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Part 1: Publishable Final Report

1.1. Executive publishable summary

This project is the continuation of the ExternE project series for the analysis of the external costs of energy. Its objectives are:

- Improving, validating and extending the methodology of ExternE;
- Providing an assessment of new technologies for energy systems;
- Implementing the methodology in the accession countries of Eastern Europe;
- Creating a permanent internet site for ExternE.

Several significant improvements of the ExternE methodology have been achieved. They concern:

- Dose-response functions for health impacts and for crops;
- Monetary valuation of chronic bronchitis, visibility, damage to cultural monuments, and energy supply security;
- Choice of background emissions for the atmospheric modeling;
- Inclusion or exclusion of impacts upstream or downstream of the power plant, depending on whether and how they have already been internalized.

Most of these improvements have not yet been implemented in the current version of ExternE because they are arriving too late for inclusion in the final report for the NewExt project [ExternE 2004]. In choosing the optimal moment for the publication of new results one has to weigh the risk of being out of data with the risk of confusion by too many different numbers.

A framework has been developed for using multicriteria analysis to quantify impacts whose monetization has remained problematic. It involves stakeholders or environmental experts, asking them for their ranking of different impacts. A preliminary test has been carried out to estimate monetary values for acidification and eutrophication. The results are promising but not yet sufficiently reliable for use.

The LCA inventory for the emission of pollutants has been updated to correspond to the energy technologies in use in 2000, and external costs have been calculated for a wide variety of advanced energy technologies, including advanced photovoltaics.

The ExternE methodology has been implemented in the new EU countries of Central and Eastern Europe, and external costs have been calculated for power production in the Czech Republic, Hungary and Poland and for transport in the Czech Republic.

1.2. Publishable synthesis report

The calculation of external costs of energy is a very difficult and complex activity, involving a wide range of different types of expertise from atmospheric modeling to environmental policy analysis. The main elements of the methodology have been developed and applied in preceding phases of ExternE, but continual improvements are required

- to extend the range of impact categories that are covered,
- to take into account the continual progress in the various scientific disciplines,
- to reduce the uncertainties,
- to clarify fundamental issues that have not yet found an adequate resolution.

The ExternE-Pol project has therefore provided several significant improvements and extensions of the ExternE methodology. The dose-response functions for health impacts have been brought up-to-date, based on advice by epidemiologists and toxicologists. As a result the impacts of particulate emissions have increased, those of NOx and SO2 decreased somewhat relative to previous calculations. Major uncertainties remain with regard to the toxicity of sulfate and especially nitrate aerosols, but a framework has been established for continuing interaction with a panel of epidemiologists and toxicologists to reduce these uncertainties.

Consultation of experts on crop damage due to air pollution has confirmed the validity of the general approach and most of the dose-response functions used by ExternE, and for some crops the functions have been updated for ozone damage.

Since chronic bronchitis has been found (by ExternE as well as analogous studies in the USA) to make the second largest contribution to the total cost, after mortality, it has been re-examined, to make sure that the dose-response function and the monetary valuation are reliable and consistent with each other. The dose-response function used by ExternE has been confirmed. A new assessment of the contingent valuation (CV) studies for chronic bronchitis has come up with a unit cost of 200,000 €, only slightly larger than the value assumed so far.

The monetary valuation of visibility reduction and of damage to cultural monuments has been reviewed but the available data do not yield sufficiently reliable unit costs for use by ExternE at this time. External costs due to energy supply security have been analyzed. A range of values is suggested; they do not make a large contribution to the total.

Several important contributions have been made to validate the atmospheric modeling of ExternE. Experts have been asked to evaluate the approach taken by ExternE. Upper and lower bounds on the calculations of the dispersion module have been established by means of a Monte Carlo analysis, taking into account the probability distributions of the uncertain input parameters. EcoSense calculations have been compared with a recent and more detailed model, and for a few cases where measured data were available, they have been compared with EcoSense calculations; in all cases the agreement has been satisfactory. A large number of model runs have been carried out to evaluate the sensitivity of EcoSense to several critical input parameters and data.

An examination of the nonlinear variation of impacts with the background emissions used for the atmospheric modelling has found that these emissions should be much closer to the social optimum than the inventories used until now. Since the optimal emission levels are not known (although certainly much lower than current levels), the process is iterative.

Since there is a movement toward internalization of external costs, especially in Scandinavian countries with pollution taxes, the current practice of including LCA impacts upstream and downstream of a power plant has been re-examined. It turns out that such impacts should no longer be included if their damage costs have already been internalized by an optimal pollution tax or by tradable permits that are auctioned by the government.

A framework has been developed for using multicriteria analysis to quantify impacts whose monetization has remained problematic. It involves stakeholders or environmental experts, asking them for their ranking of different impacts. A preliminary test has been carried out to estimate monetary values for acidification and eutrophication. The results are promising but not yet sufficiently reliable for use at this time.

The LCA inventory for the emission of pollutants has been updated to correspond to the energy technologies in use in 2000, and external costs have been calculated for a wide variety of advanced energy technologies, including advanced photovoltaics.

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Part 2: Detailed Final Report

2.1. Objectives and strategic aspects

The internalization of external costs has been recognized by the European Commission to be one of the key tools for the implementation of sustainable development, and the ExternE accounting framework for the external costs of energy is increasingly used to give policy advice on the national and international level. It is therefore crucial for this framework to be reliable and sufficiently complete. Even though the main elements of the methodology have been developed and applied in preceding phases of ExternE, continual improvements are required

- to extend the range of impact categories that are covered,
- to take into account the continual progress in the various scientific disciplines,
- to reduce the uncertainties,
- to clarify fundamental issues that have not yet found an adequate resolution.

The ExternE-Pol project provides therefore several major contributions to the assessment of external costs of energy by:

1) Improving and extending the methodology of ExternE,
2) Providing an assessment of new technologies for electricity, heating and transport,
3) Implementing the methodology in the Czech Republic and Poland, and
4) Improving the dissemination of the results by creating a permanent internet site for ExternE.

2.2. Scientific and technical description of the results

2.2.1. Improving the Methodology

2.2.1.1. Introduction

During this project a more systematic framework has been established for updating the concentration-response functions for health impacts, and after a review of the literature and discussions with experts the functions for several end points have been updated. The concentration-response functions for crops have likewise been validated and revised where necessary. The monetary valuation of chronic bronchitis, the second largest impact, has been re-evaluated and slightly revised, and the valuation of reduced visibility, of damage to monuments and of transmission lines has been reviewed. In addition, during the course of this work two fundamental issues have been recognized that may necessitate modifications in some calculations: one concerning the accounting for impacts upstream or downstream of an activity such as electricity production by a power plant, the other concerning the calculation of marginal damage for nonlinear impacts (prompted by the negative ozone damages that have been reported for many emission sites in recent years by ExternE).

2.2.1.2. Concentration-response Functions for Health Impacts

2.2.1.2.1. Framework for updating the functions

To begin, a mathematical framework has been formulated. It is convenient to write the incremental impact ΔI, for a particular end point, as a linear combination of the contributions of the individual pollutants, each with CRF (concentration-response function) slope s_i and concentration increment Δc_i

$$\Delta I = \sum s_i \, \Delta c_i \quad .$$

The Δc_i are calculated for each location where there is human population, and the impacts are summed over all locations to obtain the total for the entire region that is affected.

For the ExternE reports of 1998 and 2000 the assumption was made that the toxicity of all sulfates is equal to that of PM2.5 and the toxicity of particulate nitrates equal to that of PM10. This distinction between sulfates and nitrates was based only on size, noting that nitrates need other particles to condense on, whereas sulfates self-nucleate and are therefore smaller on average. The ratio of CRF slopes $s_{PM10}/s_{PM2.5}$ was taken as 0.6, because this is a typical value of the ratio of concentrations of PM2.5 and PM10. The composition and toxicity of primary PM emitted by different sources can be quite different; for example, automotive PM is almost entirely organic or carbonaceous whereas PM from coal combustion contains in addition a sizable portion of minerals. Since the available emissions data are simply stated in terms of PM mass, the best one can do is distinguish different typical PM compositions according to their source. ExternE treats power plant emissions as PM10 and vehicle emissions as PM2.5. In terms of the above equations one can summarize the assumptions of ExternE 1998 and 2000 for the health impact ΔI due to a concentration increment Δc_i as

for the ExternE reports of 1998

$$\Delta I = s_{PM10}\,\Delta c_{PMpower} + s_{PM2.5}\,\Delta c_{PMtrans} + s_{PM2.5}\,\Delta c_{sulf} + s_{PM10}\,\Delta c_{nitr} + s_{O3}\,\Delta c_{O3} + s_{SO2}\,\Delta c_{SO2} + s_{CO}\,\Delta c_{CO} + \text{other}$$

where

$\Delta c_{PMpower}$ = concentration due to primary combustion PM from power plants,

$\Delta c_{PMtrans}$ = concentration due to primary combustion PM from transport, and

"other" = analogous terms for carcinogens such as benzene.

For the current version of ExternE the assumptions about the toxicity of the different PM types have been changed after a careful review of the latest epidemiological and toxicological literature. Evidence has been accumulating to underline the high toxicity of combustion particles and especially of particles from internal combustion engines. For the secondary particles the evidence is less convincing. In particular for nitrates there is still not much evidence for harmful effects, whereas for sulfates quite a few studies, including the very important cohort study of Pope et al [2002], do find associations. Therefore ExternE now treats

- nitrates as equivalent to 0.5 times the toxicity of PM10;
- sulphates as equivalent to PM10 (or 0.6 times PM2.5)
- primary particles from power stations as equivalent to PM10;
- primary particles from vehicles as equivalent to 1.5 times the toxicity of PM2.5.

In equation form this can be written as

for the ExternE results of 2004

$$\Delta I = s_{PM10}\,\Delta c_{PMpower} + 1.5\,s_{PM2.5}\,\Delta c_{PMtrans} + s_{PM10}\,\Delta c_{sulf} + 0.5\,s_{PM10}\,\Delta c_{nitr} + s_{O3}\,\Delta c_{O3} + s_{SO2}\,\Delta c_{SO2} + s_{CO}\,\Delta c_{CO} + \text{other.}$$

For chronic mortality (the dominant end point in terms of costs) the CRF has been revised on the basis of the cohort study of Pope et al [2002], assuming a relative risk of 1.05 (for 10 $\mu g/m^3$) as the average to the two values 1.04 and 1.06 reported in their paper.

To formulate a better approach for ExternE, we add modifying factors f_i in front of each term $s_i\,\Delta c_i$. The CRF slopes s_i are set equal to the associations reported by the respective epidemiological studies for a particular health end point (using best estimates, preferably by means of a meta-analysis). The values of the modifying factors f_i , together with estimates of their confidence intervals, are chosen by consensus of epidemiologists and toxicologists in an attempt to obtain the most probable estimate of the health impact. Thus the f_i indicate with what weight the corresponding CRF should be counted (they could also be called causality factors because they express the extent to which the associations are considered causal). If a pollutant, for instance CO, is considered not to be causally linked to an end point, one sets the corresponding factor equal to zero, $f_{CO} = 0$ in this case. We also add terms for additional pollutants to allow for the possibility that they could have an effect, for instance NO2 for which quite a few European studies report significant associations.

So far the epidemiologists whom we have contacted have not provided their estimates of the weighting factors, but discussions are continuing. In particular A. Rabl co-organized a symposium on this subject at the 2004 ISEE (International Society for Environmental Epidemiology) Congress in New York to stimulate interest in this problem.

2.2.1.2.2. Impacts of Nitric Acid

The effect of assumptions about the toxicity of HNO3 was tested by comparing the results of two hypotheses:
1) only particulate nitrates are harmful (ExternE standard assumption),
2) all nitrates, including gaseous HNO3 (nitric acid), are equally harmful.

For this the atmospheric dispersion module of EcoSense was adapted to report HNO3 concentrations in addition to the particulate nitrate species (NH4NO3, other NO3 adsorbed to particles). Then the accumulated exposure was calculated for the standard species and the standard species plus HNO3 for three power plants analyzed in previous ExternE projects:

- Lauffen (DE) coal
- Lauffen (DE) gas
- West Burton (UK) coal

If HNO3 is considered in addition to the particulate nitrate species, the health impacts from nitrates increased by 16% for the Lauffen coal plant, 12% for the Lauffen gas plant and 35% for the West Burton coal plant. The larger effect for the West Burton plant in comparison with the Lauffen plants is mainly due to different locations (influencing above all the population affected and the background concentrations of precursor species).

Generally the contribution of HNO3 appears to be small, probably because its deposition velocity is much larger than for particulate nitrates and therefore greatly reduces the geographic range of the impact. In view of the overall uncertainties of health effects due to nitrates the role of HNO3 seems to be relatively minor.

2.2.1.3. Exposure -Response Functions for Crops

2.2.1.3.1. Questionnaire for Experts

A questionnaire about the methodology used by ExternE for agricultural losses due to air pollution formulated and distributed online to external experts. The main conclusions of the experts were:

- Opinions are mixed about the continued use of the AOT40. Nevertheless it is clear that stomatal uptake is at present the preferred methodology of most experts.
- Most experts feel that the functions used for wheat and especially barley will overestimate ozone impacts because water stress is not taken into account.

- Most experts think that potato will react differently to ozone than wheat because the nature of the damages (seeds, tubers and foliar damage) are quite different.
- Damage to other cereal species can be estimated with a modified wheat function.
- Most experts think that the total damage can be quantified with ExternE functions. Opinions on the sensitivity of maize and sugar beet are mixed, no one thinks these crops are completely resistant.

2.2.1.3.2. The AOT40 Approach

There has been a very fast evolution in the field of modelling ozone impacts since the publication of the latest ExternE-reports. Experts are particularly sceptical when exposure-response (ER) functions are applied under different climatological conditions because of the modifying effects of temperature, vapour pressure deficit and soil moisture deficit. Most recent results indicate that the spatial pattern of AOT40 in Europe and the spatial distribution of ozone stomatal fluxes for different species are different. Effect in e.g. Mediterranean countries may have been overestimated. However it is at the moment not clear how this would change total impacts.

Some conclusions from the working group that convened in Harrogate (June 2002) state that there is now "*…general agreement that the flux approach represents an improvement on the AOT40 index*." And also that the "*….AOT40 approach is not appropriate for estimates of actual damage and as such should not be used to perform estimates of economic losses attributable to ozone*". On the other hand working group 2 concluded that: "*The AOT40 …had provided a useful indicator of damage to crops and in the absence of other methods proven to be superior,* ***still has value*****"?**

As a conclusion we can say the methodology used by ExternE to estimate ozone impacts on crops was state-of-the-art until last year. In view of the changing methodology (flux based) it is necessary to update the ExternE methodology in the future.

2.2.1.3.3. AOT40 Based Exposure-Response Functions

The sensitivity of Wheat, a major crop throughout Europe, was confirmed. Different functions than for wheat now exist for other crops (meta-analysis by Mills et all [2003]). See Table 1 for a comparison with the functions in the Ecosense software.

Table 1. Percentage yield loss per AOT40 ppm.h and crop price. "Old" = used by ExternE until now, "New" = revised after review by experts.

	Old ER function	New ER function	Old price €/tonne	New price €/tonne
Barley	0-1,5	0	54	93
Oats	0,9	0	56	132
Potato	1,7	0,6	82	113
Rice	0,9	0,4	2744	199
Rye	0,9	0	156	99
Sugar Beet	0	0,6	48	64
Sunflower	1,7	1,2	235	273
Tobacco	3,4	0,5	39020	2895
Wheat	1,7	1,7	96	137

2.2.1.3.4. Monetary Valuation

Prices of most crops have changed significantly in recent years Table 1. Prices of very important crops such wheat and potato have gone up. Prices of tobacco and rice seem to have dropped by an order of magnitude, but were probably wrongly used in ExternE due to a mix-up of prices per tonne and per decitonne. However this would not markedly change the total since these crops are of lesser importance.

2.2.1.3.5. Conclusion for Crops

Based on these findings several changes will be made, including:

- Quantify ozone impacts on sugar beet because stock at risk data for this crop are available from Ecosense and it is a major crop in many European regions
- Set ozone sensitivity of barley, oats and rye to 0.
- Decrease sensitivity for sunflower, potato and rice
- Update monetary values

As a result of all proposed changes wheat becomes even more dominant in the total because of higher prices, whereas the share of potato diminishes because the price increase does not completely offset the lower exposure-response function. The changes for all the crops taken together offset each other so that the effect on the total damage is extremely small.

2.2.1.4. Monetary Valuation

2.2.1.4.1. Chronic Bronchitis

There are questions about the approach that has been used by ExternE for the quantification of chronic bronchitis (CB). It is important to resolve them because this end point is the second largest contribution to the total damage cost, due to the high unit cost that has been assumed. The first question concerns the wide range of severity of different cases of CB. The CRF (concentration-response function) has been based on the study of Abbey et al [1995], but the symptoms in this study are very light (persistent cough or phlegm during at least two months) compared to the severity levels implicit in the only available monetary valuation studies [Viscusi, Magat & Huber 1991, and Krupnick & Cropper 1992]. While some cases are mild and temporary, CB can be a truly debilitating permanent condition, making it impossible to work or lead a normal life. The monetary valuation of Viscusi et al was based on severe cases, with a questionnaire that was applied to the general population. Krupnick & Cropper 1992 used a slightly modified version of the questionnaire of Viscusi et al, but by contrast they applied the questionnaire only to individuals who knew someone with CB. Assuming that their sample was representative, the results of Krupnick & Cropper thus implicitly assume the average distribution of severity levels.

The assumptions about severity levels must be consistent between CRF, background rates and monetary valuation. As for the CRF, the study of Abbey et al yields the RR (relative risk) for an increase in CB due to an increase in ambient concentration. Looking at RR results of a large number of epidemiological studies, one finds that the RR per concentration is fairly similar across a wide variety of morbidity endpoints. This suggests that the RR of Abbey et al is likely to be appropriate even for other severity levels. Data for incidence rates are presumably for the average distribution of severity levels. With these plausible assumptions the CRF, background rates and monetary valuation are thus consistent if the latter is based on Krupnick & Cropper. The values found by these authors seem more realistic than those of Viscusi et al because someone familiar with CB is better qualified to indicate a willingness-to-pay (WTP) to avoid the condition than someone who lacks this experience.

One difficulty in applying the paper of Krupnick & Cropper is that their primary purpose was the development of the valuation methodology rather than the provision of numbers that could be used for policy. Their tables contain many different unit costs, for the two variants of the questionnaire that the authors tested and the trades (risk-risk or risk-income) offered for the WTP solicitation. The numbers in the tables range from $0.53 million to $1.6 million for the medians. But the only value explicitly mentioned in their text is $0.4 million; it is based on the risk-risk trade where the risk of CB is traded against the risk of dying, combined with a VSL of $ 2 million (chosen by the authors to convert the risk tradeoff to monetary values). If one takes the ratio of these values for CB and VSL, together with the new VSL of ExternE [2004] of 1.0 M€, one obtains the unit cost of CB as 0.2 M€. No adjustment for inflation or exchange rate is needed because the costs of Krupnick & Cropper are used only as ratio.

There are other possibilities for extracting a unit cost from Krupnick & Cropper and/or Viscusi et al, for example the method used by USEPA [Abt 2000] who obtain a WTP to avoid CB of $0.33 million. But that necessitates an assumption about the frequency distribution of severity levels and adjustments for inflation (and, for the transfer to Europe, the exchange rate). For ExternE we recommend the value of 0.2 M€ because we find its derivation better justified and more transparent. It is very close to what ExternE has used in the past (0.17 M€ in 2000).

2.2.1.4.2. Other Impacts

The monetary valuation of visibility, cultural and historical heritage, and transmission lines has been reviewed; this is described in the detailed report, available at the ExternE web site. For the reduction of visibility due to air pollution fairly reliable values are available in the USA, but in view of serious questions about their transferability to European conditions and the lack of any specific European studies, we have not included this impact category in the current calculations of ExternE.

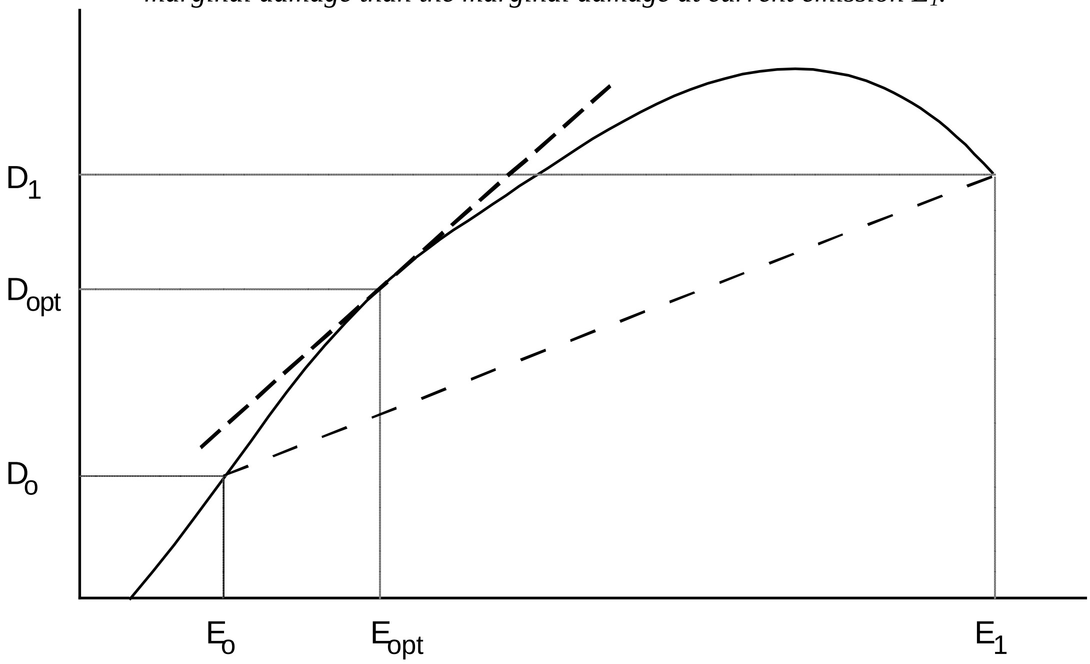
The valuation of damage to buildings of cultural and historical value has also been reviewed. Since an explicit direct valuation (based on values for specific buildings or monuments) does not appear feasible at the scale needed for ExternE, the recommendation is made to follow the approach that Rabl [1999] used for the valuation of damage to buildings in France. However, lacking sufficiently complete data on public expenditures in this sector in other countries, no results have been calculated so far.

The impacts from Transmission lines have also been reviewed, but so far there remains a gap for studies that measure the WTP for avoiding the imposition of transmission lines at all, in a given landscape.

2.2.1.5. Calculation of Marginal Damage for Nonlinear Impacts

The goal of ExternE is to estimate marginal damage costs because the socially optimal level of pollution control corresponds to the point where the sum of marginal damage cost and marginal abatement cost equals zero. However, if this seemingly simple statement is interpreted carelessly it could lead to absurd policy recommendations for impacts that are a nonlinear function of the emission. To illustrate this problem, consider Fig.1 which shows a pollutant whose damage increases with emission at low emission levels but decreases again if the emission is high. Such a situation actually occurs with O3 impacts as a function of one of the precursor emissions, NO (note that most NOx is emitted as NO). The case of O3 damage due to NO is the most extreme (complicated even more by the strong dependence of the curve on the other precursor VOC), but the problem also occurs in milder form with aerosols created by NOx and SO2 emissions.

Fig.1. Pollutant whose damage D increases with emission E at low levels but decreases again if the emission is high. Slope of thick dashed line is the appropriate marginal damage, i.e. at optimal emission (unknown). Slope of chord from pre-industrial (E_0, D_0) to current (E_1, D_1) would be a better estimate of the appropriate marginal damage than the marginal damage at current emission E_1.



With a careless interpretation one would find a negative marginal damage (tangent at the current emission level E1), implying that the policy response should be to encourage even greater emission of this pollutant. Such a policy response would miss the real optimum at Eopt. To provide the correct information to policy makers, one needs to examine carefully what the marginal damage costs will be used for and how they should be calculated. In fact, the correct calculation depends on the use of the results.

Probably the most important use of ExternE is the formulation of policies (e.g. pollution taxes or tradable permits) to reduce the emissions to their social optimum. For this application the key observation is that the optimization condition (marginal damage cost + marginal abatement cost = 0) requires knowledge of these marginal costs in the vicinity of the optimal emission level. Both the damage cost and the abatement cost can vary with emission site, and so does the optimal emission level. Ideally a policy maker should know the entire cost curves for marginal damage and abatement at each site. In the case of NOx, SO2 and VOC the damage costs are complicated site-dependent functions of not only the pollutant under consideration but also the simultaneous emission of several other pollutants with due consideration of all of their respective emission sites. The optimization requires the solution of the coupled optimization equations.

Of course this poses a problem in practice since ExternE is supposed to provide single numbers rather than complicated functions, to say nothing of the computational difficulties of determining the complete functions. If one wants a single number, it should be reasonably close to the value at the optimum. This begs the question since the optimum is not known.

The best one can do is to proceed iteratively. With an initial guess of the optimal emission levels one can derive a first estimate of the appropriate marginal damage costs. Comparing them with the abatement costs one can then improve the estimation of the optimal emission levels. In view of the uncertainties of the abatement costs (if they are known at all in the required range) the estimates of the optimal emission levels are likely to remain very rough, with the ensuing additional uncertainties of the marginal damage costs that ExternE should provide.

As starting point one could take the estimates of optimal emission levels by Rabl, Spadaro & van der Zwaan [2004], who find that the emissions of NOx and of SO2 should be reduced to levels between 0.2 and 0.8 times (depending on pollutant and country) their level in 1998. But the estimation of optimal levels would have to be extended to VOC and NH3, with due attention to the coupling between VOC and NOx through their contributions to O3 formation. Since the EcoSense calculations for ExternE have so far used emissions inventories for 1994 or more recently for 2000, they certainly should be redone.

The optimal NOx emissions are much more uncertain than those for SO2, for several reasons. Not only is the damage cost due to nitrate aerosols uncertain because of the lack of information on their toxicity, but the optimum depends also on the damage costs due to O3, because the optimization for NOx involves setting the marginal abatement cost equal to the total marginal damage cost, not the individual cost components due to nitrates and ozone. The O3 damage due to NOx depends in turn on the background emissions of VOC. So far the optimal emission levels for VOC have not been estimated, and in any case iterations would be needed because of the coupled nature of the equations.

To conclude, the marginal damage costs of ExternE have to be calculated with emissions inventories that are much closer to the optimal emission levels than what has been done until now. That will have a major effect on the results. Since the optimal emission levels are not known, the process is iterative. Fortunately there seems to be a fair amount of tolerance to errors in the determination of the optimal emissions, so even an initial estimation of the optimum may suffice for the purpose of calculating the damage costs of ExternE.

2.2.1.6. Internalization of External Costs and LCA Impacts Upstream or Downstream

ExternE has been using LCA in combination with IPA (impact pathway analysis) to get a complete assessment of external costs due to electricity production, including impacts that occur upstream and downstream of the power plant itself. That practice requires a modification if the external costs upstream or downstream have already been completely internalized. Of course, that is not the case at the present time for most pollutants and in most countries (SO_2 in Sweden being a good counter example).

The need to include upstream or downstream impacts in the external cost calculations arises from the lack of complete internalization by the current environmental policies. If an external cost that arises upstream or downstream has already been internalized by an optimal pollution tax (i.e. a tax equal to the marginal damage) or by tradable permits that are auctioned by the government, it should be no longer be included – otherwise there would be double counting when the results are used, for example in a cost-benefit analysis or to determine the pollution tax for the power plant. On the other hand, for external costs that have been internalized by tradable permits that are free, the residual damage has not been paid by the polluters and should be included in the analysis.

And, of course, the contributions upstream or downstream should be indicated separately, to avoid misuse when the results are used for regulations that concern a power plant. For example, it would not make sense to tax a power plant for damage caused by a coal mine in a different country (if all polluters had to pay a tax corresponding to the full LCA impacts, there would be double taxation).

2.2.2. Energy Supply Security

2.2.2.1. Introduction

We define energy security as “a state in which consumers and their governments believe, and have reason to believe, that there are adequate reserves and production and distribution facilities available to meet their requirements in the foreseeable futures, from sources at home and abroad, at costs which do not put them at a competitive disadvantage or otherwise threaten their well-being. Insecurity arises as a result of physical failure of supplies or as a result of sudden and major price changes” [Belgrave 1987 cited in Lockwood 1997].

In the recent past there have been a number of disruptions in supply and in the price of energy. This has led to more focused attention to the concept of ‘energy security’. Most notably, the European Commission Green Paper of 2002 concentrates on the need for reduced energy import dependence in order to reduce energy insecurity. This research responds to that policy need.

For European policy makers, energy security is an important issue because private decisions on energy use do not fully take into account the costs of energy insecurity. Disruptions in supply and dramatic price increases have macroeconomic impacts that individuals/firms do not take into account. Furthermore, agents tend to underestimate the risks of disruption and subsequent price adjustments, and there are other less tangible effects such as the psychological costs of people feeling insecure about their energy supplies

Therefore, it is important from a policy perspective, to estimate the size of the external costs of energy arising from energy insecurity. It is useful to distinguish between two types of externalities that generate external costs: *technological externality* – when the actions of an economic agent affect the welfare of another, other than by affecting prices; and a *pecuniary externality* – when the actions of one economic agent affects the welfare of another through price changes. Even though energy shocks can involve physical disruptions, the impact of these also comes through dramatic effects on price. Therefore, the external costs associated with insecurity of energy supply can said to include both technological and ‘pecuniary’ externalities.

2.2.2.2. Methodology

Previous work has identified three potential kinds of externality associated with energy security: monopsony wedge, incomplete rent capture and macroeconomic externalities. This research found major limitations in techniques available for measuring the first two types in quantitative terms. For this reason, and because this research suggested that macroeconomic externalities were likely to be dominant, we focus on this type in the current research.

Below, we report on a literature review of the impacts of energy insecurity relating to oil, gas, coal and electricity supply on the basis of which we move towards estimation of the ‘externality unit values’ for energy insecurities. The majority of empirical work has been in relation to oil and electricity supply, and our work reflects this. However, in order to compare alternative energy sources and technologies it would be important to have quantitative estimates for other energy sources. As far as the evidence allows, we report estimates for all energy sources. As part of this project, some development work was undertaken on the design of a survey that would estimate willingness to pay for economic agents to avoid energy insecurity risks. Insufficient co-funding was available to carry out the survey and this is therefore flagged for future research.

We also report on a policy modelling exercise that was undertaken to identify appropriate policy instruments for the internalisation of energy insecurity into energy pricing.

2.2.2.2. Causes of Energy Insecurity

In order to understand the policy context in which energy security externalities are positioned, it is useful to be able to categorise the sources of energy insecurity. These categories may include:

- Large changes in price (anticipated and unanticipated), due to physical interruption (as illustrated in Fig.2 below);
- Physical interruption (e.g. terrorism / conflict in Middle East).

Furthermore, there are different types of shocks: *random shocks* e.g. terrorism; and *strategic shocks* e.g. OPEC manipulating the quantity and therefore price of crude oil. Both these shocks ultimately lead into significant changes in energy prices, and this is the focus of the next section.

2.2.2.2.1. Oil

It should be noted that there is considerable discussion, [e.g. in Bohi and Toman 1996], about what aspects of the macroeconomic costs constitute externalities. The following provides a review of theoretical and empirical investigations into the macroeconomic effects of oil price shocks. However, these do not distinguish between internalized and externalized costs. These gross costs therefore provide an 'upper bound' to the externality component of energy insecurity [Sanchez 1995]. We make a distinction between two types of price movement that have a bearing to energy security: sudden increases in price and volatility of oil prices.

Increase in Price

A review of the theoretical literature suggests that there are a number of channels that could contribute to an inverse relationship between oil prices and economic activity. For example, IMF [2000] proposes five channels through which higher oil prices might affect the global economy: transfer of income from oil consumers to producers; rise in costs of production of goods and services due to increases in price of inputs; inflation; direct and indirect impacts on the financial markets, with subsequent effects on interest rates; and changes in relative prices. The consequences of such channels operating are expressed in macro-economic terms through e.g. losses of GDP (due to general increasing costs of supply); losses via negative balance of payments (due to increasing import prices); and through a rise in inflation (a sudden response to oil price increases due to direct market transmission mechanisms) and interest rates, reduced non-oil demand; lower investment in net oil importing countries. There are also a number of indirect impacts which are felt through the resulting effect of a reduction in tax revenues and increasing budget deficits. It is also argued that economic and energy-policy responses can exacerbate the negative impacts of an oil price shock [IMF, 2000]. Here, we solely focus on the changes in GDP, which we interpret as expressing changes in welfare and hence can be interpreted as equivalent to other measures of externalities.

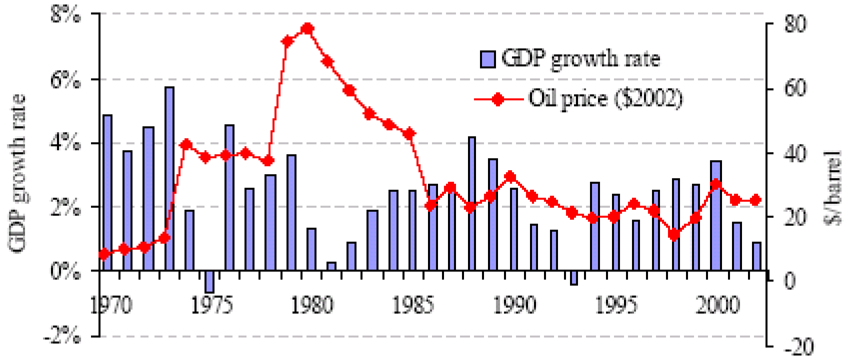
In order to substantiate the belief – constructed from the theoretical literature - that energy supply insecurity might give rise to welfare costs we reviewed the empirical evidence on linkages between oil price shocks and macro-economic consequences. A cursory glance at the statistical evidence – presented in Fig.2 below - illustrates how movements in oil prices correspond with GDP growth rates in the EU, between 1970 and 2001. It is apparent from this that there is some sort of correlation between a higher oil price and lower GDP growth rates with a one to two year lag.

Other studies have confirmed this impression e.g. Hamilton [2001] and Brown & Yucel [2001]. However, there are a number of factors that lead to a high variance in the economic costs of oil price increases, summarised in Costantini & Gracceva [2004]. These include:

- The role of fiscal and monetary policy responses. [IEA 2001], for example, argues that inappropriate policy responses to oil shocks have led to recessions, where, for instance, highly contractionary monetary policies and fiscal policies to contain inflation reduce national income and increase unemployment.

- Level and duration of the oil price increase - effects are greater the more sudden and pronounced the increase in price;
- Response of oil market. Whether – in the face of a price shock from one source – other suppliers can and do act to alleviate the impact;
- Amount of oil reserves available at the national level
- Import dependence
- Features of the individual national economy, including the weight of energy costs in GDP, the share of energy intensive sector in industry and the prevailing macro-economic state;
- Flexibility of energy sector i.e. capacity to shift from one fuel to another

Fig.2. Oil price and GDP growth rate in the European Union, 1970 – 2001. From Costantini & Gracceva [2004] based on data from the World Bank (GDP growth rate) and EconStat (oil price).



Consequently, when analyzing the differential effects of oil prices on each of the countries within the European Union [Cunado et al 2000] found significant differences between countries.

Price Volatility

We define price volatility as being the standard deviation of return/price, which measures how widely actual values are dispersed from the average. The larger the difference between the actual value from the average value, the higher the standard deviation will be and the higher volatility. Oil prices have become more volatile over the medium and long-term since the mid-1990s [IEA, 2001] and in part, this is explained by the fact that OPEC has changed from setting the price and letting production fluctuate to setting production quotas and letting the price fluctuate. Its possible importance as source of external costs stems from the fact that during periods of high volatility, the level of oil prices contains little information about future oil prices. This acts as a disincentive for rational agents to invest since the uncertainty associated with future returns is higher. This increasing uncertainty can push up risk premiums, and discourage oil companies investment. Thus, high volatility can be seen as a barrier to investment in the oil industry.

The empirical work supports this hypothesis. For example, IEA [2001] found that whilst the level of prices is the key determinant of exploration and production investments, the degree of price volatility has a significant impact. These findings are supported also by Federer [1996, in Hamilton 2001] whereby oil price volatility was found to depress spending and investment through its effects on uncertainty [Federer 1996]. In particular the analysis showed that the elasticity of investment with respect to changes in volatility is -0.11, while it is 0.44 against price change. In other words, a one percent increase in volatility is associated with 0.11 percent decline in investment, when other things such as interest rates are kept constant, and a one percent increase in price results in a 0.44 percent increase in investment.

Results from Predictive models

Several models have been developed to estimate the impact of energy price increases and/or supply disruptions on the macro-economy and these have largely focused on oil supplies. A summary of results from these models is presented in Table 4 below.

Table 4. Macroeconomic cost estimates.

Source	Driver	Estimate	Units	Country/ Region
EC [2002]	$10 increase in price of crude oil (per barrel)	- 0.5%	Economic growth	Industrialised countries
IEA [2004]	Increase from $25 to $35 i.e. by $10 per barrel of crude oil	- 0.5%	GDP (2004)	Euro zone
		0.5%	Inflation (2004)	Euro zone
IMF [2000]	Sustained increase of $5 per barrel of crude oil (20% increase)	- 0.25% (over first four years, then fades away)	Global output	World
		- 0.4% (percentage deviation from baseline after one year)	Real GDP	Euro zone
		0.5% (percentage deviation from baseline after one year)	CPI Inflation	Euro zone
		- 7.8 ($ billion)	Trade balance	Euro zone
IMF [2004]	Sustained increase of $5 per barrel of crude oil (20% increase)	- 0.4% (after one year)	Real output	Euro zone
Donald et al [2002]	Price change exceeding a three year high	- 0.05 to – 0.06	Elasticity GDP to oil price shocks	USA
Sauter and Awerbuch [2003]	10% rise in oil price	- 1.5% (for 3-6 months)	GDP growth	Euro zone
		- EURO 35 to 70 billion	GDP	Euro zone
World Bank [2000] in IMF [2000]	50% increase in price in first year, then decline back to by the third year.	- 0.25% (over first two years)	GDP	Industrial countries
		0.2%	Inflation	Industrial countries
Huntington [2004]	Doubling of oil price	3.7%	Percentage of loss in GDP	USA and Euro zone
IEA [2001]	Price level: 1% increase	0.44%	Percentage change in Investment	IEA member countries
	Price volatility: 1% increase	- 0.11%	Percentage change in Investment	IEA member countries

Military expenditure

Some have argued that military expenditure should be factored into the external cost of energy security given that without this type of expenditure (particularly in the Middle East) there would be a tangible threat to the secure supply of oil. Delucchi and Murphy [1996] go as far as arguing that if US motor vehicles (a major user of petroleum) did not use petroleum the U.S. would reduce its defence expenditures in the long run by roughly $1 to 10 billion dollars per year. However, other authors such as Bohi and Toman [1996] argue that there are good reasons why this expenditure should not be considered as part of the external cost calculations. These include the arguments that:

- Military expenditure is a cost of mitigating energy security rather than a cost of insecurity itself
- Other national security interests are being served, not just oil
- Military presence is potentially on behalf of many other countries too

We are persuaded by these arguments, and by the difficulty of identifying the appropriate expenditure data from a large number of countries within the constraints of the project resources, that we should not look to include a military expenditure component in estimates of energy security externalities.

2.2.2.2.2. Gas

The rising demand for energy and an increasing dependence on external sources of gas in the future are potential sources of energy insecurity in the EU. The insecurity derives from source dependence; transit dependence; and facility dependence (extent of spare capacity in the event of failure of a major component – almost all gas connections between European member countries are said to be fully used). However, the evidence suggests that it is hard to make a convincing case that security of gas supply is currently an imminent threat within the European Union.[1] There appears to be no problem of scarcity even in the long term and conventional reserves should be sufficient at least until 2035–40. This implies that the risk of an increase in prices is small. Additionally, to date there have not been major gas-import supply interruptions in the EU. Therefore, energy security may not be under threat to the extent that it is for oil and electricity[2]. Thus, whilst we acknowledge the potential insecurity these arguments, together with the absence of quantitative estimates, oblige us not to seek any estimates of external costs in this research.

2.2.2.2.3. Coal

Evidence relating to the energy security nature of coal to the European Union is disappointingly scarce, and there appears to be no evidence available that seeks to quantify the macro-economic costs of coal supply disruption in Europe. We suspect that this lack of evidence may reflect the fact that these costs are perceived to be low relative to those for oil. However, there are growing dependencies in the EU on imported coal, particularly from China, that suggests a potential source of insecurity. This suggests the need for new empirical modelling work in order to simulate these potential insecurities in a credible enough way to provide comparisons with the oil sector.

2.2.2.2.3. Electricity

The paragraphs above have reported evidence on energy insecurity relating to energy fuel sources, which manifest themselves principally in price changes. A separate component of energy insecurity is the non-supply of energy that occurs in the case of electricity blackouts, or power cuts. The following paragraphs summarise the findings of a literature review on this topic.

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[1] INQUIRY INTO EUROPEAN UNION ENERGY POLICY: GAS SUPPLY AND ACCESS http://www.oxfordenergy.org/pdfs/House%20of%20Lords3.04.pdf

[2] Oil Security Short- and Long-Term Policies, Valeria Costantini and Francesco Gracceva http://ceps01.link.be/files/No2%20INDES%20pdf.pdf.copy

Costs associated with electricity supply disruptions (termed as 'social costs' by Costantini & Gracceva [2004]) are:

- Expenditure for military, policy and emergency services
- Expenditure on public transport e.g. costs of subway interruptions and increased delays with flights etc
- Health care expenditure e.g. costs relating to reduced refrigerating capacity
- Sanitation and waste disposal e.g. interruption in sanitation services
- Other public services e.g. interruption of schools
- Human life values i.e. costs relating to mortality and ill health, as well as lost leisure time and fear.

Factors that influence the extent of social costs include: the area affected; existence of alternative energy sources; duration of disruption; time of day and season; availability of advance warning and information.

The literature estimates the costs of supply disruptions by multiplying the energy not served by a factor called the Value of Lost Load (VOLL). VOLL can be estimated by different methods including econometric models and case studies of interruptions. However, customer surveys are the most prominent e.g. willingness-to-pay to avoid a supply disruption. The official value of VOLL used until recently by the Pool in England and Wales is a function of the duration of an outage, averaged across different kinds of customers. It ranged between €3.8/kWh for a one-hour outage to €1.8/kWh for an outage of longer than 24 hours [Egenhofer et al 2004]. A more recent survey by Kariuki and Allan [1996] found that a higher value of €4.6/kWh. This value is similar to that found in a study on the blackout in 2003 in New York City, where the estimated direct cost (e.g. lost production and wages) was €0.66/kWh, with indirect costs amounting to about €3.45/kWh. Ex post studies, not yet available, on the series of blackouts in Europe in 2003 – particularly in Italy, Denmark, Sweden, and London are expected to up-date this estimate, which we adopt in the meantime in our subsequent analysis.

It should be noted that there is some volatility in prices in the electricity market. However, there is little empirical work on the costs of such volatility and so we do not consider this further here.

2.2.2.3. Estimation of Externality Unit Value

The above sections provide estimates for the overall macroeconomic implications of increases in oil prices and of physical disruptions in electricity supply, but not for coal and gas. These estimates do not distinguish between internal and external costs and so they provide an upper bound to the external costs of energy insecurity. In order to facilitate comparison with other energy external costs we wish to express these costs in terms of mEuro per kilowatt hour. Whilst the estimates for electricity given above are in this unit, the macroeconomic costs of oil price changes are not. We therefore convert these aggregate costs to mEuro per kilowatt hour. A number of strong assumptions are adopted in order to derive these values and these are explained in detail in the technical report. In addition, the macroeconomic cost estimates only allow us to include the effect of a sustained price increase. No estimate based on price volatility is made.

The conversion requires the following steps.

1) Determination of a benchmark as a reference value in the event of an oil price change for instance. We assume here that average global oil production of 8.5m barrels per day over the last three years provides for a "normal" oil price, of €25 per barrel, excluding shocks.
2) We assume a given price increase of €10 per barrel, resulting from a supply disruption of 3 million barrels per day, lasting for three months to one year.

3) We estimate the resulting loss of GDP in the EU25 according to a range of the estimates of macroeconomic costs presented in Table 4 above, specifically relating to Europe. Estimates were taken from EC [2002] and IMF [2004] and the length of impact differed from one year to four years.
4) We divide total GDP loss by the number of oil barrels lost in the supply disruption. This gives a range of between €44 and €290 per barrel.
5) We use the conversion factors: 1 barrel of oil = 5,800,000 British thermal units (Btu); 1 kilowatt hour = 3.413 Btu, together with a thermal efficiency factor of 50%, to generate unit cost estimates of **0.05 – 0.8 mEuro per kilowatt hour**.

These estimates are low compared to estimates for health externalities from energy but similar to externalities to materials. Note however that the externalities are only derived from those macroeconomic costs that fall directly on the EU. Estimates for the global economy would be perhaps four times larger. It is also expected that estimates that included oil price volatility and risk aversion would be significantly higher.

2.2.2.4. Policy Analysis

Much of the cost associated with energy insecurity is the result of increased uncertainty about supplies. This causes lower profits to producers by increasing the variance in the returns on their activities, and causes costs to consumers in terms of potential unemployment, disruption of lifestyles etc. Although all this is generally acknowledged, the formal modelling of ES in an uncertainty framework is rare. Yet, the tools for such modelling are available and include risk aversion modelling within the Von-Neumann-Morgernstern expected utility framework.

As part of this project, we constructed a simple expected utility model of the ES problem, to see what insights it offered. The model is simple: it sets a social goal of maximizing expected utility of consumer surplus generated in an economy with a single aggregate good and two sources of energy - an imported cheap source and a domestic, more expensive source. A probability of disruption of the imported source is defined, in which case the amount available is reduced and the corresponding price of that energy inside the country goes up. The control variable for the government is the domestic price of energy; by keeping it above the world price it reduces imports and increases incentives for domestic production. Hence a tax has to be placed on energy, the level of which is determined by the values of domestic and imported energy (which are perfect substitutes for each other) that maximize the expected utility of consumer surplus.

The model is run for plausible values of the coefficient of risk aversion, the probability of disruption, the impact of disruption on the imported energy price, the elasticity of demand for energy and the relative costs of imported and domestic energy. Functional forms of the relevant equations (demand for energy, costs of supply, utility function) that are frequently used in the economic literature are employed.

The model yields a number of important results. First, we note that the optimal solution requires a single tax on energy – it is not optimal to subsidize domestic energy supply, for example, other than implicitly through a tax on all energy sources. Second, the model finds the optimal solution highly sensitive to the costs of disruption. As the costs increase, the optimal tax rises sharply. Third, the quantitative simulations are not so sensitive to the probability of disruption or to the coefficient of risk aversion (within the range in which such coefficient are generally found to lie). Finally the results are sensitive to the elasticity of demand. The optimal tax rates mostly lie in the range 12 to 45 percent but can go as high as 90 percent.

The model is of course, only a partial representation of reality. But it is an important one and captures the significant role that internal energy pricing can play in reducing the impacts of uncertainty of foreign supply. To make the model more 'realistic' we need to:

- Model risk and costs more realistically as joint probability distribution for the two
- Take account of measures that reduce costs of disruption but have a cost themselves (e.g. holding of stocks). Stock levels are not calculated in this way at present.
- Develop links between measures of dependence and vulnerability and parameters such as risk of disruption.
- Assess more carefully exactly how much ES is an externality – how much of the risk has been internalized.

2.2.2.5. Conclusions about Energy Security

Measurement of energy security externalities remains a complex and difficult exercise. Problems of definition as to what constitutes these externalities make agreement on what the policy issue is hazardous. Additionally, the range of assumptions that need to be made in order to calculate quantitative estimates of the size of these externalities means that these estimates should be viewed as indicative, only.

However, our policy analysis has shown that there are potentially important implications for the design of an optimal energy tax that incorporates energy security. It is therefore hoped that future projects will allow us to make more robust estimates of energy security external costs – including other costs such as those associated with risk aversion, additional to the macro-economic costs - and that these can therefore more fully be considered in the design of future energy policy.

2.2.3. Multicriteria Analysis for Monetary Valuation

2.2.3.1. Introduction

Despite great progress in the quantification of damage costs in recent years, the determination of monetary values remains elusive or problematic for certain impact categories, including impacts of acidification and eutrophication of ecosystems, reduced visibility etc. The objective of this work package was therefore to develop a framework based on Multi-Criteria Decision Analysis (MCDA) that could be used for exploiting the preferences of stakeholders or environmental experts (in the following simply referred to as "stakeholders") in order to derive monetary values for impacts whose monetization has remained problematic.

2.2.3.2. Selection of the Most Appropriate MCDA Method

The methodology of MCDA has undergone an impressive development during the last 30 years because it has been recognized as a valuable tool for analyzing today's complex problems in which the level of conflict between multiple evaluation axes is such that intuitive solutions can not be satisfactory. A multiplicity of MCDA methods is currently available for use in a wide variety of situations [Belton and Stewart, 2002]. Furthermore, several weighting techniques have been developed to help stakeholders involved in a MCDA procedure understand and articulate their preferences concerning the relative importance of the examined criteria. MCDA methods can be classified in two broad categories:

i) **Multi-Attribute Value Theory methods** (MAVT) try to associate a unique number ('value') representing the overall strength of each alternative if all criteria are taken into account. If there is significant uncertainty about the performances of alternatives, the term 'utility' is used to indicate that the attitude of stakeholders towards risk is formally included in the analytical procedure. The starting point is the definition of partial value (or utility) functions in each criterion which are then aggregated for deriving total values and constructing a complete initial ordering of the examined alternatives. The weights used in the aggregation formula reflect human preferences and play the role of scaling factors of the criteria performances.

ii) **Outranking methods** proceed to a pairwise comparison of alternatives in each single criterion in order to first determine partial binary relations according to the intra-criterion preferences of the stakeholders. These relations are then synthesized over all criteria to provide total preference indices for each pair of alternatives denoting the evidence that '*an alternative **a** is at least as good as alternative **b***'. Contrary to MAVT methods, the weights used in the aggregation formula play the role of importance coefficients in constructing the total preference indices. The exploitation of these indices results in partial initial ordering, meaning that some of the alternatives might appear as incomparable to each other if not enough arguments exist to support that one alternative is better than (outranks) the other(s).

The selection among these two broad categories was based on their anticipated use in cost-benefit analysis (CBA). It has been found that among MCDA approaches, MAVT methods are most frequently associated with CBA. Both are rooted in utilitarian theory, which assumes that there exists a common measure of social welfare on which alternative actions can be gauged and compared. Therefore we have chosen MAVT for this project.

2.2.3.3. Selection of Weighting Technique

The next step was to select the appropriate technique for deriving the stakeholders preferences that implicitly reflect the monetary equivalent for the examined impacts. From the literature review different weighting methods have been identified. These can be distinguished in compensatory and non-compensatory methods. Taking into account that the additive aggregation model implemented in both CBA and MAVT methods assumes strong compensation between criteria, it emerges that a combination of the two approaches should rely on a compensatory weighting method. The weights so derived play the role of scaling factors in the sense that they relate scores in one criterion, to the scores of all other criteria. This means that by assigning weights of relative importance, decision makers implicitly determine how many units in one criterion they are willing to give up, in order to improve the performance of another criterion by one unit. The extensive literature review has also revealed an increasing interest in using constructive preference elicitation approaches and in their indirect exploitation in cost-benefit analyses.

The available compensatory weighting methods follow a different approach to elicit human preferences. They also differ with respect to a number of properties that may significantly influence their capacity to translate human preferences into numerical values:

- Simplicity and transparency
- Degree of inconsistencies in the articulation of preferences
- Ability to handle problems with small or large number of alternatives or criteria
- Sensitivity to impact range

Based on the above characteristics, two methods are found to be the most appropriate for our exemplary policy problem: The SWING method developed by von Winterfeldt and Edwards [1986] and the TRADE-OFF method. Both methods have been developed in order to be tested in the implementation phase. The testing procedure has shown that the SWING method was by far preferred by most respondents mainly because of the following advantages:

1. The much simpler way of eliciting the stakeholders' preferences.
2. The sensitivity to impact range (comparable to the TRADE-OFF method which is generally accepted to be the most sensitive one).
3. The reluctance of certain stakeholders to directly define trade-offs between ethical values (e.g. human health vs cost).

The SWING method highlights the hidden dilemmas behind a number of mutually exclusive options evaluated across multiple criteria for making stakeholders aware of the potential gains and losses implied by their choice. For this purpose, two extreme hypothetical Scenarios W and B are constructed, the former presenting the worst performance in all criteria (worst score of the examined alternative options) and the latter the corresponding best performance. It is assumed that the current state for the stakeholder is Scenario W. The preference elicitation procedure consists in asking stakeholders to carefully look at the potential gains of moving from W to B and then to decide which of the criteria they want to first shift to Scenario B. Assuming that this first swing is valued with 100 units on a hypothetical value scale, the stakeholders are asked to assign a value (<100) to the second criterion moved to B, then to the third and so on until the last criterion is moved to Scenario B.

This relative value scale v_i is then transformed in normalized weights w_i:

$$w_i = \frac{v_i}{\sum v_i}$$

If one of the criteria is a cost, the monetization is based on the assumed equivalence of the stakeholder's relative preferences, as given by the following equation, relating the weight calculated for each physical impact with the weight of the cost criterion, both reduced to the corresponding impact scale:

$$\frac{w_i}{IR_i} = \frac{w_c}{IR_c}$$

where IR_i and IR_c denote the impact range (i.e. the maximum potential gain) of the physical impact *i* and of the cost criterion, respectively. The underlying assumption is that the value functions for all impact categories are linear, e.g. improvements in the impact level are valued the same, independently from the absolute impact level. The linearity assumption reflects a neutral behaviour against risk which is a reasonable hypothesis, for the limited range of impact levels under consideration. Hence, the per unit monetary value of the physical impact *i*, m_i is calculated as follows:

$$m_i = \frac{IR_c \cdot w_i}{IR_i \cdot w_c}$$

It can be seen that for each pair *i/c* the higher the ratio of weights and/or the lower the ratio of impact ranges, the higher is the unit monetary value implicitly assigned to the physical impact *i*.

2.2.3.4. Problem Formulation

The policy problem formulated aims at the monetization of acidification and eutrophication, two forms of ecosystems degradation that are causing major concern to policy makers at the international and European level. A preliminary investigation of other non-monetized impact categories (e.g. on visibility and cultural monuments) has shown that existing indicators are very site-specific and their quantification is only possible through a detailed analysis at the local scale. Such an analysis was out of the scope of the present project and of the specific exploratory task.

The selected policy problem refers to the choice among three possible scenarios for reducing the emission of NOx, NH3, SO2 and VOC in Europe, relative to the base level of 1990. The reductions are described in terms of the corresponding physical impacts for acidification, eutrophication, mortality, and changes in agricultural production. The corresponding abatement costs are also shown, i.e. the costs necessary to achieve the reductions. The scenarios, are drawn from IIASA [1999] and defined as follows:

- CL: reference, based on the anticipated reduction due to all current legislation and abatement plans (not including the Gothenburg Protocol or the National Emission Ceilings Directive of the EU)
- GP: based on the limits set by the UNECE Convention on Long Range Transboundary Air Pollution (Goteburg Protocol)
- MFR: based on the Maximum Feasible Reduction resulting from the full application of currently available control technologies.

Table 5 presents the emission reductions assumed in each scenario.

Table 5. Emission reduction of scenarios with respect to 1990 level.

	CL	GP	MFR
NO_x	**-48%**	**-50%**	**-79%**
NH_3	**-12%**	**-13%**	**-40%**
SO_2	**-71%**	**-75%**	**-91%**
VOC	**-49%**	**-53%**	**-72%**

There is no single best scenario because lower emissions require higher abatement costs. So, the final choice depends on the relative weights that each stakeholder assigns to the considered criteria. Data for impacts and abatement costs are also drawn from IIASA [1999]. Table 6 presents the impact levels (as absolute rounded numbers and as relative indicators), both as they were in 1990 and for each of the three reduction scenarios. Impact levels refer to the population and other receptors in EU-15.

Table 6. Impact levels of scenarios

IMPACTS	1990	CL	GP	MFR
Abatement cost (bil. €/yr) **(€/yr per household)**	**0**	**58** **380 €/yr,hh**	60 **395 €/yr,hh**	**101** **665 €/yr,hh**
Acidification (1000 km²) **(% loss of total ecosystems area)**	**370** **24.8%**	**64** **4.3%**	53 **3.6%**	**9** **0.6%**
Agricultural loss (bil.t of cereals & potato) **(% loss of total agricultural production)**	**13** **5.2%**	**10** **4.0%**	9 **3.6%**	**6** **2.4%**
Eutrophication (1000 km²) **(% loss of total ecosystems area)**	**667** **55%**	**484** **40%**	476 **39%**	**194** **16%**
Mortality (1000 YOLL/yr) **(months/person per lifetime exposure)**	**3 300** **7.8 months**	**1 900** **4.5 months**	1 800 **4.3 months**	**1 100** **(2.6 months)**

2.2.3.5. Development and Application of Questionnaire

The questionnaire was developed as a simple EXCEL workbook on the basis of the SWING method. In addition to the sheet where the stakeholders indicate their preferences, it contains sheets with detailed explanations. The questionnaire is interactive in that the respondent is directly informed about the monetary equivalents of his/her preferences and has the opportunity for revisions.

The questionnaire was first tested by the project partners. In its final form it was sent by e-mail to 105 environmental experts from several EU countries and the USA. 20 of these were involved in various phases of the ExternE project, while the other 85 respondents were experts in ecosystems modeling, environmental impact assessment and externalities assessment. The total response was 25 questionnaires (24%) with a much higher rate recorded for the ExternE participants (12 questionnaires or 60%). One questionnaire was excluded from further consideration due to high inconsistency in the responses, while three additional questionnaires were discarded in the subsequent analytical phase because of extreme and unrealistic values shifting average estimates to very high levels.

2.2.3.6. Analysis of Results

The completed questionnaires have been analyzed for determining the range of the weights attributed to the considered impacts and of the implied monetary equivalents. Results assume a confidence level of 80% by excluding outliers, i.e. 10% of the lowest and 10% of the highest values. Average values with the same confidence level have also been calculated for comparing the variation of preferences between impacts and among different groups of stakeholders. Fig.3 shows the spread of weights assigned to the impacts under consideration. It can be seen that mortality is generally assigned the highest weight, followed by abatement cost and eutrophication, while acidification and agricultural loss are generally assigned a lower weight. Fig.4 shows the implied monetary values.

Fig.3. Spread of weights (80% confidence)

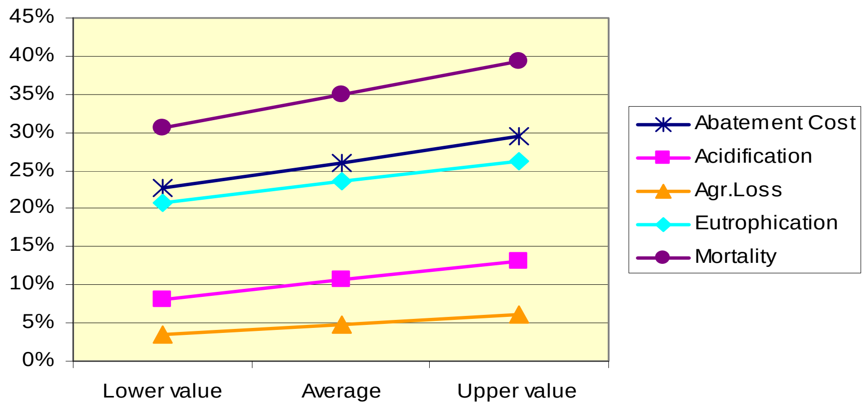
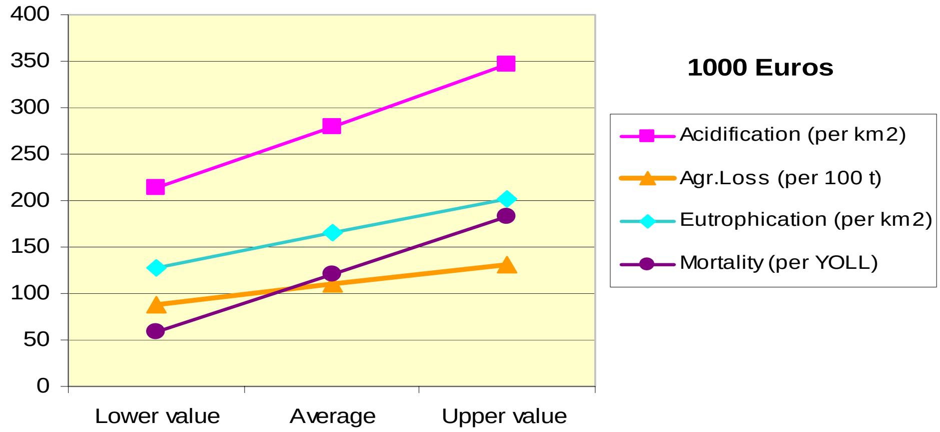


Fig.4. Spread of monetary equivalents (80% confidence).



It can be seen that the highest variation of the estimated monetary values is observed in mortality and acidification impacts, while in the case of agricultural crops (mainly wheat) the range of values is more restricted. Regarding the relevance of the obtained monetary equivalents and focusing on the average values the following remarks can be made:

1. **For mortality impact**, the calculated average monetary value (120,000 € per YOLL) is of the same order of magnitude with values resulting from valuation approaches used in the ExternE project, although relatively higher than the last estimates agreed.
2. **For acidification and eutrophication**, the average monetary values amount at 280,000 and 165,000 € per km^2 (2800 and 1650 € per ha) which may be considered as relatively high if compared to recent valuation attempts. The difference between acidification and eutrophication could be due to the difference in the considered impact ranges.
3. **For agricultural loss**, the average monetary value (1050 € per ton) is around 6-7 times higher than the current market price.

In order to validate the proposed multicriteria procedure and confirm the effect of the impact range on the estimated monetary values, a parallel survey has been conducted in Greece. The formulated problem consists in the evaluation of alternative scenarios for the expansion of the Greek electricity system. The examined impacts include mortality, CO_2 emissions, impacts on ecosystems and agricultural loss and the obtained monetary values were close, although lower than those for the European problem.

2.2.3.7. Discussion and conclusion

This research has been exploratory, relying on an open scientific debate [e.g. Gregory and Slovic, 1997; McDaniels Roessler, 1998; Sagoff, 1998]. The results are very promising but the monetary values are not yet sufficiently firm for application in ExternE. The number of responses has been too small to be considered representative. The questionnaire needs further improvements; in particular the influence of the impact range needs to be clarified, to minimize biases due to the choice of the impact range in the questionnaire. Another factor affecting the resulting monetary equivalents is the degree to which the respondents are familiar with monetization approaches and aware of existing estimates. It was found that among the respondents, those involved in previous phases of the ExternE project attributed lower values to acidification and eutrophication. The European scale of the scenarios and impacts leads to a rather general, vague and abstract presentation that may have rendered the expression of preferences more difficult than would have been the case for a local problem with which the respondents are familiar, such as choice of a power plant technology for a specific site. It would also be interesting to implement the elicitation of preferences in an open interactive procedure (as is the usual practice in MCDA), where stakeholders have the possibility to exchange ideas and maybe revise their initial preferences.

There are interesting parallels and differences between this approach and contingent valuation (CV). Whereas typical CV studies interrogate a representative sample of the general population, the MCDA approach elicits the opinion of experts who have a better understanding of the goods to be evaluated. Is it better to insist on a representative sample by asking people who do not understand the issues (CV), or to ask experts whose values may not be representative of the general population (MCDA)? The key question is to what extent the experts have the same fundamental values such as the importance of protecting the environment, of avoiding risks to human life or health, of secure employment, etc.

2.2.4. Validation of Atmospheric Modeling

2.2.4.1. Validation Methods

The validation of a model for atmospheric chemistry and physics is an extremely difficult task. Several aspects of the model need to be examined, from the validity of the models and equations for the individual processes to the specification of the input parameters and data. In principle there are two possible approaches, the first being a comparison of calculated with measured data, the second being a critical examination, based on literature review and consultation of experts, of the models and equations that have been assumed for the various processes. The first is of limited value even under the best of circumstances because the number of potential calculations that should be evaluated is so large that only a small subset could be compared with data. Furthermore, suitable measured data are difficult and costly to obtain in practice: even for dispersion calculations without chemistry one would need a sufficient number of tracer gas measurements (with sufficient accuracy at very low concentrations if the quantity of the gas is to be kept acceptably small) covering the entire region up to thousands of km from the source. In view of these difficulties the review of the literature and consultation of experts become all the more essential. For reactive species such as SO2 the only feasible data-based validation beyond simple dispersion is a comparison of calculations and data for the actual emission inventory in the entire region. Not only are there significant uncertainties about the inventory, but an agreement is no guarantee that the model would be correct for other emission levels because of the strong nonlinearities of some of the processes.

In view of this situation the following approach has been taken in this project:
a) upper and lower bounds on the calculations of the dispersion module have been established by means of a Monte Carlo analysis, taking into account the probability distributions of the uncertain input parameters;
b) for a few cases where measured data were available, they have been compared with EcoSense calculations;
c) EcoSense calculations have been compared with a recent and more detailed model.
d) a large number of model runs have been carried out to evaluate the sensitivity of EcoSense to several critical input parameters and data;
d) experts have been consulted.

2.2.4.2. Monte Carlo Analysis of Uncertainties

The uncertainty of the dispersion model used by ExternE has been estimated by means of a Monte Carlo calculation, taking into account the uncertainties of the numerous input data. Probability distributions are used for the possible values of the input parameters. Since some of the distributions are not well known, several possible cases are considered. Only dispersion is taken into account, without chemical reactions.

The analysis starts from the mass balance for the average pollutant concentration in a column of air that moves with the wind from source to receptors. For an initial analysis several assumptions are made to calculate the ground level concentrations; they are generally made by models that calculate collective exposure and are believed to be sufficiently realistic for that purpose:
(A1) the pollutant moves along straight trajectories away from the source;
(A2) the wind speed does not vary with height;
(A3) wind speed and stability class are constant for a puff moving along its trajectory;
(A4) there is no exchange with the upper atmosphere above the mixing layer height;
(A5) the distributions of the parameters are statistically independent;
(A6) for the ratio of the ground level and the column-average concentrations one can take the ratio of a Gaussian plume, multiplied by a random number with a lognormal distribution.
Then a sensitivity analysis is carried out to test what happens when assumptions A1 to A3 are relaxed. Since some of the distributions are not well known, we consider several possible cases. This approach provides a model-independent assessment of the uncertainty of any dispersion model that satisfies the assumptions, including EcoSense.

Results have been obtained for power plants (with stack height 75 m and typical plume rise) at three locations: an extremely large population center (Paris), an intermediate site (Lauffen near Stuttgart), and a rural site (Albi). The uncertainty of the collective exposure, expressed as geometric standard deviation σ_G, ranges from about 1.2 for Paris to about 1.9 for Albi. The uncertainty is larger for the latter because for a rural site the regional impacts dominate and the regional impacts are very sensitive to the assumptions about the deposition velocity, whereas deposition is almost negligible in the local zone (for PM_{10}, SO_2 and NO_x). A σ_G of about 1.9 is close to the value of 2 assumed by Rabl & Spadaro [1999] in their estimate of the uncertainty of the ExternE damage costs.

For the interpretation, note that a geometric standard deviation σ_G corresponds to a multiplicative 68% probability confidence interval [μ_G/σ_G, $\mu_G\ \sigma_G$] around the median estimate μ_G; the 95% confidence interval is [μ_G/σ_G^2, $\mu_G\ \sigma_G^2$]. The median is very close to the geometric mean because the distribution of the result is very nearly lognormal. These results show that the dispersion calculations of ExternE are correct within at least a factor of 2 (with 68% confidence) and in most cases much better.

2.2.4.3. Comparison with Measured Data

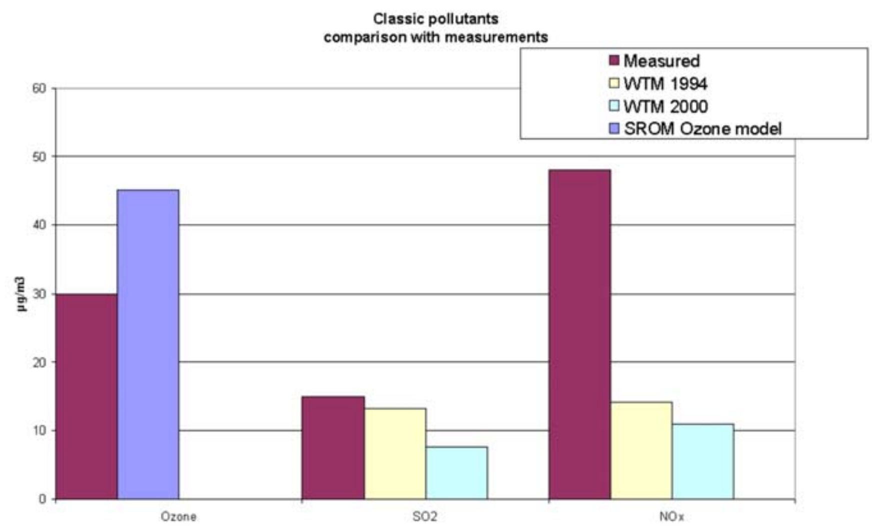
a) The ISC model for Local Dispersion

Situations with a single dominant source are extremely hard to find. ARMINES has made an interesting case study for a refinery near Nantes, the dominant source of SO2 in that zone. EcoSense 2.1 uses the ISC2 model to calculate local concentrations due to power plant emissions. According to EcoSense/ISC the refinery contributes about 3.5 $\mu g/m^3$ to the annual average of 8.8 $\mu g/m^3$ measured at the station near the refinery. Since the background in the nearby cities is 3.6 and 4.7 $\mu g/m^3$ in St.-Nazaire and Nantes respectively, the refinery really contributes about 4 to 5 $\mu g/m^3$. By the standards of such comparisons of models with data this can be considered excellent agreement, and it is entirely consistent with the Monte Carlo analysis reported above.

b) NOx, O3 and SO2 Data in Belgium

Some of the predicted concentrations (using two different sets of background emissions) have been compared with measured data for a station in Antwerp, see Fig.5. It turns out that both ozone and SO_2 concentrations are very good (within a factor of 2), but predicted concentrations of NOx are much lower. Although this is a “high-NOx” station situated near a busy highway, this may not explain the entire difference (also see the conclusion at ‘Comparison of EcoSense with an advanced and detailed PM model’, below Fig.6).

Fig.5. Measured and predicted concentrations (EcoSense) for a station in Antwerp.



2.2.4.4. Comparison with the EUROS Model

The state-of-the-art PM module for the EUROS model of VITO was built by combining the advanced CACM gas phase mechanism [Griffin et al. 2002] and the state-of-the-art aerosol module

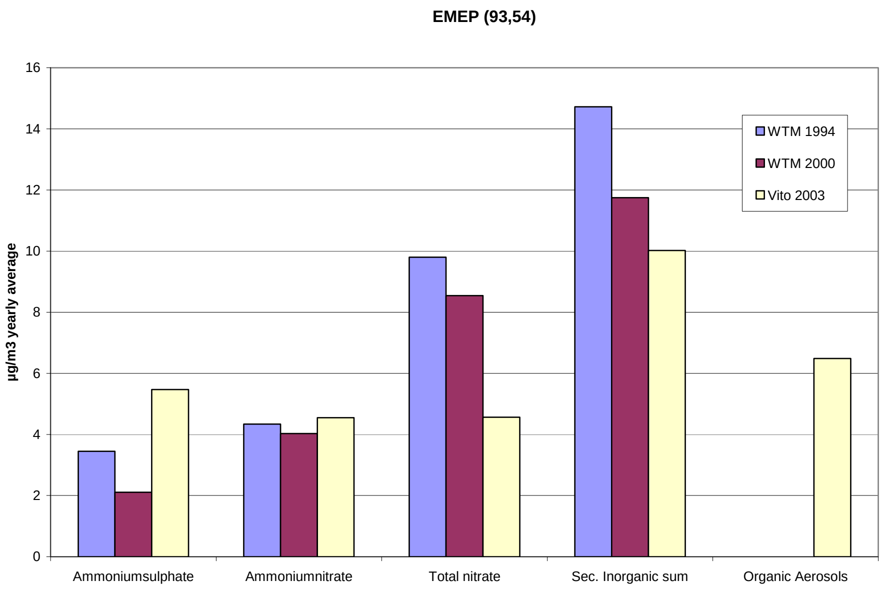
MADRID 2 [Pun et al. 2002], currently the most advanced aerosol module in its kind [Deutsch, pers. comm.]. The CACM mechanism is the first that was specifically designed to model the formation of secondary PM. Several generations of PM precursor compounds, formed from reactions of both anthropogenic and biogenic emissions are calculated. This is an important innovation since (especially in summer) the fraction of secondary aërosols in the PM_{10} mixture can be quite high. The aerosol module MADRID 2 describes the formation of secondary aerosols through a set of equilibria between the gas phase and the aerosol phase for both organic and inorganic components. It also describes the dynamic nucleation process in which new particles are formed and the growth of existing particles. The new module, combining both mechanisms, is therefore capable of estimating both the mass and chemical composition of the PM_{10} and $PM_{2,5}$ the size fractions.

Comparison of EcoSense with EUROS shows remarkably similar results for yearly averages in Belgium, see Fig.6. The similarity in the concentrations of ammonium sulphate, ammonium nitrate (and the sum of both), is surprising given that both models have used different background emissions and different meteorological data.

The predicted concentration of "unspecified" nitrates in WTM is quite high, and there is no similar compound in the detailed model. This may be consistent with the fact that WTM seems to convert more NOx to nitrates at a continuing rate whereas the detailed module models this as a reversible equilibrium. This issue is however still unresolved and further contacts between experts are necessary to clarify this especially because the Ecosense software is thought to attribute health impacts to "unspecified nitrates" (although this cannot be validated independently).

A very important result of this comparison is that organic aerosols are a major component of the PM10 mixture. This pollutant is not modelled at all by the WTM-module although its compounds have a potentially high toxicity.

Fig.6. Comparison of PM components between EcoSense and EUROS.



2.2.4.5. Effect of Background Emissions

For another perspective on the validity/uncertainties of the atmospheric modelling by EcoSense we have carried out a large number of sensitivity studies. They concern the role of the mixing layer height, of the NOx/SO2 ratio of the source, and of the background emissions. Here we report briefly on the latter.

Most people that use Ecosense are probably still using the outdated 1990 (Pointsource) or "1994" (Transport) background emissions. For this validation exercise 6 new versions of the background emissions database were prepared. The 1994 emissions included in Ecosense-Transport are not the 1994 emissions currently distributed by EMEP. The total emissions over the whole grid are very similar for NH_3, SO_2 and NO_x, but apparently significant amounts of NO_x and especially SO_2 were switched between high and low sources, see Fig.7. The projected emissions of NH_3 for 2005 were not completely reported by all countries and can therefore not be used for calculations. Total emissions decrease over time. The decrease between 1990 and 2020 is projected to be 80% for SO_2 and 60% for NO_x. This changes the SO_x/NO_x ratio of the model significantly and the different atmospheric chemistry leads to higher impacts per tonne emitted, as illustrated by Fig.8.

Fig.7. Comparison of total emissions over the EMEP grid for different years.

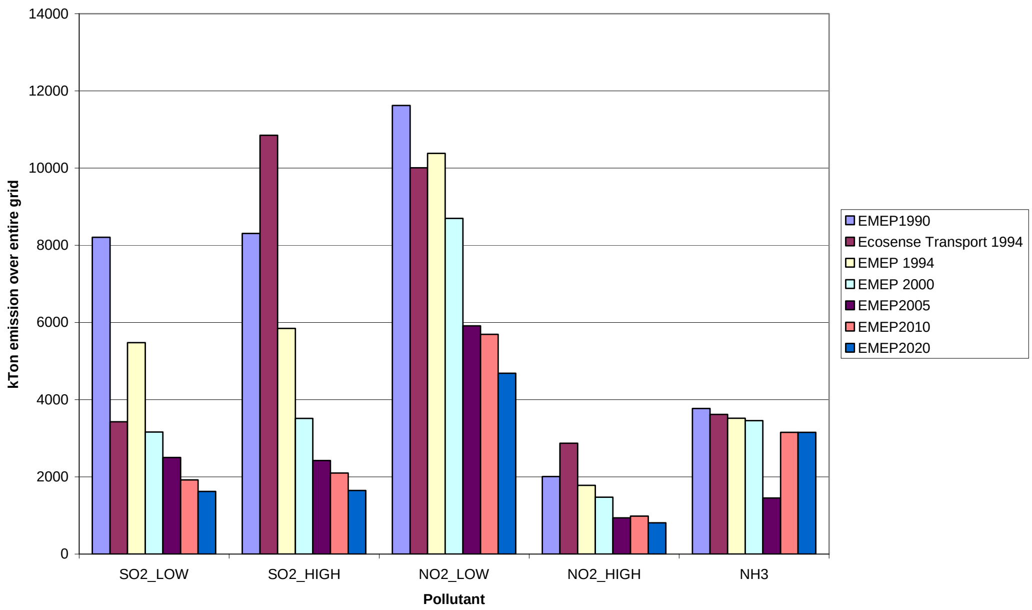
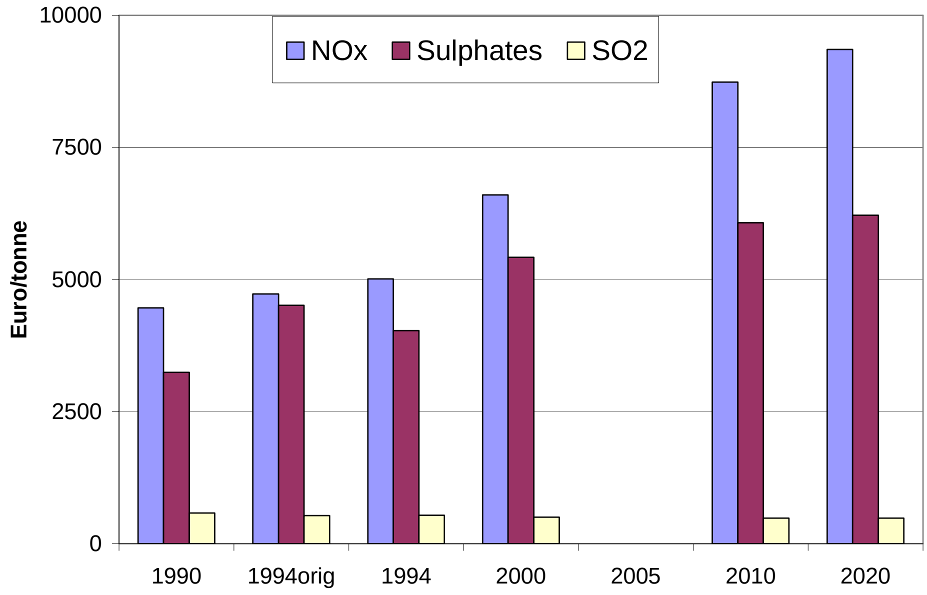


Fig.8 shows the results obtained with Ecosense transport for runs with different background emissions. The original results (labelled 1994orig) are quite similar to the results obtained with the emissions for 1994 currently distributed by EMEP. This result was obtained despite the (locally very large) differences. This exercise therefore constitutes an important independent validation of the methodology.

The costs per tonne are expected to rise significantly in the future. It is important to take this into account when analyzing policy decisions that take their full effect in 2010 or later. Using external cost data obtained with software using 1990 or 1994 background emissions could yield spurious results because the cost per one tonne of NOx emitted will be more than twice as high in 2020 than it was in 1990. The emission of one tonne of SO2 will also lead to sulphate impacts that are nearly twice as high in 2020 as compared to 1990. This effect can easily be understood from the Ecosense reaction scheme. Because the emissions of NH_3 are expected to stay at a similar level where NOx and SO2 decrease significantly, more NH_3 is left to react with the marginal emission increase.

Fig.8. Damage cost per tonne emitted under different background conditions (years).



The continuous update of background emission files and the use of the correct files for the policy questions under study should therefore be a constant point of attention. This finding is related to the question whether nitric acid impacts are also toxic (see Section 2.2.1.2.2. above).

2.2.4.6. Consultation of Experts

A questionnaire was designed with questions on: the general approach, the models, implicit and explicit assumptions and specific parameters. It was offered online to experts in atmospheric modelling, selected by the ExternE-Pol team. The questionnaire was carefully introduced to the experts to ensure that they fully understood the rationale of the ExternE work. It was considered important that the experts were familiar with some specific features of ExternE when filling out the questionnaire, in particular that ExternE needs to calculate the time averaged collective exposure.

Most of the answers came from direct discussions with air quality modellers rather than from the electronic questionnaire. The main conclusions of the experts were

1. The reaction rates used in WTM for the gas phase look OK, especially the important conversion rate of SO_2 to sulphates and the amount of SO_2 directly emitted as sulphate.
2. The reactions from HNO_3 and H_2SO_4 to secondary inorganic aerosols are considered to be out-of-date as the ones currently implemented in WTM do not treat equilibrium reactions (e.g. the decomposition of nitrates when more sulphur dioxide enters the atmosphere).
3. It is an important drawback that O3 levels are constant at 30ppb in all grid cells because of the important photochemical effects in the generation of secondary inorganic aerosols.
4. Formation of secondary organic aerosols (SOA) is completely missing from the reaction scheme although some compounds have been shown to have high externalities per tonne.
5. The height of the mixing layer is considered to be the most critical factor determining the PM concentrations. In the EcoSense versions used by ExternE until now this height is constant (once the user has specified it), which is considered a serious limitation.

2.2.5. New Energy Technologies

2.2.5.1. Objectives

The goal of the analysis of new (i.e. selected advanced) energy systems was to estimate the associated external costs, by combining detailed Life Cycle Inventories (LCI) with damage factors based on the impact-pathway approach. For comparison, also several current average energy systems were analysed employing the same method. The ecoinvent database v1.1, available online at www.ecoinvent.ch, offered a consistent basis for the analysis.

2.2.5.2. Data and Analysis

External costs were quantified for advanced technologies for Western European conditions and as a reference for currently installed average technologies and technologies available on market around year 2000, with associated energy chains. The main characteristics of the systems considered are given in Tables 7 and 8. The analysis on the basis of ecoinvent is internally consistent and the results can be used in scenario analysis. Fossil, nuclear, and renewable energy systems were assessed using a full process analysis methodology. The full life cycle of all stages of the energy systems have been considered (energy resource extraction and processing, conversion in power plants, production of infrastructure and fuels, transport, waste management, etc.). As a basis for such analyses, ecoinvent provides detailed technological and environmental data covering different economic sectors: energy systems, transportation, waste treatment and disposal, construction materials, metals, chemicals, detergents, papers, and agriculture. Approximately 2600 individual processes have been modelled in ecoinvent, of which about half are energy-related (electricity and heat). The methodology used in ecoinvent is extensively described in Frischknecht et al. [2004]. Complete information on current energy systems, on the model data, and analyses of selected results are covered in the German report Dones et al. [2004]; an extended summary in English is also available [Dones et al. 2003]. The work on the energy systems included in the ecoinvent database was supported by the Swiss Federal Office of Energy (BfE).

Mainly the countries of the Union for the Co-ordination of Transmission of Electricity (UCTE) as of year 2000 have been considered for the analysis of the systems. The UCTE countries in year 2000 were: Austria, Belgium, Bosnia Herzegovina, Croatia, France, Germany, Greece, Luxembourg, Macedonia, the Netherlands, Portugal, Serbia and Montenegro, Slovenia, Spain, and Switzerland. The ecoinvent database includes also the CENTREL countries (since 2001 part of UCTE): Czech Republic, Hungary, Poland, and Slovak Republic.

Different types of small natural gas and diesel combined heat and power (CHP) plants are included. With the exception of the 1 MW_e unit, Swiss conditions for the gas supply at low pressure distribution network were considered for CHPs in our analysis. However, considering that the shares for the origin of the gas are similar for Switzerland and UCTE, for the purpose of this external cost assessment it can be assumed that the results are valid for central European conditions. Most important is the share of Russian gas, due to the higher leakage rate and energy uses for long-distance transportation from this production region. The assumed share of the Russian gas to total is about 35%.

Table 7. Characteristics of the electricity systems analysed with ecoinvent.

Energy Source / Technology	Identifier in Fig.9	Technology description	Net efficiency (%)	Allocation exergy to el. (%)	Notes
Coal	Lignite	Average present plant for UCTE & energy chain	39	-	Installation of more efficient units and scrubbers will somewhat reduce external costs
	Hard Coal	Average present plant for UCTE & energy chain	36	-	Installation of more efficient units and scrubbers will somewhat reduce external costs
	Hard Coal PFBC	Pressurized Fluidised Bed Combustion (PFBC) power plant, technology around 2010 & present coal chain for Germany	47	-	• Efficiency may improve to 50% • The coal chain may differ in future (origin of the coal)
Oil	Oil	Average present plant for UCTE & energy chain	38	-	• The average includes base load and peak plants • Heavy oil used
	Oil CC	Combined Cycle (CC) best present technology & present oil chain for Europe	57.5	-	• Can be assumed for new units • Net efficiency may increase up to 60% • External costs roughly inversely proportional to efficiency increase
Natural gas	Gas	Average plant for UCTE & energy chain	38	-	
	Gas CC	Combined Cycle (CC) best present technology & present gas chain for UCTE	57.5	-	• Can be assumed for new units • Net efficiency may increase up to 60% • External costs roughly inversely proportional to efficiency increase
Nuclear	LWR	Average Light Water Reactor (LWR) for UCTE & close fuel cycle	33	-	• Damage factors for radioactive emissions approximated by DALY • Not all isotopic species have been given a damage factor
	PWR (centrifuge enr.)	Average Pressurized Water Reactor (PWR) for Switzerland & close fuel cycle with centrifuge enrichment only	32	-	• Can be assumed approximately for Advanced LWR, if the chain remains unaltered • In the current assessment, external costs associated with power plant are only a few percent of total
Hydropower	Hydropower (alpine)	Average reservoir plant for Switzerland & relevant energy chain	78	-	• Small improvements in average efficiency expected (84%) • May not be representative for specific units/sites for different material intensity for the dam and different flux of greenhouse gases from reservoir surface
Photovoltaic	PV panel (S-Europe)	Average present technology for monocrystalline-Si 3 kWp grid-connected units manufactured in Europe, panel mounted on slanted roof, average irradiation in South Europe (1200 $kWh/kW_{peak}\cdot a$)	12 (16.5 cell)	-	• External costs inversely proportional to irradiation (for Central Europe it can be assumed average irradiation of 800 $kWh/kW_{peak}\cdot a$) • Boundary of system include inverter • The inventory may not be valid for systems produced outside Europe, for production technologies and electricity supply mixes for manufacturing might be different
	PV integrated (S-Europe)	Same as above but with panel integrated in roof		-	
	PV integrated fut. (S-Europe)	Near future technology for monocrystalline-Si 3 kWp grid-connected units manufactured in Europe, panel integrated in slanted roof, average irradiation in South Europe (1200 $kWh/kW_{peak}\cdot a$)	13 (17.5 cell)	-	• Near-future scenario for purified silicon production and improved cell technology • Can be assumed for units around 2010
Wind	Wind onshore 800kW	Present technology, average capacity factor in Germany (20%)	25	-	• External costs inversely proportional to capacity factor • Lower external costs with higher nominal power rate
	Wind offshore 2MW	Current technology, shallow sea, reference capacity factor (30%) applicable near cost of North Sea (Middelgrunden, Denmark)	25	-	• As above for onshore • Environmental inventories and associated external costs may differ with depth of sea
Cogeneration Diesel	cogen diesel SCR 200kWe	Modern diesel unit, installed in Europe, using Selective Catalytic Reduction (SCR) and an oxidation catalyst	39 (el.) 43 (th.)	85	New units & associated average European oil chain
Cogeneration Natural gas	cogen gas lambda=1, 160kWe	Modern Lambda=1 motor gas cogeneration plant in Europe, using three-way catalytic converter	32 (el.) 55 (th.)	77	• New units installed & associated average Central European natural gas chain. • Different gas origins may change the contribution from the upstream chain to external costs
	cogen gas lean burn 1MWe	Modern gas cogeneration plant in Europe, without catalysts	38 (el.) 44 (th.)	84	

- Boundary for the analysis is the busbar of the power plant.

Table 8. Characteristics of the heating systems analysed with ecoinvent.

Energy Source / Technology	Identifier in Fig.10	Technology description*	Net efficiency** (%)	Allocation exergy to heat (%)	Notes
Natural gas	cond-mod <100kW	Modern boiler condensing, modulating	102	-	• New units & average Central European natural gas chain
	cond-mod >100kW		102	-	• Different gas origins may change the contribution from the upstream chain to external costs
	mod <100kW	Modern boiler modulating	96	-	
	mod >100kW		96	-	
	industrial >100kW	Modern industrial boiler	95	-	
Oil	heavy oil, industrial 1MW	Currently installed industrial boiler	95	-	• New units & average European oil chain
	light oil, cond- non-mod 10kW	Modern boiler condensing, non modulating	100	-	
	light oil, cond- non-mod 100kW		100	-	
	light oil, non-mod 10kW	Modern boiler non-modulating	94	-	
	light oil, non-mod 100kW		94	-	
	light oil, industrial 1MW	Currently installed industrial boiler	94	-	
Wood	logs heater 6kW	Modern fireplace	75	-	• Available on market in 2000 & average Swiss soft & hard wood mix.
	logs 30kW	Modern boiler burning logs, including water storage	68	-	• Can be used for central European conditions in the 2000s (no major changes in efficiency expected)
	logs 100kW		70	-	
	chips 50kW	Modern boiler burning chips produced at forest	80	-	
	chips 300kW		82	-	
Cogeneration Diesel	SCR 200kWe	Modern diesel unit, installed in Europe, using Selective Catalytic Reduction (SCR) and an oxidation catalyst	39 (el.) 43 (th.)	15	New units & associated average European oil chain
Cogeneration Natural gas	Mini 2kWe	Modern Lambda=1 motor gas cogeneration plant in Europe, monovalent operation	25 (el.) 65 (th.)	27	• New units & average Central European natural gas chain
	lean burn 50kWe	Modern gas cogeneration plant in Europe, without catalysts	30 (el.) 54 (th.)	23	• Different gas origins may change the contribution from the upstream chain to external costs
	lambda=1, 160kWe	Modern Lambda=1 motor gas cogen plant in Europe, using three-way catalytic converter	32 (el.) 55 (th.)	23	
	lean burn 500kWe	Modern gas cogen plant in Europe, without catalysts	36 (el.) 46 (th.)	18	
	lean burn 1Mwe		38 (el.) 44 (th.)	16	
Heat Pumps	air-water 10kW UCTE-el.	Modern present technology, SPF = 2.8, UCTE electricity mix in year 2000	280***	-	• UCTE electricity mix (2000) = Lignite 11.7%, Hard coal 14.5%, Oil 6.4%, Natural Gas 12.6%, Industrial gases 1.6%, Nuclear 35.6%, Hydro 14.7%, Wind & PV 0.8%, rest (including pumped storage & small cogen) 1.7%
	brine-water 10kW UCTE-el.	Modern present technology, 150m deep borehole, SPF = 3.9, UCTE el. mix in year 2000	390***	-	• Refrigerant R134a
	air-water 10kW future CC-el.	Future technology, SPF = 4.2 (seasonal performance factor), electricity from gas CC	420***	-	Technology level expected in 2020-2030
	brine-water 10kW future CC-el	Future technology, SPF = 5.0, electricity from gas CC	500***	-	
	air-water 10kW future nuclear-el.	Future technology, SPF = 4.2 (seasonal performance factor), nuclear electricity	420***	-	
	brine-water 10kW future nuclear-el.	Future technology, SPF = 5.0, nuclear electricity	500***	-	

* Boundary for the analysis is the outlet of the boiler/cogeneration unit; the distribution in house is excluded. The given unit capacity is representative of a class more than of a specific boiler/cogeneration unit.

** Calculated on the basis of the Low Heating Value (LHV) of the fuel.

*** Based on SPF = Seasonal Performance Factor (yearly averaged Coefficient Of Performance, COP).

Major outputs of life cycle assessment are cumulative emissions from all steps of the energy chain. In order to estimate the related external costs, average damage factors per ton pollutant have been used (Table 9). The factors refer to the most important pollutants and take into account the latest methodological advances of the NewExt and ExternE-Pol phases of ExternE. They represent an average location of the emission sources in EU15. It has been assumed that only the fraction $PM_{2.5}$ within PM_{10} causes health damages. For each species, the same factors have been used for the direct emissions from the power plant as well as from the other contributions to cumulative emissions, i.e. from the infrastructure of the power plant as well as the rest of the energy chain (upstream and downstream). Although some of these indirect emissions may occur outside Europe, they are generally minor contributors to total. Furthermore, the characteristics of the database are such that application of location-specific damage factors for indirect contributions is not straightforward. Extension of the methodology should be attained in follow-up work. The external costs per kWh are calculated by multiplying the cumulative emissions of each system with the damage factors.

Table 9. Damage factors per ton of pollutant emitted in EU15.

Species	Damage factors [$€_{2000}$/ton]
CO_2-equiv.	19
SO_2	2939
NO_x	2908
PM_{10}	11723
$PM_{2.5}$	19539
Arsenic	80000
Cadmium	39000
Chromium	31500
Chromium-VI	240000
Chromium-other	0
Lead	1600000
Nickel	3800
Formaldehyde	120
NMVOC	1124
Nitrates, primary	5862
Sulfates, primary	11723
Radioactive emissions	50000 * [$€_{2000}$/DALY]

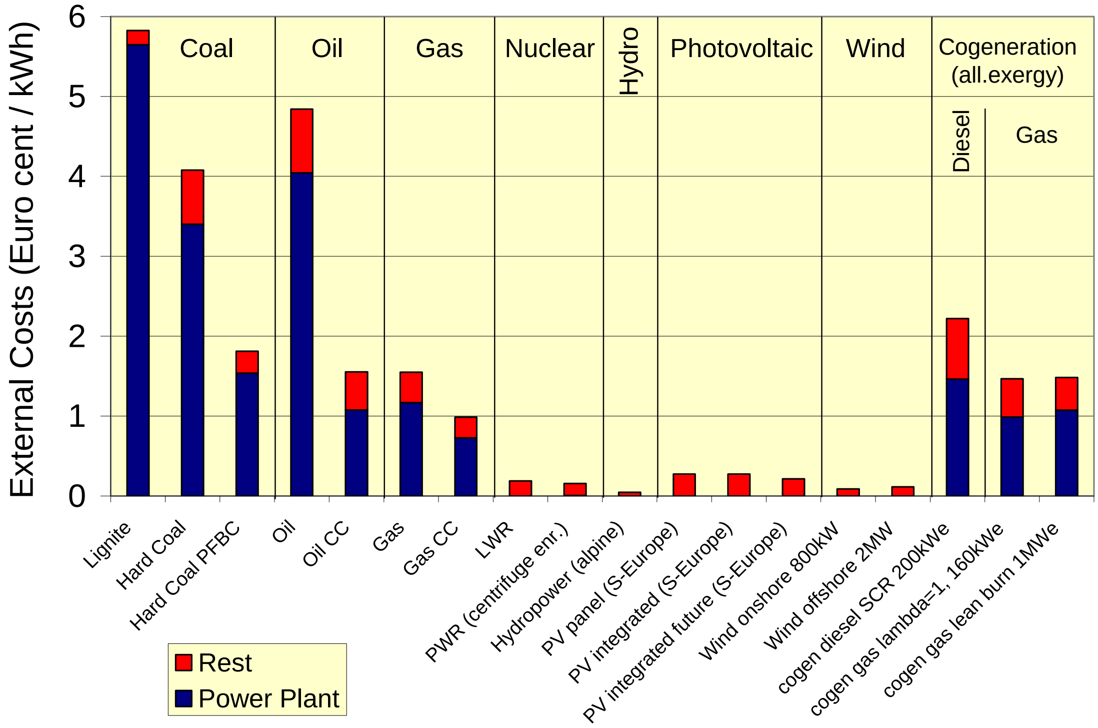
* Disability-Adjusted Life Years (DALY), assuming equal to the unit value of chronic YOLL.

2.2.5.3. Results for Current and Advanced Electricity Systems

Results obtained for new and current technologies on the basis of ecoinvent are discussed in the first part of this section, whereas the second part shows results for new energy technologies for energy chains expected for Germany in year 2010. Fig.9 presents the results for current and advanced electricity systems, with the external costs per kWh in part a) and the contributions of the individual pollutants in part b). Likewise Fig.10 summarises the results for the different heating systems.

Fig.9. External costs of current and advanced electricity systems, associated with emissions from the operation of power plant and with the rest of energy chain.

a) the costs in €cent/kWh



b) the contribution of the individual pollutants

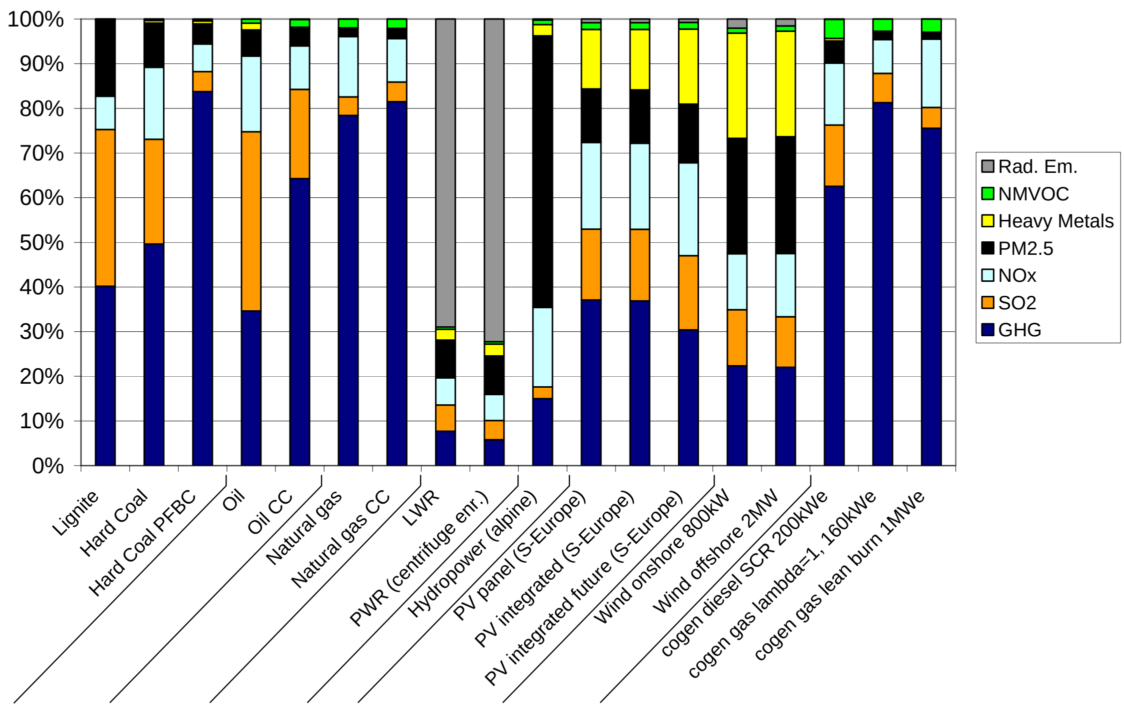
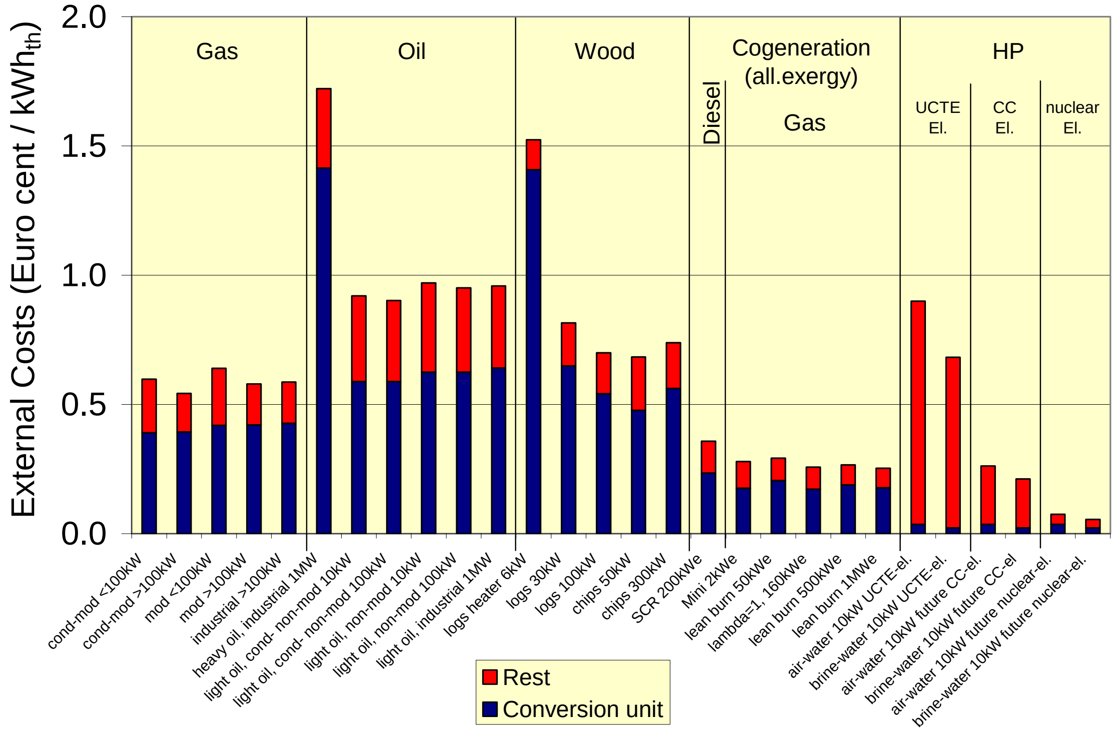
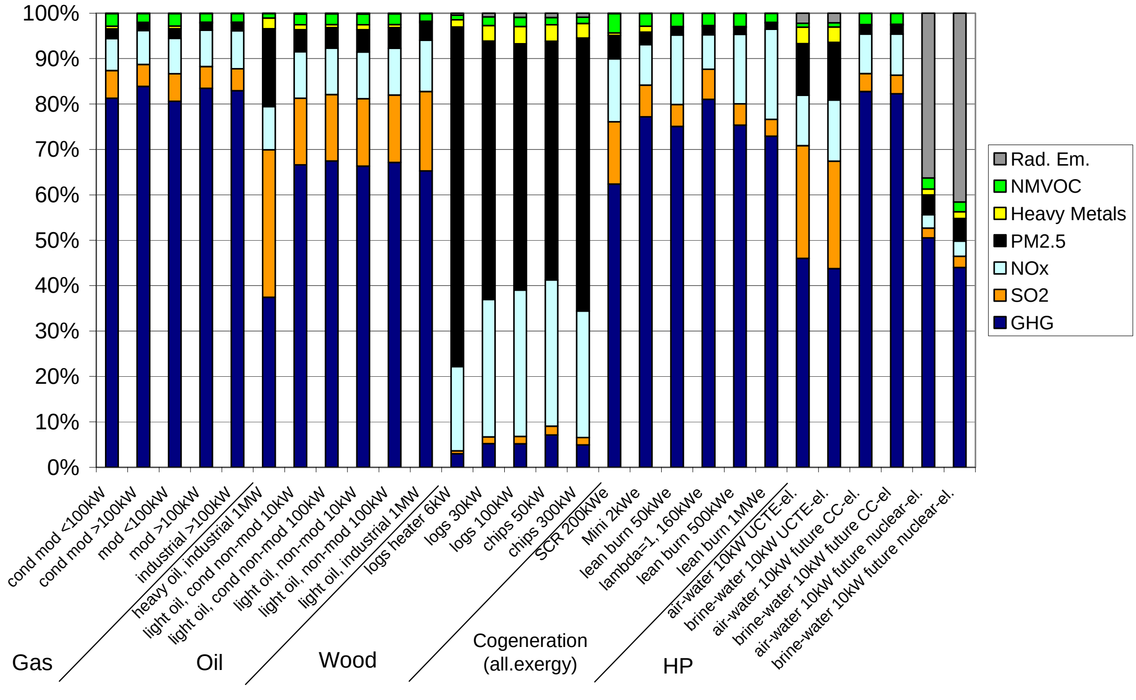


Fig.10. External costs of heating systems, associated with emissions from the operation of boiler/cogeneration unit and with the rest of energy chain.

a) the costs in €cent/kWh



b) the contribution of the individual pollutants



Current fossil systems exhibit the highest external costs, in the range of 1.6 - 5.8 c€/kWh (Fig.9). Introduction of advanced technology (CC and PFBC) substantially reduces the external costs of fossil systems, but they still remain in the range 1 - 2 c€/kWh. This also applies to cogeneration, for which gas technology generates external costs one third lower than diesel technology. Greenhouse gas (GHG) contribution to total costs is prevailing over other species for advanced fossil technologies, making about 80% of total external costs for CC and PFBC. Current averages of coal and oil plants show still high contributions from SO_2, depending on the extension of installation of scrubbers in UCTE.

Nuclear external costs are below 0.19 c€/kWh of which 70% is radioactivity-dependent. However, if discounting would be introduced, this contribution would strongly decrease, because most of the calculated damages from radiation are either related to very long term emissions (e.g., radon from uranium mill tailings) or to very long-lived isotopes giving very small doses. On the other hand, the present estimation of external costs from ionizing radiation is based on a preliminary calculation using the Disability-Adjusted Life Years (DALY) concept, a rough attribution of cost/DALY, and a not complete (though meaningful) subset of isotope releases from the ecoinvent database. It is recommended to rework the estimation of damage factors from radioactive emissions in future projects of the ExternE series. The nuclear power plant contributes 5% or less to external costs from the nuclear chain.

Wind onshore with nearly 0.09 c€/kWh performs slightly better than wind offshore with 0.12 c€/kWh. Monocrystalline silicon photovoltaic (PV) panels of European fabrication, installed in Southern Europe cause nearly 0.28 c€/kWh, which would mean 0.41 c€/kWh for the average yield of 800 $kWh/kW_{peak}\cdot a$ in Central Europe. Assuming improvements in manufacturing technology of crystalline silicon, improved cell efficiency and an expanded photovoltaic market, 0.21 c€/kWh has been estimated for future (2010) systems. External costs associated with imported panels may differ due to different manufacturing technology and electricity supply. Due to the relatively high material intensity of PV and wind, the contribution from heavy metals is about 15% and nearly 25%, respectively. Hydropower exhibits the lowest external costs of all systems, below 0.05 c€/kWh, but this may increase on sites were higher direct emission of GHG from the surface of reservoir occur.

In general, gas boilers have lower external costs than boilers burning light oil: approximately 0.6 c€/kWh_{th} vs. 0.94 c€/kWh_{th} (Fig.10). The upstream chain of gas and light oil contributes roughly one third to total external costs. GHG contribute two third of total external costs for oil, over 80% for gas boilers. Burning heavy oil gives the highest damages with over 1.7 c€/kWh_{th}, where SO_2 makes about 33% and GHG 38% of the damages. A range of about 0.7 - 0.8 c€/kWh_{th} has been calculated for wood boilers, where the upstream chain contributes 20% - 30% to total damages. Particles and nitrogen oxides emissions contribute most, i.e. nearly 60% and about 30%, respectively, to total damages. The modern fireplace gives more than 1.5 c€/kWh_{th}, mostly due to the high particle release. GHG contribute 7% or less to total external costs for modern wood systems, because the CO_2 from wood combustion is compensated by tree sequestration.

Cogeneration plants perform well when allocation is based on exergy: 0.36 c€/kWh_{th} for diesel and an average of 0.27 c€/kWh_{th} calculated for the gas units.The magnitude of external costs of heat pumps (HP) is controlled basically by two factors: the Seasonal Performance Factor (SPF) and the energy supply source. For current systems and average UCTE electricity mix the external costs are nearly 0.9 c€/kWh_{th} and 0.7 c€/kWh_{th} for the air-water HP and brine-water HP, respectively. Due to the fact that about 26% of the UCTE electricity mix is from coal systems, damages from SO_2 contribute nearly one quarter to the total external costs. For future HP technologies and electricity delivered by gas CC or nuclear, these costs go down to 0.26 c€/kWh$_{th}$ and 0.21 c€/kWh$_{th}$ or nearly 0.08 c€/kWh$_{th}$ and 0.06 c€/kWh$_{th}$, respectively for the two heat pump systems and the two electricity supply cases (Fig.10).

Advanced power and cogeneration plants for electricity supply from fossil fuels and biomass were also analysed based on Briem et al. [2004a] and Mörschner and Eltrop [2004]. Work for both fuel types was based on Frischknecht et al. [1996], modifying the most important processes to reflect the situation (power plant technologies, fuel chains) expected in Germany around 2010. Table 10 shows the main technical parameters of the plants analysed, as well as the abbreviations used.

Table 10 Main technical parameters of the plants analysed for German conditions around 2010.

		Electricity production				Cogeneration (Biomass)		
		Natural gas combined cycle	Hard coal IGCC	Lignite IGCC	Lignite steam turbine	Steam turbine, flue gas condensing	Internal comb. engine, biomass gasification	Organic Rankine cycle
	Unit	NG-CC	C-IGCC	L-IGCC	L-ST	B-ST	B-ICE	B-ORC
Electric capacity	MW_{el}	817	450	450	1050	6.1	2 x 1.2	1.0
Thermal capacity	MW_{th}	-	-	-	-	max. 22	max. 4.4	6.3
Electric Efficiency	%	60	51.5	51.5	50	19.5	28.9	10.6
Full load operating hours (electricity)	h/a	7500	7500	7500	7500	6560	7500	4600
Full load operating hours (heat)	h/a	-	-	-	-	4660	2620	4890
Fuel		Natural gas, high pressure	Coal, mix, at power plant	Rhenish lignite	Rhenish lignite	Wood chips	Wood chips	Wood chips

The following airborne emissions were included in the analysis: CO_2, CH_4, N_2O, NO_x, SO_2, NMVOC, and PM_{10}, with the damage factors average for EU15 emissions at stacks, shown in Table 9, for the direct emissions of the power and cogeneration units and "adjusted" damage factors developed in order to account for different conditions for up- and downstream processes (including construction of the power plant, fuel supply, and decommissioning of the power plant), i.e. different heights of point sources and population density. The adjusted damage factors are given in Table 11. For electricity production from cogeneration the emissions are allocated by exergy. CO_2 emissions from biomass burning were treated as climate neutral, i.e. they were valued with a cost of zero.

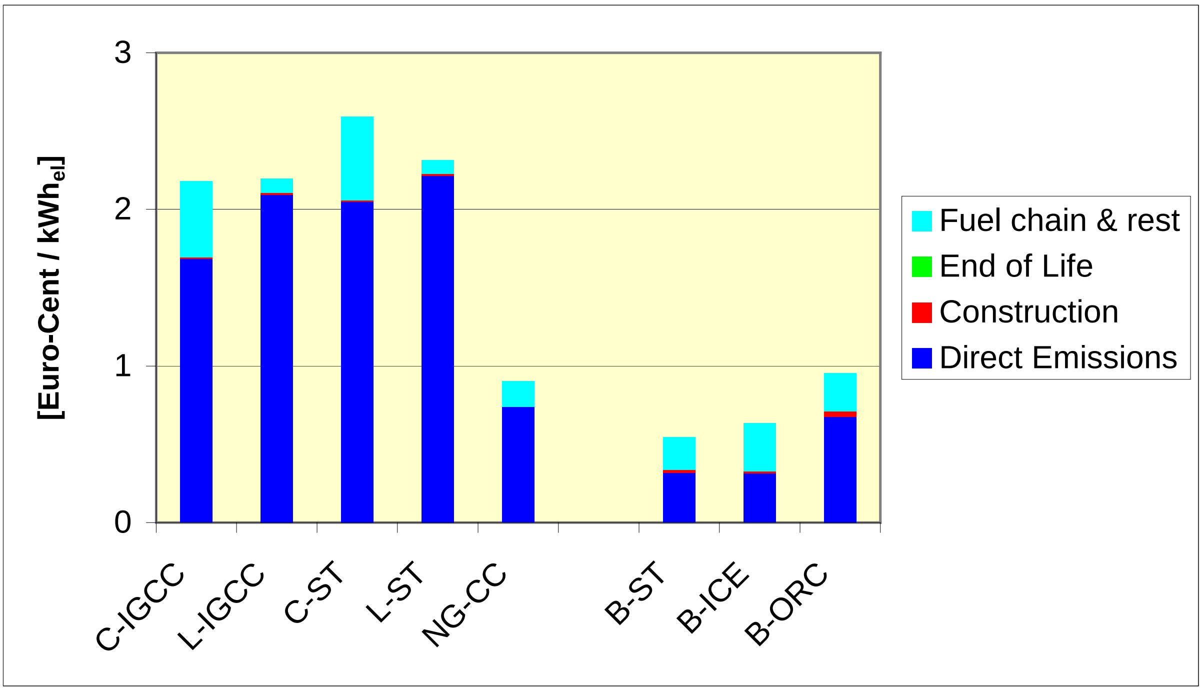
Table 11 Adjusted Damage Factors for the calculation of external costs caused by up- and downstream processes (including construction of the power plant, fuel supply, and decommissioning of the power plant) of fossil and bio-fuelled technologies.

[Euro/kg]	Damage Factors (Euro/kg)
Group/Species	(EU-15 adjusted -fossil)
GHG	0.019
SO_2	3.442
NO_x	3.054
PM_{10}	14.698
NMVOC (total, unweighted - w/o Formaldehyde)	1.124

Fig.11 presents the calculated external costs due to electricity production. The lowest costs are caused by the biomass steam turbine (B-ST). The natural gas combined cycle (NG-CC), the biomass internal combustion engine (B-ICE) plants and the biomass organic rankine cycle plant (B-ORC) cause also comparably low external costs, below 1 Euro-Cent/kWh_e. The coal and lignite plants cause external costs above 2 Euro-Cent/kWh_e.

The results for energy systems in Fig.11 complement the spectrum of new technologies illustrated in Figs. 9 and 10. The external costs calculated for natural gas CC match well – the minor difference can be easily explained with the slightly different net efficiency and differences in the main assumptions for the upstream chain (origin of the gas and leakage rates assumed). The advanced hard coal technologies PFBC and IGCC exhibit external costs of the same order of magnitude.

Fig.11. External costs of new fossil- and bio-fuelled energy systems at different life cycle stages, using average damage costs for EU15 for power plant operation and adjusted EU15 damage factors for other life cycle stages.



A comparison of the process chain approach (PCA) and the combination of the PCA with input-output-analysis (IOA) – the so called hybrid approach – shows that if no single processes are dominating in a system, the use of IOA can help to cover residual emissions with small efforts. In the case of fossil systems as shown in Fig.11, the results obtained with detailed PCA and the hybrid-approach would not differ significantly because the emissions over the whole life cycle are dominated by emissions during operation phase, and this life cycle stage is balanced well by both approaches.

2.2.6. Implementation in Central and Eastern Europe

2.2.6.1. Objectives and Methods

The goals of this work package (WP) were

- to build up scientific capacity in Eastern Europe for the analysis of external costs, and
- to estimate the external costs of energy use in the Czech Republic, Hungary and Poland.

Several round tables, seminars and conferences were organized to extend scientific capacity on assessing external cost in the Central and Eastern European Countries (CEEC) [see details in TIP and full report]. The concepts and approaches that have been used for expressing external costs from energy production and transport in CEEC were reviewed and discussed during these seminars. The main institutes and organizations that have a major role in this field in CEEC were contacted by WP team and the co-operation with several of them was established.

Here we present a summary of the approach and the results, beginning with the collection of data for the technical characteristics of the power and transport sectors and for the emission of pollutants. Monetary values have been provided for impact categories where significant differences were expected between CEEC and EU15. Then the external costs of energy production and transport were assessed using the EcoSense and RiskPoll software packages of ExternE.

2.2.6.2. Data for Energy and Transport in CEEC

The fuel mix used for electricity production in the Czech Republic, Hungary and Poland is shown in Table 12. We calculated the external costs for following technologies because of their major share on electricity production in HU, PL and CZ:

- Coal fired power plant burning hard coal
- Coal fired power plant burning brown coal
- Natural gas fired power plant
- Lignite fired power plant.

For each type of fossil fuel we selected the reference power plants with the characteristics shown in Table 13. Since no specific data were available for upstream and downstream processes, we used LCA data from Röder et al [2004].

Table 12. Electricity generation by source in selected CEEC in 2002. Source: IEA/OECD Energy Balances and IEA/OECD Energy Statistics of OECD Countries.

	Czech Republic		Hungary		Poland	
	TWh	%	TWh	%	TWh	%
Coal	50.7	66.7%	8.98	24.9%	134.69	94.5%
Oil	0.4	0.5%	2.8	7.8%	2.38	1.7%
Gas	3.0	3.9%	10.08	27.9%	2.2	1.5%
Renew. & Waste	0.7	0.9%	0.08	0.2%	0.89	0.6%
Nuclear	18.7	24.7%	13.95	38.7%	0	0.0%
Hydro	2.5	3.3%	0.2	0.6%	2.28	1.6%
Total	76.0	100%	36.09	100%	142.5	100%

Table 13. Characteristics of the reference power plants in 2002.

a) in Czech Republic

Fuel	brown coal	hard coal	lignite
Local environment	rural	urban	rural
Stack height	210	269	100
Desulphurization	yes	yes	yes
Energy production, net [GWh/yr]	7 000	2000	300

b) in Hungary

Fuel	brown coal	hard coal	natural gas
Local environment	rural	rural	rural
Stack height	122	102	250
Desulphurization	no	no	no
Energy production, net [GWh/yr]	500	500	2400

c) in Poland

Fuel	hard coal	brown coal
Local environment	rural	rural
Stack height	200	300
Desulphurization	yes	yes
Energy production, net [GWh/yr]	8300	25500

In the Czech Republic energy statistics were obtained from energy companies which publish their annual reports on their web sites. We also used the statistics from the Czech Energy Regulatory Office. Emission data and selected technical parameters of pollution sources were taken from the Register of Emissions and Air Pollution Sources (REZZO) which collects data on stationary and mobile sources. This register is operated by the Czech Hydrometeorological Institute (CHMI). We have crosschecked the REZZO data with data obtained directly from energy producers. CUP also collected various predictions for CEEC countries for all relevant pollutants.

In Hungary the Clean Air Action Group (CAAG) for the collection of data from the energy sector was contacted. Data were also obtained from Hungarian Energy Office (MEH) and directly from energy companies.

In Poland the energy data collection was based on a collaboration with Polish energy agencies and appropriate power plants. The meteorological data for local dispersion modeling were obtained from Polish Hydrometeorological Institute.

Data on transport inventory were gathered from different sources with different levels of detail. The transport data for the Czech Republic include an inventory of motor vehicles and railway equipment, their performance and their total emissions for the years 2000-2002 as provided in the Statistical Yearbook of the Ministry of Transport. Furthermore, emissions from road transport on a regional scale were obtained from the Transport Research Centre in Brno.

For Hungary we retrieved equipment inventory of motor vehicles, transport performance and aggregated data on emissions from mobile sources for the time series 1990-2000 from Hungarian Central Statistical Office.

For Poland the inventory of motor vehicles was determined based on data from Road Transport Institute in Warsaw. They also provided an inventory of locomotives and rail cars, but for the emissions we could find only the total from railway transport for 1997, from the Central Statistical Office.

2.2.6.3. Data for Monetary Valuation in CEEC

The other task was to provide information on the monetary valuation of the different impact categories. Data for costs of respiratory and cardiovascular health effects related to air pollution have been collected in Poland and the Czech Republic. The available data cover only part of the population and we assume them to be representative. The results are summarized in Table 14.

The cost of a doctor visit in the Czech Republic as well as the cost of hospitalization was derived from statistics of the General Health Insurance Company for the year 2001. The cost of treating asthma attack is given as price of medication as reported by the State Institute for Drug Control. Average amount of sick leave is based on calculation formula set by law for average monthly salary in 2001 retrieved from the Czech Statistical Office. Data for the average length of sick leave and total absenteeism were retrieved from statistics provided by Institute of Health Information and Statistics for 2001.

In Poland all the data except cost of treating asthma attack and sick leave were obtained from the Malopolska Health Fund for 2003. The coverage is limited to the southern part of Poland but the reliability was verified by the National Health Fund. Average length of sick leave was calculated as the total work days lost divided by the number of employees, based on data from the Statistics of the Social Insurance Fund 2002.

Table 14. Medical Costs in Czech Republic and Poland for 2002, in € per case.

		Czech Republic	**Poland**
	Doctor visit		
General practitioner	Adults	3	
	Children	4	
Cardiology		17	
Pulmonary		6	6
	Asthma attack		
Inhalation	Per package	13-17	16-33
Antiasthmatics	Per package	8,3	
	Hospitalization		
General		70	62
Respiratory		64	40
Cardiovascular		114	105
	Sick leave		
Per case	Respiratory	165	308
Per case	Cardiovascular	636	(per month)
Average length of incapacity for work	Respiratory	16,3 days	14,7 days
	Cardiovascular	60,5 days	(in general)

The differences between Poland and Czech Republic are not large. We assume that the costs in Hungary will be comparable, and we have contacted Hungarian National Institute for Strategic Health Research for verification.

Data on inventory of materials and repair costs were difficult to obtain because in CEEC this issue has not much received much attention. However we were able to obtain specific data for Prague, see Table 15. On this topic we have collaborated with the National Research Institute for Protection of Materials.

Table 15. Cost of materials maintenance, in €/m^2 for 2004.

Surface type	Czech Rep.	EU	Ratio
Natural stone	226	341	0.66
Paint	3	15	0.20
Zinc	22	31	0.72
Limestone	226	341	0.66
Sandstone	226	341	0.66
Rendering	13	38	0.33
Mortar	16	38	0.42
Galvanized steel	22	n.a.	

So far the values in Tables 13 and 14 have not been used; instead EcoSense has been run without any modifications, as it has been for all the EU15 countries until now. Any change due to these values would have been completely unnoticeable because the contribution of these endpoints is negligible compared to mortality for which a single VOLY value has been chosen. The use of a single VOLY for all countries of EU25 is a political choice, similar to the choice made at the start of ExternE in the early 1990s when a single VSL was chosen for all countries of EU12 despite very large differences in GDP/capita.

2.2.6.4. Results for Power Production

For typical power plants combusting various types of coal and natural gas were calculated marginal external costs which are expressed in eurocents per kWh of produced electricity. Values presented in Table 16 were calculated by using of EcoSense 4.1. Impact on local and regional level caused by operating selected power plants is represented by values related to damage on building material, crops and human health. Impact of CO_2 emissions on climate change is expressed by the value of category global warming. Estimated value for the impact of 1 tonne of carbon dioxide is 19 €. This value is based on marginal abatement costs to reach environmental target negotiated in Kyoto for Germany [Friedrich et al, 2001] and it is in the range of the mainstream damage cost estimates.

Most of the external cost of these power plants is due to two categories. The first is global warming which comprises one half to two thirds of the total. The second is the impact on human health which is split between mortality (60 %) and morbidity (40 %). Impacts on building materials and crops are negligible (less than 1 % of total). To assess the local contribution (up to 50 km from pollution source) we used the RiskPoll 5.1 model, taking into account local metrological conditions (hourly data) and population density distribution (grid 5 x 5 km). RiskPoll results show that the local impact contributes a small portion (2-6 %) to the total.

Since EcoSense and RiskPoll use the monetary valuation of EU15, the costs in Tables 15 and 16 should be reduced. However, the end points in Table 14 carry so little weight in the total that the change would be negligible. Far more important is the valuation of mortality, by far the dominant health cost. The EU15 value is based on contingent valuation and thus expected to be lower by the ratio of GDP/capita between CEEC and EU15. We have not tried to apply such a reduction because stakeholders in CEEC are likely to object to the use of a lower value of statistical life (VSL) or life year.

Table 16. Damage costs of the fuel cycles during 2002, in €c/kWh.

a) Czech Republic

	Hard coal	Brown coal	Lignite
Power generation			
Public health, of which	0.90	1.61	2.26
mortality	0.60	1.08	1.53
morbidity	0.30	0.53	0.74
Crops	-0.007	-0.01	-0.007
Materials	0.05	0.08	0.16
Global warming	1.90	2.02	3.38
Total	2.84	3.70	5.79
Upstream fuel cycle stages	0.33	0.08	0.15
TOTAL	3.17	3.78	5.94

b) Hungary

	Brown coal	Hard coal	Natural gas
Power generation			
Public health, of which	10.84	7.82	0.57
mortality	7.30	5.26	0.38
morbidity	3.54	2.56	0.19
Crops	0.03	0.04	0.01
Materials	0.82	0.56	0.03
Global warming	3.51	2.64	0.80
Total	15.20	11.02	1.42
Upstream fuel cycle stages	0.16	0.43	n.q.
TOTAL	15.36	11.45	1.42

n.q.: not quantified

c) Poland

	Brown coal	Hard coal
Power generation		
Public health, of which	4.10	3.47
mortality	2.51	2.12
morbidity	1.60	1.35
Crops	0.01	-0.003
Materials	0.30	0.22
Global warming	1.93	2.20
Total	6.34	5.89
Upstream fuel cycle stages	0.10	0.41
TOTAL	6.45	6.30

2.2.6.5. Results for Transport

One of the problems with traffic in Prague is a major thoroughfare that passes directly through the inner city. This is the part of the town with the highest population density and traffic. In this case study we therefore estimated the impact of a car going one km on this road. To put this road to contrast with situations elsewhere in the Czech Republic we chose rural area in central bohemia.

Data we used for these calculations were obtained from various sources. Data for emission from cars were obtained from the MEFA database [Sebor, G. et al, 2002], meteorological data from Czech Hydro meteorological institute and data for receptor density (population) from Czech Statistical Office and Prague City Hall.

For calculation we used RiskPoll software version 5.1. This was mainly because in the Czech Republic the detailed meteorological data (stability class, mixing height, temperature gradient etc.) which are needed for EcoSense 4.1 are unreasonably expensive and beyond the project budget. RiskPoll needs less detailed data that we were able to obtain. The developer of RiskPoll, Dr. Joe Spadaro of ARMINES, helped us with these calculations. Results for Prague (urban) and central bohemia (rural) are shown in Table 17. As average speed we assumed national limits which are 50 km/hr in a city and 90 km/hr outside of a city.

Table 17. External costs from traffic in the Czech Republic for the year 2000 in €c/km.

	Health	GHG	Total
Passenger cars			
URBAN - Gasoline EURO 3	1.48	0.30	1.78
RURAL - Gasoline EURO 3	0.15	0.21	0.36
URBAN - Diesel EURO 3	3.18	0.35	3.53
RURAL - Diesel EURO 3	0.46	0.25	0.71
URBAN - Gasoline EURO 2	3.45	0.34	3.80
RURAL - Gasoline EURO 2	0.27	0.26	0.52
URBAN - Diesel EURO 2	10.63	0.40	11.03
RURAL - Diesel EURO 2	0.52	0.30	0.82
Light duty vehicles			
URBAN - Diesel EURO 2	30.67	0.55	31.23
RURAL - Diesel EURO 2	2.52	0.35	2.87
Heavy duty vehicles			
URBAN - Diesel EURO 2	206.05	1.26	207.31
RURAL - Diesel EURO 2	12.01	1.76	13.78
Buses			
URBAN - Diesel EURO 2	151.40	1.21	52.61
RURAL - Diesel EURO 2	11.07	1.66	12.74

2.2.6.6. Conclusions for CEEC

The results for the Czech Republic show that external costs incurred by lignite power plants are twice as high as for plants burning brown or hard coal. The main reason is due to the relatively low carbon efficiency of lignite. External costs brown and hard coal power plants in Hungary are twice as high as in Poland and three times as high as in the Czech Republic. However, one should note that these results are for 2002; thanks to continuing reductions of the emissions significantly lower external costs can be expected in the future.

Local impacts from power plants are small, about 3.9 % of the total in the case of the brown coal. This is because of several factors. Main reasons are location of the plant which is situated in a rural area (low population density) and height of the stack which dilutes the pollutants before they reach the ground. Also, the main contribution comes from secondary rather than primary pollutants, and the secondary pollutants are created mostly beyond the local zone.

2.3. Assessment of Results and Conclusions

Significant progress has been achieved in updating, validating, improving and extending the methodology of ExternE, although most of the new elements have not yet been implemented in the current results. Among the extensions of the methodology are preliminary estimates of the externalities of energy supply security; their contribution to the total does not appear to be large. A new approach for the elicitation of monetary values has been developed, based on multicriteria analysis by stakeholders and environmental experts; a first test has been carried out to obtain values for mortality, acidification and eutrophication, but the results are still too preliminary to be applied at the present time.

The LCA inventory for the emission of pollutants has been updated to correspond to the technologies in use in 2000, and external costs have been calculated for a wide variety of advanced technologies, including advanced photovoltaics.

The ExternE methodology has been implemented in the Czech Republic, Hungary and Poland, and damage costs have been calculated for power plants and for transport.

All the results, in particular the detailed reports for each work package, are available at the ExternE web site www.externe.info. The results of this project are very important for policy makers and for stakeholders.

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