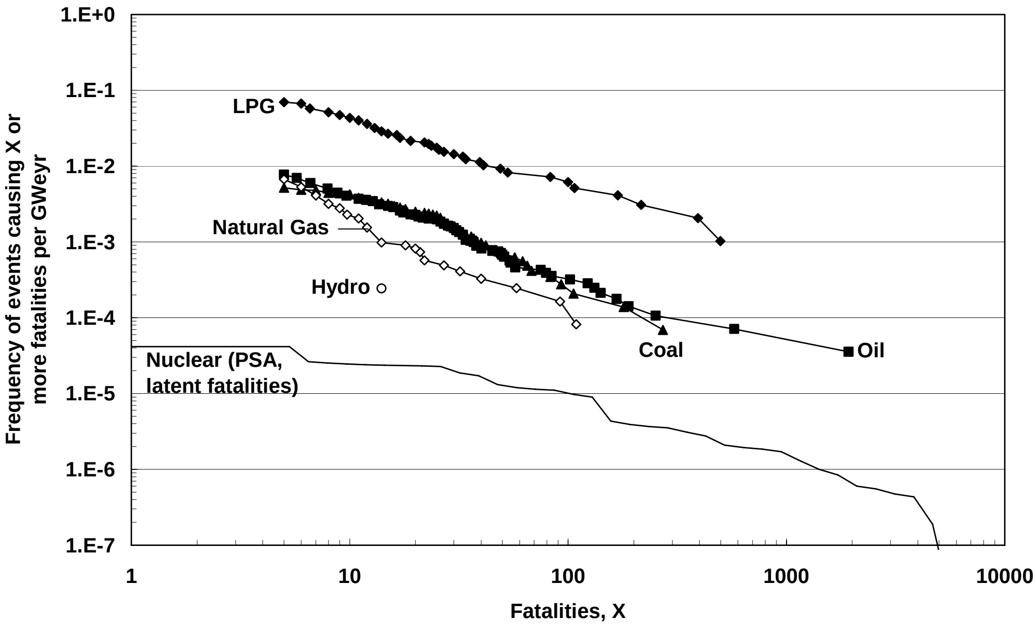

Figure 7: Comparison of frequency-consequence curves for full energy chains in OECD countries with partial reallocation for the period 1969-2000. The curves for coal, oil, natural gas, liquefied petroleum gas (LPG) and hydro are based on historical accidents and show immediate fatalities. For the nuclear chain, the results originate from the plant-specific Probabilistic Safety Assessment (PSA) for the Swiss nuclear power plant Muehleberg and reflect latent fatalities.

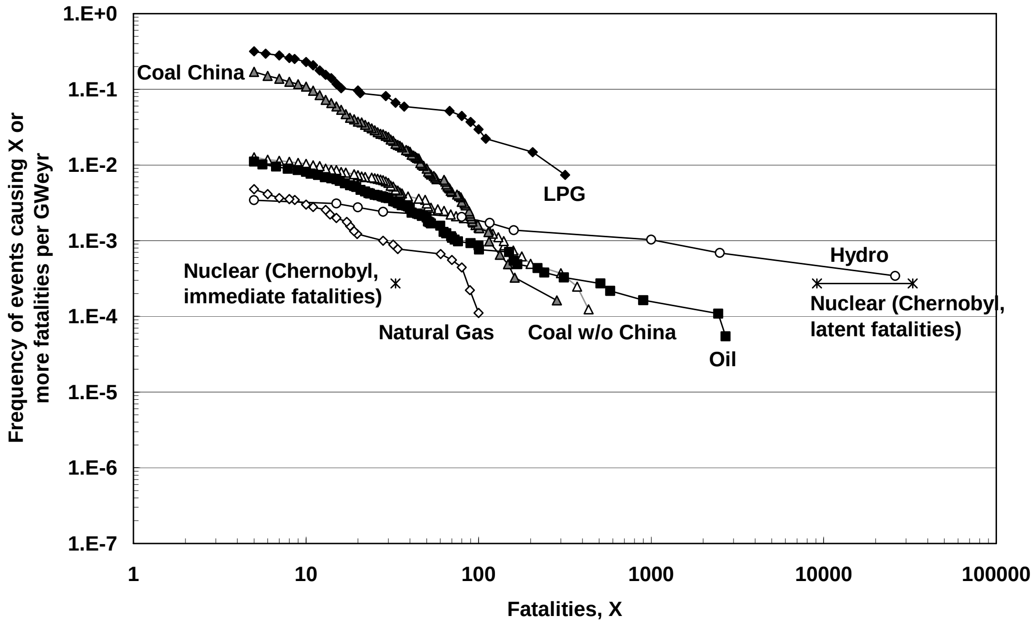

Figure 8: Comparison of frequency-consequence curves for full energy chains in non-OECD countries with partial reallocation for the period 1969-2000. The curves for coal w/o China, coal China, oil, natural gas, LPG and hydro are based on historical accidents and show immediate fatalities. For the nuclear chain, the immediate fatalities are represented by one point (Chernobyl); for the estimated Chernobyl-specific latent fatalities lower and upper bounds are given.

Expectation values for severe accident fatality rates associated with the nuclear chain differ strongly between the two cases displayed in Figures 7 and 8. The maximum credible consequences of nuclear accidents may be very large, i.e. in terms of fatalities comparable to the Banqiao & Shimantan dam accident that occurred in China in 1975. However, the large differences between Chernobyl-based historical estimates and probabilistic estimates for Muehleberg illustrate the limitations in the applicability of past accident data to cases which are radically different in terms of technology and operational environment. In this sense the Chernobyl accident is in fact also not representative for currently operating plants in non-OECD countries.

- **Damage costs and external costs of severe accidents**

Damage costs and external costs of severe accidents in different energy chains were estimated, based on the unit cost values for the various types of consequences. Unit values for fuel cycle accident end-points were derived, expressing the welfare impacts of accidents in the non-nuclear energy supply chain in monetary terms in order to enable calculation of the external costs of such accidents. End-points include: premature death (with or without hospitalisation); physical injury; mental trauma e.g. from physical injury or evacuation; evacuation (costs of resettlement/accommodation); clean-up/repair costs and willingness to pay (WTP) for recreational/ecosystem losses from oil spills; a ban on consumption of food; land contamination, and other economic losses. Our methodology and findings for each of these categories are summarized below.

For workplace accidents we first looked at studies that estimate the wage-risk trade-offs (and other factors that affect wages) to estimate wage differentials related to different mortality risks. However, a number of difficulties were found to be associated with this method, including (a) inaccuracy of the risk data; (b) omitted variables bias and endogeneity; (c) the issue that the dependent variable (wage) is explained by, among others, the risk variable. As a consequence, estimates using this approach were not judged to be sufficiently robust. For a central value we therefore used the results of a context-free study undertaken within the work package of the NewExt project dealing with mortality valuation across three EU countries; this gave a value of statistical life (VSL) of €1.045 million. Use of this value is supported by a study by Carthy et al. (1999) in the transport accident context, which identifies a central WTP for risks of approximately €1 million.

For non-fatal injury, using average values found in the empirical literature, we weighted the risk value for severe injuries at 13% and for minor injuries at 1% of the risk value of fatalities. We then estimated the degree to which these costs are internalized in producer costs, either through *ex ante* wages that account for fatality risks, through ex post compensation to families of the victim or out of the work-place where insurance internalizes the cost. On the basis of available evidence we established plausible ranges for the degree of internalisation that could be assumed for different world regions in these contexts.

A literature search provided estimates of evacuation costs from the US, but not from the context of the non-nuclear fuel cycle. Two studies, one from the context of a simulated radioactive evacuation, the other from the hurricane evacuation context estimated unit values for this end-point. However, these estimates did not include an element for the disutility of suffering evacuation though this is thought likely to be substantial. Resettlement costs associated with the construction of dams exist, though these are in relation to countries outside the EU. Comparison, of these is, however, limited by inconsistency with regard to the cost elements included in estimates for individual dams. For this reason, robust unit values are difficult to recommend and we therefore make no unit value recommendations for this impact end-point.

The welfare impacts of oil spills are likely to be determined by the scale of the spill, the ecological services that the impacted area supports and the scale and nature of "human" related services affected in the area. The wide discrepancy between contexts and welfare components considered in studies that have valued oil spills persuades us that value ranges have to be used in any benefit transfer associated with this impact category. The lower value, derived from the Sea Empress incident is in fact supported by evidence from a number of oil spills in the Caspian Sea that have resulted in average damage costs of €2,600 per ton.

Estimates were made for the welfare impacts of a ban on consumption of food though these were judged to be too context specific to be transferable to the energy fuel cycle. For the same reason, contamination and other economic losses were not given unit values.

It is clear that the evidence to support estimation of unit values for many of the impact categories considered is either of poor quality, of wide variance or non-existent. As a result, unit values are presented in terms of ranges. These ranges would have to be used in full in subsequent policy analysis for the results to have credibility. Table 7 summarizes the monetary valuation results obtained for the end-points considered.

Table 7: Summary of unit values for fuel cycle accident end-points (in €$_{2002}$), provided for various levels of internalisation (expressed in parentheses).

	Central	Minimum	Maximum
Value of a Statistical Life	1,000,000	400,000	3,310,000
Occupational fatalities			
Central OECD (80%)	200,000	80,000	662,000
Lower internalisation OECD (70%)	300,000	120,000	993,000
Upper internalisation OECD (100%)	0	0	0
Central Non-OECD (50%)	500,000	200,000	1,655,000
Lower internalisation Non-OECD (0%)	1,000,000	400,000	3,310,000
Upper internalisation Non-OECD (100%)	0	0	0
Occupational injuries			
Central OECD (80%)	14,000	5,600	46,340
Lower internalisation OECD (70%)	21,000	8,400	69,510
Upper internalisation OECD (100%)	0	0	0
Central Non-OECD (50%)	35,000	14,000	115,850
Lower internalisation Non-OECD (0%)	70,000	28,000	231,700
Upper internalisation Non-OECD (100%)	0	0	0
Public fatalities			
Central OECD (50%)	500,000	200,000	1,655,000
Lower internalisation OECD (30%)	700,000	280,000	2,317,000
Upper internalisation OECD (70%)	300,000	120,000	993,000
Central Non-OECD (20%)	800,000	320,000	2,648,000
Lower internalisation Non-OECD (0%)	1,000,000	400,000	3,310,000
Upper internalisation Non-OECD (50%)	500,000	200,000	1,655,000
Public injuries			
Central OECD (50%)	35,000	14,000	115,850
Lower internalisation OECD (30%)	49,000	19,600	162,190
Upper internalisation OECD (70%)	21,000	8,400	69,510
Central Non-OECD (20%)	56,000	22,400	185,360
Lower internalisation Non-OECD (0%)	70,000	28,000	231,700
Upper internalisation Non-OECD (50%)	35,000	14,000	115,850
Evacuation			
Fixed costs per household	144	108	180
Daily costs per household	168	88	248
Oil spills - welfare costs per ton of oil	2,600	2,300	24,000

Table 8 shows the damage and external costs for immediate fatalities associated with sample energy systems and the associated fuel cycles, obtained on the basis of historical experience with accidents in OECD and non-OECD countries. Since the costs in table 8 only cover immediate fatalities it is of interest to relate them to the accident damage costs based on PSA for the Swiss nuclear power plant Muehleberg, which are dominated by the costs of latent fatalities. The mean value has been assessed at 1.2E-3 US-cents/kWh_e, with 5-th and 95-th percentiles at 1.0E-4 and 3.8E-3 US-cents/kWh_e; these results include damage costs of non-health effects (Hirschberg et al., 1998).

The assessed costs of injuries and evacuations are based on a less complete statistical basis than those for fatalities and are generally much less significant than the latter. The central estimate of oil spill damage costs is 3.7E-3 €-cents(2002)/kWh_e for OECD and 5.5E-3 €-cents(2002)/kWh_e for non-OECD, with the maximum estimates one order of magnitude higher. Other types of economic damages due to accidents were assessed and expressed in terms of damage costs; these may be significant in some cases but the basis is too heterogeneous to allow a reasonably consistent comparison.

Table 8: Summary of full chain damage costs and external costs (€-Cents(2002)/kWh_e) of severe accidents with at least five immediate fatalities; the reference coal, oil and natural gas electricity generating plants have efficiencies of 40, 31 and 53%, respectively. Value of a Statistical Life (central value) = 1.045 million Euro.

Energy chain	Reference countries	Damage costs in €-Cents(2002)/kWh_e			External costs in €-Cents(2002)/kWh_e		
		Occupa-tional	*Public*	*Total*	*Occupa-tional*	*Public*	*Total*
Coal	*OECD*	1.7E-3	1.2E-5	1.7E-3	3.4E-4	6.1E-6	3.5E-4
	non-OECD w/o China	6.5E-3	4.3E-5	6.5E-3	3.2E-3	3.5E-5	3.3E-3
	China (1994-1999)	1.2E-2	ng[3]	1.2E-2	6.1E-3	ng[3]	6.1E-3
Oil	*OECD*	9.9E-4	9.0E-4	1.9E-3	2.0E-4	4.5E-4	6.5E-4
	non-OECD	1.8E-3	1.1E-2	1.3E-2	9.1E-4	8.7E-3	9.6E-3
Natural gas	*OECD*	2.2E-4	4.4E-4	6.6E-4	4.5E-5	2.2E-4	2.6E-4
	non-OECD	3.3E-4	5.9E-4	9.2E-4	1.6E-4	4.7E-4	6.3E-4
Hydro	*OECD*	ng[3]	4.1E-5	4.1E-5	ng[3]	2.0E-5	2.0E-5
	non-OECD	ng[3]	1.2E-1	1.2E-1	ng[3]	9.8E-2	9.8E-2
	non-OECD w/o Banqiao/Shimantan	ng[3]	1.6E-2	1.6E-2	ng[3]	1.3E-2	1.3E-2
Nuclear	*OECD[1]*	ng[3]	ng[3]	ng[3]	ng[3]	ng[3]	ng[3]
	non-OECD[2]	5.7E-4	ng[3]	5.7E-4	2.9E-4	ng[3]	2.9E-4

[1]Based on PSA for the Swiss plant Muehleberg [2]Based on the Chernobyl accident [3]ng = negligible

- **Conclusions**

- Comprehensive historical experience of energy-related severe accidents is available and can be used as a basis for quantifying the corresponding damages and external costs. Small accidents are strongly under-reported but their contribution to external costs appears to be quite small.
- Energy-related accident risks in non-OECD countries are distinctly higher than in OECD countries. The results obtained for OECD-countries are also representative for EU-15.
- The results for OECD and non-OECD countries can be thus regarded as a lower and upper limit: For a European power plant that buys coal or oil from non-OECD countries, the attributable risks occur to certain shares within OECD but also non-OECD countries.
- Hydro-power in non-OECD countries and upstream stages within fossil energy chains are most accident-prone.
- Expected fatality rates are lowest for western hydropower and nuclear power plants. This results in low associated external costs. However, the maximum credible consequences are very large. The corresponding risk valuation is subject to stakeholder value judgments.
- The damages caused by severe accidents in the energy sector are substantial but quite small compared to those caused by natural disasters. External costs associated with severe accidents are quite insignificant when compared to the external costs of air pollution.
- Future comparative work on severe accidents should comprise: (a) Maintenance and further extensions of accident database; (b) Improvements of specific indicators (e.g. land contamination, economic damages); (c) Implementation of a simplified Probabilistic Safety Assessment for hydro power; (d) Use of a simplified state-of-the-art PSA-approach applied to several representative designs and European sites.

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v) REVISION OF EXTERNAL COST ESTIMATES

It has been beyond the scope of this project to provide a general update of the extensive database on previous external cost estimates, but nevertheless an indication is given on how existing external cost estimates will be affected by using the new or extended methodology developed in this and former projects. The new methodological elements of NewExt have been applied to a small set of key technologies that include coal and oil fired plant and combined cycle plant using natural gas in four countries of the EU.

Since technologies have developed more rapidly in the renewable energy sector than for fossil power plants, it does not make much sense at this point (as originally planned in this project) making new calculations for those photovoltaic plants and wind turbines that have been assessed in the National Implementation phase – the criticism might arise to have used unfavourable results of renewable energy systems that are now far from being today's state of technology. In the ongoing project ExternE-Pol, however, one focus is the life-cycle analysis of several new and future technologies especially including renewables.

It has to be emphasised that the project is dedicated to show the outcomes of the improved methodology. This means, that the same specifications of the power plants, e.g. emission data, as for the National Implementation in 1997 (except some additional updated data for power plants in France for comparison), have been used, although the emissions of the power plants of course would have been changed for several reasons. So, the differences in the results of the National Implementation in 1997 and the new calculations lead to some general conclusions on how the new methodology affects current external cost estimates.

There has been more than one step of improvements of the methodology between National Implementation and now, especially during the projects ExternE CoreTransport (Friedrich and Bickel 2001), followed by GREENSENSE (European Commission 2003).

- **Changes between ExternE National Implementation and the state of the art of NewExt**

Several changes in methodology have been made during these project phases between National Implementation and NewExt and implemented into the EcoSense software. In the following the major changes are listed:

- New background emission data from 1998 (EMEP and Corinair) and meteorological data instead of the 1990 data
- Change of the grid cell system from Eurogrid (100 km x 100 km) to EMEP50 grid (50 km x 50 km), which covers a larger area with 19 % more population.
- New, slightly updated weighting factors for the CO_2-equivalents of CH_4 and N_2O, based on IPCC (2001) for 100 years
- Use of the figure of €19 / ton CO_{2equiv} for the evaluation of global warming damages (marginal costs of controlling carbon emissions in Europe) compared to a large range of damage costs used before (the “restricted” inner range used to be €18 to €46 / ton CO_{2equiv} in 1990 prices).
- Changes of important exposure-response functions before and during the phase of NewExt. They are based on results of several projects; the latest of these was DIEM that ran parallel to NewExt (Hurley 2003). The functions refer to the primary pollutant PM_{10} and the secondary pollutants nitrates and sulphates. The changes as a whole are shown in the following Table 9. There has been a decrease of exposure-response function factors for chronic mortality, chronic bronchitis, and other respiratory health impacts, dependent on the type of pollutant causing the effect, and increases only for cough of asthmatics caused by PM_{10} and sulphates.

Table 9: Changes of exposure-response functions (ERF), described as quotient of ERF factors with the NewExt methodology (2004) versus National Implementation (1999)

Pollutant / Human health impact	PM_{10}	Nitrates	Sulphates
Chronic mortality	0.82	0.41	0.5
Chronic bronchitis	1	0.5	0.63
Cough of asthmatics	2	1	1.20
Other respiratory health impacts	1	0.6	0.5

The main change directly due to the insights of the NewExt project has been the update of monetary values: As a direct consequence of the improved methodology for the monetary valuation of mortality impacts from air pollution, gained by the questionnaire survey in Great Britain, France, and Italy, the monetary values for ‘acute years of life lost’ and ‘chronic years of life lost’ have been updated. Due to the survey results, the new values used are 50,000 €(2000) for chronic mortality and 75,000 €(2000) for acute mortality. Therefore, the component of human mortality in the results has become smaller than in previous phases.

For global warming damages, in the National Implementation phase an “outer” and “inner (or restricted)” range of damage costs were used that show a large spectrum of potential damages. The inner range is spanned by the mid values for a discount rate of 1 % and 3 %, based on the two models FUND and OPEN FRAMEWORK, the outer range by further sensitivity analysis of critical parameters and Monte-Carlo-simulation. In the following tables, for the sake of lucidity and comparableness, only the “mid value 3 %” is shown, that establishes the low bound of the restricted range and uses damage costs of 18 € (at this time still called ECU for European Currency Unit) per ton of CO_2. This is nearly identical to the 19 € (2000) abatement costs per ton CO_2 used now although the approach to get this value is completely different.

The external costs for accidents derived in NewExt are too low to have an influence on the external cost estimates. The same holds for the external costs due to heavy metals via ingestion and inhalation.

- **National Implementation and NewExt results for the different fuel cycles**

The following table 10 shows the overall comparison of the results gained in the ExternE National Implementation phase (European Commission 1999) and those with all the updates since then including the NewExt methodology. Results for the step in between (i.e. the “before NewExt” status used in the GREENSENSE project), where parts of the changes described above have already been realized, have also been calculated. They are shown in the extended version of the final NewExt report, as well as the distribution of external cost results according to the components

- Human health / global warming / others (crops and materials damage)
- Power generation itself versus other fuel chain stages.

Table 10: Results of the coal, oil and natural gas fuel cycles, ExternE National Implementation (1999) and NewExt methodology (2004) [€-Cent/kWh]

	Site, size [MW]	Technology	Subtotal National Implementation (1999) 1)	Subtotal NewExt (2004)
Coal Fuel Cycle				
Be	Genk, 300	No FGD nor SCR	**12.3**	**6.33**
Be	Genk, 300	With FGD and SCR	**3.7**	**3.00**
Fr	Cordemais, 600	Pulverized fuel, FGD (hypothetical), steam turbine	**6.9**	**5.03**
Fr	Cordemais, 600 (new data)	Pulverized fuel, FGD (actually installed), steam turbine	nd	**3.34**
Ge	Lauffen, 652	Pulverized fuel, FGD, DENOX, and dedusting	**3.0**	**2.61**
UK	West Burton, 1800	Coal-fired station with FGD	**4.2**	**2.53**
Oil Fuel Cycle				
Fr	Cordemais, 700	Low S oil, steam turbine	**8.4**	**5.50**
Fr	Cordemais, 700 (new data)	Low S oil, steam turbine	nd	**4.45**
Ge	Lauffen, 157	Gas-turbine peak load power plant	**5.1**	**3.30**
UK	Fawely, Hampshire (south coast), 528	Combined cycle oil-fired power station	**3.3**	**2.14**
Natural Gas Fuel Cycle				
Be	Drogenbos, 467	Combined cycle gas turbine	**1.1**	**0.85**
Fr	Cordemais, 250	Hypothetical new plant, combined cycle gas turbine	**1.9**	**1.55**
Fr	Cordemais, 400 (new data)	Hypothetical new plant, combined cycle gas turbine	nd	**0.83**
Ge	Lauffen, 791	Combined cycle	**1.2**	**0.93**
UK	West Burton, 652	Combined cycle gas turbine (CCGT)	**1.1**	**0.80**

1) National implementation results included occupational health, which was not taken into respect in later ExternE phases. For global warming damages, mid values of damage costs for an underlying discount rate of 3 % have been used.

Remark: It has to be emphasized that the results shown may not be representative for the respective technology or the corresponding country. Rather, the results shown in Table 10 display the evaluated external cost of one special plant at a special location; the emissions are those assumed in the National Implementation Project, and thus do not reflect the actual emissions of such plants. The results shown in this report are dedicated to show the impacts of the improvements in methodology from the state-of-the-art of the National Implementation to the state-of-the-art due to the findings in NewExt on the results.

- **Discussions and conclusions**

From the results shown in Table 10 the following conclusions can be drawn:

For the investigated technologies, the updated methodology including the NewExt improvements leads in sum to smaller results compared to the results of the ExternE National Implementation. This is caused mainly due to changes of dose-response functions for human health and the lower value of a life year lost gathered from the questionnaire survey. A comparison of the contribution to the results in detail shows that the impacts on human health morbidity and human health mortality have sometimes increased and sometimes decreased, depending on the composition of the emissions. Furthermore other improvements have contributed to the change. In previous times the creation of nitrates was overestimated. Due to the better solution of the underlying grid (smaller grid cells) and the updated background emissions of NO_x, SO_2 und NH_3 the EcoSense model now calculates less nitrates. Moreover, a model, which accounts for tropospheric ozone due to NO_x and NMVOC, is now implemented; with this model more accurate results for impacts due to ozone are calculated.

Thus, the sum of the external costs caused by different impact categories and the exact ratio of the results calculated with the different methodologies depend on the composition of the pollutants and the location of the power plant.

Depending on the respective technology the external costs vary in the investigated countries up to a factor of three, the gas fuel cycle having in general very low external costs. This result, i. e. the ranking of different technologies at a site, remains stable, no matter whether the old or improved methodology is used.

Summary

Based on a survey in three countries in the European Union, new values to assess the value of a statistical life (of 1.05 Mio. € as central value and 3.3 Mio. € as upper bound) and the value of a life year lost (75 000 €, upper bound 225 000 €) have been derived.

By analyzing the decisions of policy makers and in addition public referenda, shadow prices for global warming (ca. 5 to 22 € per ton of CO_2) and exceedance of critical loads for eutrophication and acidification (ca. 100 € per hectare of exceeded area and year with a range of 60 – 350 €/ha * year) have been developed.

The analysis of pathways of substances in air, water and soil made it possible to include the damage caused by the release of further substances into the framework for calculating external costs. Damage costs per kg of emitted pollutant of 80 €/kg for arsenic, 39 €/kg for cadmium, 29-34 €/kg for chromium, 1600 €/kg for lead, 4 €/kg for nickel and 0,2 €/kg for formaldehyde have been estimated.

The analysis of severe accidents in the non-nuclear fuel chains revealed, that the external costs associated with fatalities caused by these accidents are very small for power plants operated within EU-15: 0.0003-0.0007 €-cent/kWh for fossil fuels, 0.00002 €-cent/kWh for hydropower; in non-OECD countries external accidents costs could be up to 0,1 €-cent/kWh for hydropower.

The use of these findings for estimating external costs leads to certain changes in results. For coal-fired plants, figures based on the new methodology are between 13 and 49 % lower than those calculated with the methods applied in the ‘National Implementation’ project phase of ExternE. The ranking of different technologies however does not change when using the improved methodology.

- **References**

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vi) FURTHER RESEARCH NEEDS FOR EXTERNE

The research of this project has shown that almost all elements of the ExternE methodology need to be further improved and updated. Some of these will be addressed by the project NEEDS going on in the 6th Framework Program.

- **Global warming**

This subject is so vast and complex, with such rapid accumulation of new knowledge, that the need for further research is obvious.

- **Atmospheric dispersion and chemistry**

The models of atmospheric dispersion and chemistry used by ExternE can be improved and updated due to new insights to further increase the credibility of the results.

- **Health impacts**

The assessments need continual updating because of the intense worldwide research on air pollution epidemiology. The monetary valuation of health impacts also needs to be improved, especially for mortality and chronic bronchitis.

- **Damage to buildings and materials**

The inventories of buildings and materials need updating, and so do the dose-response functions. A major gap is the valuation of damage to buildings and monuments of cultural value.

- **Acidification and eutrophication**

The monetary valuation is still very uncertain; furthermore critical loads data are not freely available. Other methodologies should be explored.

- **Amenity impacts**

Whereas the valuation of noise is well developed, the reduction of visibility is a potentially very significant impact that has been neglected by ExternE so far. The cost of visual intrusion has not yet been addressed either.

- **Land use**

Land use, for example by surface mines or by roads, can have very severe ecosystem impacts that should be evaluated.

- **Supply security**

Some work is being done in ExternE-Pol, but it will not be sufficient.

- **Other issues**

For several impact categories quantification in monetary terms is very difficult, if not meaningless, in particular the storage of waste, nuclear proliferation and risks of terrorism. Alternative approaches may have to be explored for the internalization of such impacts.

IV OTHER INFORMATION AND DISSEMINATION ACTIVITIES

Beside the project website of NewExt (http://www.ier.uni-stuttgart.de/newext/) established at the beginning of this project for internal and external information and communication, a permanent website http://www.externe.info/ with more general information about the ExternE project series has been built up at the beginning of 2002. It has been and will further be extended for this purpose (within the concerted action DIEM) in order to contain all information about methodology and existing results. This web site http://www.externe.info/ also forms the backbone of the dissemination activities; all available publications will be provided as electronic versions for a better diffusion of relevant results. Some of them are already available at http://www.externe.info/reports.html.

All these activities have been the task of work package 7, the dissemination of the project. The objectives to make the new methodological elements available to the scientific community and to the end users of the EU external costs accounting framework have been met by the four workshops having taken place within the concerted action DIEM - see the elaborate description at the website http://www.externe.info/diem.html that also includes all contributions of the workshops for stakeholders and end users for download.

Papers describing project results have also been submitted to a series of scientific conferences and journals for review and dissemination. See in detail the technology implementation plan.