Differences in methodologies used for externality assessment

Lotte SCHLEISNER
Risø National Laboratory, Denmark

1 - ABSTRACT

The production of energy gives rise to different kinds of damage to the environment depending on the specific type of technology used in producing a given energy supply. The common term that expresses the costs of these environmental damages is externalities. These are costs that are not included in the cost and price structure faced by the producer and the consumer.

During the last few years, external costs related to power production technologies have been calculated making use of different methodologies. The external costs may turn out to be very different for the same fuel cycle depending on the methodology that has been used to assess the externalities.

The paper will focus on some of the most important reasons for differences in the results. As an example, two studies using the same approach and with integrated computer models are compared. The models are in principle built up in the same way with air dispersion modules and dose-response functions for the calculation of impacts.

Although the models seem more or less similar, the resulting external costs turn out to be four times larger when one model is used compared to the other model for the same power plant.

2 - INTRODUCTION

Choosing one energy option over another may influence many aspects of society and the environment, which should be accounted for if we want to procure the highest benefits for society. These impacts on society or environment, which have not previously been accounted for, are termed externalities. Externalities related to energy production are in general defined as costs imposed on society that are not accounted for by the producers or consumers of energy. In other words, damages not reflected in the market price. Normally, when one thinks of externalities related to energy, the externalities are environmental. A frequently cited example is the loss of production in fisheries due to the spillage of pollutants in rivers, which are a direct result of energy use. Public health, agriculture and ecosystems are other examples of aspects of society affected by the use of energy. The effects may be positive (external benefits) or negative (external costs), and their consideration may make some energy options more attractive than others in spite of their higher costs, or vice versa.

During the past several years, external costs related to power production technologies have been calculated using various methodologies. Some studies have used a “top-down” approach, calculating the externalities in an aggregated way, typically at a regional or national level, while others are based on a “bottom-up” approach, giving site-specific estimates. Some studies are based on a life cycle assessment, including all impacts from the extraction of materials for manufacturing to disposal, while others assess only impacts related to the fuel cycle.

Differences in methodologies may also be noticed in the quantification and valuation procedure. Some studies rely on previous estimates, which are not site-specific; others rely on abatement costs. Still other studies use the damage function approach, where the impact from each burden related to the technology is identified, and the damage caused by the burden is quantified and monetised.

An important aspect to consider when estimating externalities based on earlier studies is that some studies include only regional and local impacts and do not take into account the global impacts related to greenhouse gases.

Considerable uncertainty arises when considering the global externalities regarding the time horizon for the greenhouse effect, choice of dose-response function and monetisation values. Assumptions on famine and the monetisation of human life may be the totally dominant factor in estimating external costs.

The external costs may turn out to be very different for the same fuel cycle, depending on the methodology that has been used to assess the externalities. As a consequence of this, it seems rather important to be aware of the methodology that is made use of, which impacts are included and the monetary values used in a given study before utilising the external costs from a specific study as a policy measure. However, when the same approach is employed, the differences in the results for the same fuel cycle should be limited.

3 - EXTERNAL COSTS FROM DIFFERENCE STUDIES

In Table 1, seven externality studies are compared to show the large differences in results from different studies, assessing the same fuel cycle. The studies are chosen in order to cover old, well-known studies as well as new, less known, but interesting ones. Some of the new studies are based on results from earlier ones, while others implement new ideas concerning the methodology. Most of the studies chosen are bottom-up studies. In the table, the results from the different studies have been translated to mECU/kWh year 1995.

The results from the US-EC study are very low. One reason for this is that the global warming effect is not included in the results. The results from the Swiss study are rather high compared with those from the other studies. Looking at the natural gas fuel cycle the results in the ExternE study are high compared to the other studies. The reason for this is, that external costs related to CO_2 are included in this study, while CO_2 is not included in the New York study, and in the IEA study CO_2 is captured and therefore not monetised as an externality. Both the Swiss and Hohmeyer studies use a top-down approach, and both result in rather high external costs.

Table 1: External costs in mECU/kWh year 1995 for different fuel cycles for the studies chosen

	Coal /Oil	Natural gas	Nuclear	Wind	Biomass
ExternE (Schleisner et al. 1997)		NGCC: 7.1-80		Off-shore: 0.7-3.6 On land: 0.6-2.6	Biogas: 4.4-16.1
IEA (ETSU 1994)	PC: -0.6-5.4	NGCC: 0.6-2.3 IGCC: 1.6-3.9			
New York (Rowe et al. 1995)	PC: 4.5 FB: 0.9	NGCC: 0.2			Wood: 3.5
US-EC (Oak Ridge 1992)	Coal: 0.4-1.0 Oil: 0.1-0.2	0.01-0.2	0.1-0.2		Wood: 1.6
India (Bhattacharyva 1997)	Coal: 9.4				
Swiss (Ott 1997)	Oil:99.6-158	NGCC: 68-101	4.8-11.5		
Hohmeyer (Hohmeyer 1988)	Fossil fuels: 7.4-40	Fossil fuels: 7.4-40	7.8-78.3	On land:0.1	

PC: pulverised coal, FB: fluidised bed coal, NGCC: natural gas combined cycle, IGCC: Integrated gasification combined cycle

The above comparison shows the importance of possessing knowledge of which kind of methodologies have been used, which impacts are included etc. to explain why the numbers vary so much in different studies for the same fuel cycle. It is evident at the outset that the impacts, damages and externalities are very project specific. For example, emissions from an integrated gasification combined cycle coal plant are considerably lower than from a pulverised fuel plant. The specifications of the plant to be analysed will in this way affect the magnitude of the externalities. The specifications include installed pollution abatement technologies and their efficiencies as well as stack height and other source parameters that are used in atmospheric transport modelling. All of these parameters may be problematic, when they are used to define future technologies.

4 - OVERVIEW OF TWO STUDIES FOR FURTHER ANALYSIS

Two studies have been selected for further analysis. The following overview gives a description of these studies in regard to which methodology has been used, the impacts included, valuation methods etc.

4.1. ExternE National Implementation

The objective of the ExternE National Implementation project (CEC 1995), (Schleisner et al. 1997) has been to establish a comprehensive and comparable set of data on externalities of power generation for all EU member states and Norway. The tasks include the application of the ExternE methodology to the most important fuel cycles for each country. The study is from 1997. A wide range of technologies has been analysed, covering more than 60 cases for 15 countries and 11 fuel cycles, including fossil fuels, nuclear and renewables.

The methodology used for assessing externalities of the fuel cycles selected is a bottom-up methodology with a site-specific approach; i.e. it considers the effect of an additional fuel cycle, located in a specific place. The study estimates the damage costs related to different fuel cycles.

Quantification of impacts is achieved through the damage function approach, an approach that proceeds sequentially through a pathway, where emissions and other types of burdens, such as risk of accident, are quantified and followed through to impact assessment and valuation. The study employs a unified approach to ensure compatibility between results. This is being achieved through the use of the EcoSense model, which assesses the environmental impacts and resulting external costs from electricity generation systems. The system has an environment database at both a local and regional level including data on population, crops, building materials and forests. The system also incorporates two air transport models, enabling local and regional scale modelling to be made. A set of impact assessment modules, based on linear dose-response relationships, and also a database of monetary values are included for different impacts. There is no model for ozone included in the software, but ozone is estimated by assuming a simple relationship between it and NO_x.

Local, regional as well as global impacts are assessed. The monetisation values used for CO_2 have been estimated by employing two different models. Four different values have been used: 3.8 ECU/t CO_2, 18 ECU/t, 46 ECU/t and 139 ECU/t CO_2. The estimate given in Table 1 is based on a CO_2 value of 18 ECU/t.

The underlying principle behind the economic valuation is to obtain the willingness to pay by the affected individuals in order to avoid a negative impact, or the willingness to accept the impact. A limited number of goods - crops, timber, building materials, etc. - are directly marketed. However, many of the more important goods of concern are not directly marketed. These include human health, ecological systems and non-timber benefits of forests. Alternative techniques have been developed for valuation of such goods, the main ones being hedonic pricing, travel cost methods and contingent valuation.

For the valuation of health risk, a value of 3.1 MECU has been used for the value of a statistical life (VSL). This value has been used for valuing fatal accidents and mortality impacts in climate change modelling. In the case of deaths arising from illness caused by air pollution, the YOLL (years of life lost) approach has been used. YOLL depends on a number of factors, such as how long it takes for the exposure to result in illness and the survival time for the individuals.

4.2. The New York Electricity Externality Study

In this study (Rowe et al. 1995) the EXMOD model is used, developed at the Tellus Institute in Boston. The model is built up in the same way as the European EcoSense model. The EXMOD model is an American model, which models air dispersion from locations in New York State to receptor cells throughout the north-eastern U.S. and eastern Canada. The study is from 1995.

It is a bottom-up study, also based upon "The damage function approach". Here damage costs are estimated for 23 new electric resource options within coal, oil, natural gas, nuclear, municipal solid waste, hydroelectric, biomass, wind, solar and demand side management. Default air emission rates, land use and other characteristics are specified for each facility in the model; however, these characteristics may be replaced. The air dispersion models in EXMOD are annual average or simple peak models used by U.S. regulatory agencies. The two models are used to predict short-range dispersion changes (<50 km) and long-range changes (50-1500 km) covering local and regional ranges. Also, ozone models are included driven by changes in NO_x concentrations. So far the model does not compute CO_2 damages (i.e. EXMOD implicitly assumes 0$/ton CO_2). However, it is possible to include other values for CO_2.

Impact calculations are based on dose-response parameters in EXMOD with default high, central and low parameter values. Based on a review of the literature, EXMOD uses a central VSL estimate of 4.0 million $ for individuals under 65 years, and a central estimate of 3.0 million $ for those 65 years or older. The argument for the decrease with age of VSL is that the years of expected remaining life does decrease with age. Thus, life expectancy and health status tend to decrease with age, so that the quality of life is reduced.

The study uses control cost valuation to estimate the environmental cost associated with various air emissions. For other impacts the study uses the contingent valuation method.

5 - COMPARISON OF RESULTS FROM EXTERNE AND THE NEW YORK STUDY

In the following a comparison of the impacts and damage costs related to air emissions is made for the two studies using the EXMOD model and the EcoSense model for the same plant. The plant is a pulverised coal-fired plant with a capacity of 300 MW. The impacts from this plant have been calculated in EXMOD as well as in EcoSense. However, EXMOD only includes data for emission levels and population for a part of the USA, while EcoSense only includes data for Europe. Therefore the same plant has been located in two different sites. Using EXMOD, the plant is situated in the Capital District of New York State, which is a suburban site outside of Albany, while the same plant in EcoSense is situated in Roskilde, Denmark.

Table 2: Central estimates of external costs for a coal-fired plant

Externalities	**EXMOD (mECU/kWh)**	**EcoSense (mECU/kWh)**
Human health	2.42	9.27
Mortality	*1.72*	*7.97 (32.46)*
Morbidity	*0.70*	*1.30*
Crops	0.002	0.134
Materials	0.10	0.22
Others	0.32	0
Greenhouse gas effect	0	6.10
Total	2.84	15.72 (40.21)

On comparing the externalities for the same power plant estimated in the two studies using different models, we see that the externalities are five times higher in the ExternE study than in the New York study. The difference in the external costs in the two studies reflects differences in impacts, differences in monetary values included in the two studies and especially differences in location of the plants.

The differences in the estimates that are most apparent are the extent of the greenhouse gas effect and the estimation of mortality. The greenhouse gas effect is not included in the New York study (by default monetised to zero), but in the ExternE study four different values of CO_2 have been estimated. In the above table, a value of 18 ECU/t CO_2 has been used. Excluding the global warming effect the estimate in EcoSense is three times higher than the estimate in EXMOD.

The external costs of mortality are four times as high in ExternE as in the New York study. EcoSense normally uses the YOLL approach; the figures in brackets are based on the VSL approach. In EcoSense mortality includes as well chronic as acute mortality, while EXMOD only covers acute mortality. Including as well chronic mortality as the global warming effect in EXMOD, the estimate in EcoSense becomes less than the estimate in EXMOD.

The emission of ozone causes mortality as well as morbidity cases for the population at large and also affects crops. The quantification and valuation of the emission of ozone has been included in the US EXMOD model, while in the case of the EU EcoSense model quantification and valuation of the emission of ozone has not been included. Instead, damages due to ozone are calculated, based on the NO_x emissions related to the plant. However, there is no large difference (14% higher in EXMOD) in the total external costs due to ozone, but the difference in crops is a result of ozone (0.13 mECU/kWh in ExternE).

Others are impacts like visibility loss, which is included in EXMOD, but not in the EcoSense model. Apart from global warming, human health is the dominant impact in both models. The reasons for the differences in the estimates of the effect on human health using the two models will be explained below.

5.1. Human health impacts

Human health impacts are the most dominating impacts, when analysing externalities from energy production technologies. The impacts may be divided into mortality and morbidity impacts. Mortality impacts are impacts causing fatal illness, while morbidity impacts are impacts causing different kinds of illness.

5.1.1. Mortality

The external costs of mortality are 19 times as high in ExternE as in the New York study, when using the VSL approach for both models. The VSL value used in EcoSense is larger than that used in EXMOD, which explains some of the difference between the results. However, the most important parameter is that as well chronic as acute mortality is included in EcoSense, while only acute mortality is included in EXMOD. (Chronic mortality is people dying from a long-cycle pain evoked by emissions). Another important factor is that impacts due to ozone is included in EXMOD, but not in EcoSense (ozone has been included in a later version of EcoSense).

5.1.2. Morbidity

In order to compare the externalities related to morbidity, the morbidity impacts, monetary values and damage costs for the two computer models have been compared. The morbidity impacts caused by ozone have been excluded from the analysis, as these impacts are omitted in the EcoSense model.

The damage costs have been calculated for the same pulverised coal-fired plant, using the EXMOD and EcoSense models. On comparing the damage costs for the same plant, we note that there are higher damage costs when the EcoSense model is used than when the EXMOD model is used. This is shown in Figure 1. The first two columns in the figure represent the external costs calculated in EXMOD, the first column with monetary values from EXMOD, the second with monetary values from EcoSense. The last two columns represent the external costs calculated in EcoSense, the first column with monetary values from EXMOD, the second with monetary values from EcoSense.

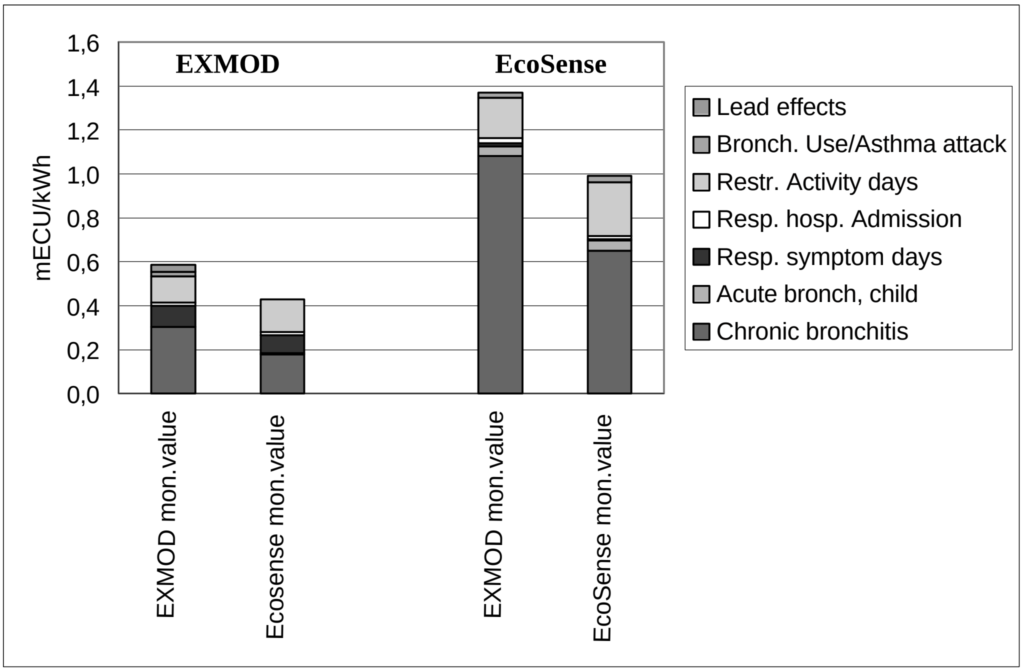

Figure 1: *Damage costs for morbidity calculated in EcoSense and EXMOD for the same power plant*

The figure shows more than a doubling of the damage costs using EcoSense rather than EXMOD. Chronic bronchitis is the dominant impact in both models, accounting for more than 50% of the damage costs. Also, restricted activity days are important, having a greater effect in EcoSense than in EXMOD. Restricted symptom days account for 16% of the damage costs using the EXMOD model, while they are negligible using the EcoSense model. Other impacts have lesser significance in both models.

As seen from the figure, using monetary values from EXMOD gives rise to higher external costs. When the same monetary values for the two models are used, much higher morbidity costs are encountered with the EcoSense model. Why are the damage costs different in two different models for the same plant when the same monetary values are used? To answer this, we note that one important parameter, not included in this analysis, may be the location of the plant. Using EXMOD the plant is situated in the New York Capital District, which, as noted above, is a suburban site outside of Albany, while the same plant in EcoSense is situated in Roskilde, Denmark. There may be differences in the dispersion and impacts of the emissions in the two cases, because of differences in background levels of the emissions in the two locations with different surroundings and because of differences in population size. This is shown in the following analysis.

5.2. Analysis of morbidity impacts

Figure 2 shows the importance of the difference in emissions in the two models. In EcoSense, SO_2 and NO_x have nearly the same weight, while particulates have much smaller weight on the impacts. Comparing this with the weighting factors in EXMOD, NO_x are the most dominant, followed by particulates, while SO_2 has a relatively small effect. The reason for these different dispersions may be that the background level of the emissions in Europe and US differ.

The air quality models predict the level of the emissions in different locations influenced by the emissions from the plant. This level is called the delta concentration. The delta concentration is the only factor that is calculated in the models and is different for the involved emissions. For each impact the delta concentration times the population is multiplied by a dose-response function. This is included in the EcoSense as well as the EXMOD model. The difference in delta concentration and population used in the two models is a result of different locations of the same plant, andwill result in different amount of impacts for the two locations.

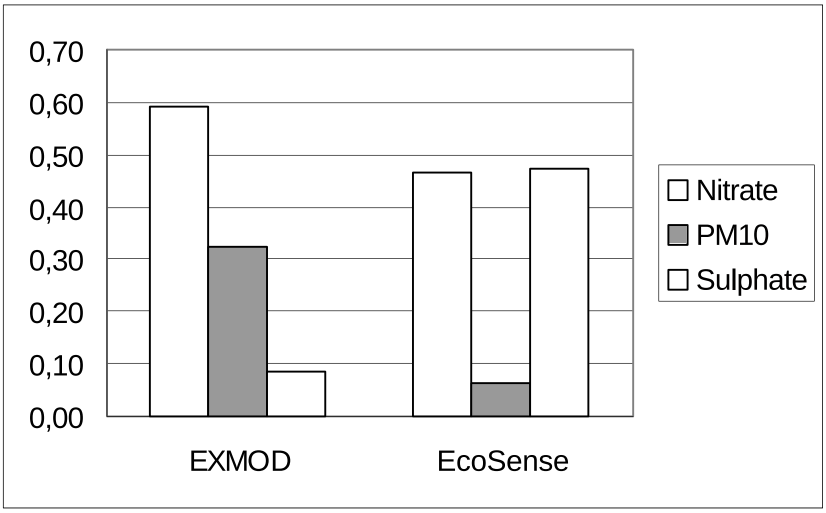

Figure 2: *The relative weighting factors of nitrate$_x$ particulates and sulphate on the impacts in the two models*

The different morbidity impacts calculated for the same plant in EcoSense as well as EXMOD have been compared in the next three figures. Figure 3 shows large differences in the extent of the impacts for the two models. Especially in the case of children with acute bronchitis, the impacts are much higher in EcoSense than in EXMOD. This is caused by differences in the dose-response functions used to define a case of children with acute bronchitis. As can be seen in Figure 1, cases of children with acute bronchitis are also more significant in EcoSense than in the EXMOD model.

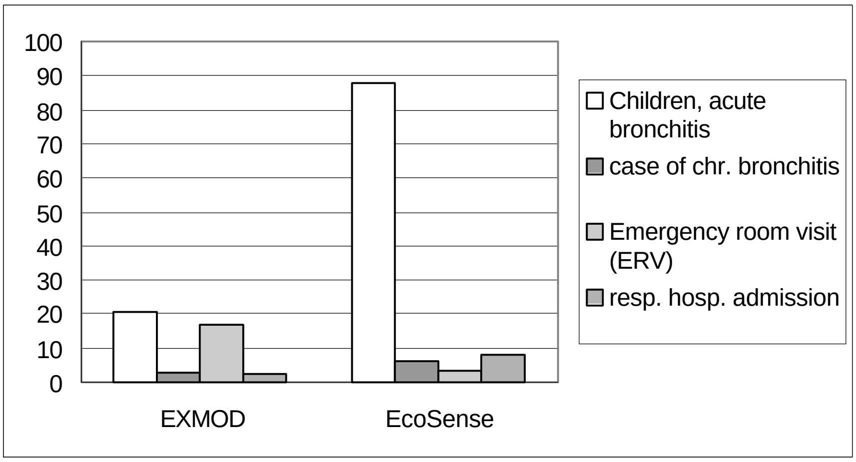

Figure 3: *Cases of impacts calculated in EXMOD and EcoSense*

Figure 4 shows the same impacts as Figure 3, but the cases of children with acute bronchitis have been excluded from the figure. This figure also shows large differences in the cases of impacts; however, the number of cases is much smaller. Comparing these results with those of Figure 1 shows that although the number of cases of chronic bronchitis is small, this impact is the most dominant one in the external costs. The reason for this is the large monetary value of this impact. The damage costs of chronic bronchitis in Figure 1 are larger in EcoSense than in EXMOD. This is a result of more cases of chronic bronchitis using EcoSense, although the monetary value is larger in the EXMOD model.

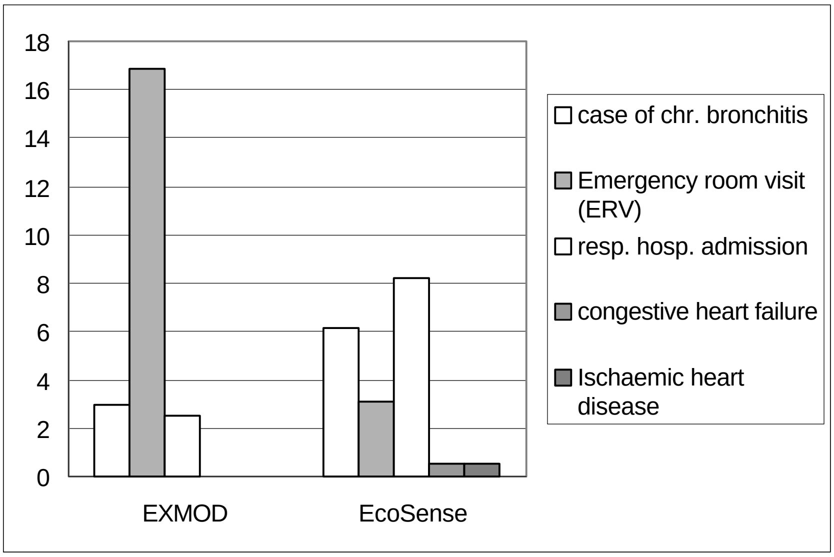

Figure 4: *Cases of impacts calculated in EXMOD and EcoSense*

Figure 5 shows a very large difference in the cases of respiratory symptoms days in the two models. This is visible in Figure 1, where respiratory symptom days are important in EXMOD, but not visible in EcoSense. Taking the large number of cases into consideration, the damage costs related to respiratory symptom days are small due to a low monetary value.

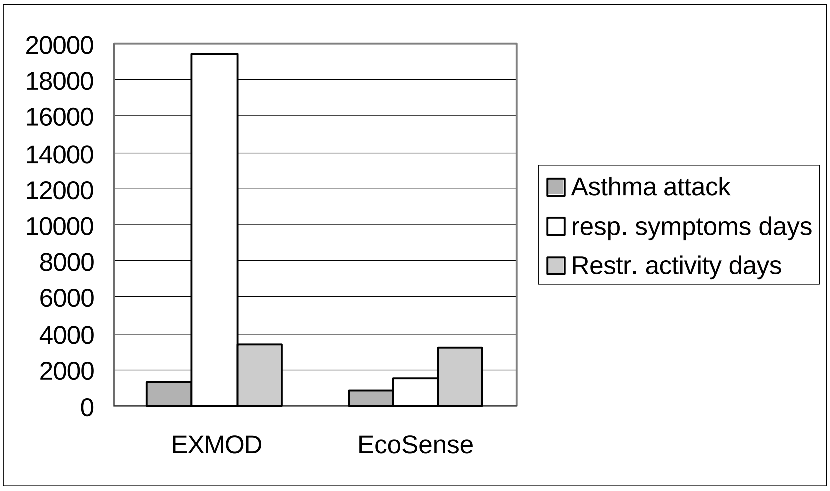

Figure 5: *Cases of impacts calculated in EXMOD and EcoSense*

The different morbidity impacts calculated for the same plant in as well EcoSense as EXMOD have been compared in the above figures. As illustrated the amount of impacts for the different categories is like the monetary values used an important factor, when analysing the external costs calculated from different models.

6 - CONCLUSION

External costs for power generation technologies may be assessed using different approaches, and therefore the external costs may differ for the same technology depending on the approach used. In this paper the same approach – the bottom-up approach – has been used, but with two different models. The models are in principle built up in the same way as with air dispersion models and dose-response functions for the calculation of impacts. These impacts are multiplied with monetary values to calculate the external costs.

Although the models seem more or less similar, the resulting external costs are much larger in the ExternE study using the EcoSense model than in the New York study using the EXMOD model for the same power plant. First of all this is a result of CO_2, which is included in ExternE, but not in the New York study. However, excluding CO_2 the results still are much higher in the ExternE study. When the external costs estimated in the two models are analysed, it is found that most of the impacts can be divided into the same categories. Only a few impacts are included in either EcoSense or EXMOD, but not in both.

When the results are compared, it becomes clear that the monetary values used in the models as well as the dose-response functions used to calculate the impacts are quite important. However, another important issue is the location of the plant, as differences in population size and differences in background levels of the emissions are quite important parameters, when utilising dispersion models for externality estimations.

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