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Solutions for
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External costs of coal

Global estimate

Report

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Contents

Summary

To help Greenpeace International to approximate a true cost for coal, the independent, Dutch research institute CE Delft conservatively evaluated the external costs of the human health impacts from air pollution from coal, damages attributable to climate change and fatalities due to major accidents resulting from mining operations. These costs were separately compiled and then combined to arrive at a figure which estimates a lower limit for the annual costs that coal exacts on humans and the environment.

The cost of coal presented in this report does not represent a comprehensive evaluation of all the external impacts attributable to the coal chain-of-custody. Accurate and reliable data for many parts of this chain, i.e. economic damages attributable to acid mine drainage, simply do not exist on a global scale. What's more, quantifying many social impacts, such as community displacement, loss of cultural heritage and human rights violations, in a credible manner is virtually impossible.

The calculation for the external costs of coal examined the following factors:
- Costs for society attributable to climate change.
- Human health impacts that result from air pollution.
- Fatalities due to major accidents resulting from mining operations.

Emissions are separately assessed for power generation (plant level) and for mining. As the aim of this study is to derive an estimate of global damages, it is not necessary to link exact flows of coal from mines to power plants. Instead, we assess emissions related to mining and emissions related to global power generation (based on IEA data) separately. About 80% of global coal is used for power production.

Based on the CO_2 emissions we arrive at a ranking of countries of which the top-10 account for 85% of global emissions. Together with emissions from other EU countries, we cover 91% of global emissions. These are the countries that are assessed further for polluting emissions. The selected countries cover 90% of global production. Of global mining of coal to be used power production, 100% was covered.

Combining all damages, we arrive at a total annual damage figure of approximately **360** billion Euro. The estimates do not include all possible emissions or all possible damages and should therefore be considered as lower limits. Especially including emissions of particulate matter from India might increase the estimate. The global value is not very sensitive to the type of economic value transfer that is used.

The highest damages can be attributed to coal combustion in power plants. This contributes to the total annual damage burden in over 99%. Damage burden due to mining emissions is estimated to be about 674 million Euro per year, and damage burden due to accidents - about 161 million Euro per year.

The figure for emissions damages of combustion emissions covers 90% of global coal power production for CO_2, SO_2 and NO_x emissions. The largest contribution is in fact due to SO_2 emissions, with 38%. The contribution of CO_2 emissions is 37%, NO_x contributes 14%. The contribution of $PM_{2.5}$ is low with 11%, but as mentioned above, the emissions figures are not complete, since no data are available from India.

1 Introduction

1.1 Background

Greenpeace International wants to draw attention to the external damages caused by the use of coal power around the world. To this end, GPI is writing an international report on the damages of coal power, partly in a qualitative sense, supported by local stories as reported by country offices, and partly drawing on quantitative information. This quantitative information is based on the findings of this report by CE Delft.

1.2 Approach

An estimate of damages due to current coal power generation and mining around the globe, for the following damage categories:

- Human health impacts (air pollution).
- Damages of climate change.
- Fatalities due to major accidents (mining).

This means the estimate provides a lower limit to damages, in the sense that several damage categories are not assessed. These include damages to ecosystems, agricultural production, et cetera. In a recent study of the impacts of new proposed national emission ceilings, it was estimated that in the European context damages to ecosystems are 20% of health damages or less (CE Delft, 2008). Damages to agricultural production and materials (buildings) amount to less than 2% of health damages. Apart from damages due to emissions to air that are not quantified (and mostly not quantifiable), other damages are also excluded, such as social effects or damages due to emissions to water (especially for mining). Therefore, the calculation will yield a lower limit to real damages.

Emissions are mostly derived from existing data on a national level, for the largest coal-power producing countries. Emissions are derived separately for combustion (power plant) and for mining, as well as for storage and handling of coal near the power plant. Details of the assessment of emissions are given in Chapter 2.

Direct assessments of damage costs are unavailable for many countries around the world. The most comprehensive set of damage costs estimates related to energy production to date was produced within the recently completed project of the ExternE series - NEEDS (New Energy Externalities Developments for Sustainability). These damage estimates are in our project translated in terms of purchasing power parities (PPP's).

For CO_2 damage costs, one approximate value of 20 Euro per tonne is used, which is based on expert estimates of marginal abatement costs.

Details of the assessment of damage costs are given in Chapter 3.

2 Determining global emissions

2.1 Introduction

Emissions are separately assessed for power generation (plant level) and for mining. As the aim of this study is to derive an estimate of global damages, it is not necessary to link exact flows of coal from mines to power plants. Instead, we assess all emissions related to mining and approximately 90% of emissions related to global power generation (based on IEA data).

We therefore discuss below the data collection approach separately for power plants and mining.

2.2 Power plants

2.2.1 Climate

Information on coal power generation and associated CO_2 emissions is available from IEA - see Table 1.

Table 1 Production of coal power per country and associated CO_2 emissions

COUNTRY	**Electricity (GWh)**	**Heat (PJ)**	**Fuel consumption (PJ/year)**		**Net electric eff.**	**CO_2 emission (ktonnes/ year)**
			Hard coal	**Lignite**	**IEA report**	
USA	2,153,928	50,805	19,843	971,848	36%	1,973,502
China	1,972,267	2,091,954	24,779		32%	2,341,616
India	479,955		5,391	527.22	27%	562,840
Japan	309,331	574	2,250		42%	212,648
EU						
Germany	305,447	158,009	1,200	1,469.7	38%	262,089
Poland	145,165	308,298	1,178	529,737	36%	164,973
Spain	80,767		650	94	38%	70,957
UK	136,564	8.602	1,257		38%	118,784
Czech Republic	49,782	89,430	15	521,451	32%	54,164
Italy	49,419	5,372	466		38%	44,025
Greece	35,543	2,034		363.32	36%	36,768
France	30,641	17,337	368		39%	34,774
Netherlands	26,926	18,399	234		39%	22,151
Romania	22,138	32,748		222.68	-	22,535
Bulgaria	18,625	20,398		231.47	-	23,425
Denmark	15,466	34,247	144		43%	13,567
Finland	11,661	58,434	129		39%	12,183
Belgium	10,493		97		38%	9,137
South Africa	228,601		2,113		37%	199,634
Australia	201,087		1,485	629,982	33%	204,132
Russia	165,729	1,263,316	912	1,273.68	32%	215,090

Based on the CO_2 emissions we arrive at a ranking of countries of which the top-10 account for 85% of global emissions. Together with emissions from other EU countries, we cover 91% of global emissions. The selected countries cover 90% of global production. These are the countries that are assessed further for polluting emissions.

2.2.2 Other emissions

Sources of data concerning other emissions than greenhouse gases are much more scattered and less complete. For the selection of 6 countries and EU-25, we derived the following information (Table 2).

For PM emissions the $PM_{2.5}$ fraction has been considered. The $PM_{2.5}$ fraction has a significantly more negative health impacts than the PM>5 ppm particles. The $PM_{2.5}$ particles are small enough to be absorbed in the lungs causing damage to the cardiac system and cause more damage to the bronchi than the larger PM>5 particles.

Table 2 Overview of SO_2, NO_x and PM emissions in kton per year for power production in considered countries

	SO_2	NO_x	$PM_{2.5}$	CH_4
USA	10,068	3,595	87	
China	20,567	7,434	2,537	
India	2,959	1,580	X	
Japan	23	21	11	
EU	1,470	1,200	43.5	
Germany				
Poland				
Spain				
UK				
Czech Republic				
Italy				
Greece				
France				
Netherlands				
Romania				
Bulgaria				
Denmark				
Finland				
Belgium				
South Africa	1,177	526	51	
Australia	605	614	20.5	
Russia	1,056	511	1	
	37,924	15,481	2,600	725

Figures are discussed in more detail in the subparagraphs below.

Methane emissions

Methane emissions from storage at the power plant were derived from annual environmental report for the Willem-Alexander coal fired power station in the Netherlands. The emissions mentioned in the annual report have been estimated applying a generic emission factor of 0.34 kg CH_4/tonne coal equivalent for methane from coal storage. Methane is produced during storage due to heat generation within the pile. The emission factor applied in this study refers to the Dutch situation, but heat generation in the pile will of course also occur in other countries. For lack of emission factors for other countries we however used the Dutch emission factor also for other countries.

China

Coal applied in public power generation has an average sulphur content of 1.0%-1.1%, but in certain regions coal with sulphur contents up to 4% are fired (Larsen, 2006). Desulphurization had in that year been implemented at 53 Gwe installed production capacity, 14% of total installed capacity in 2005. Another 100 Gwe is said to be under construction.

Specific emission factors for coal powered power stations given in literature amount to:

- 0.83 kg SO_x/GJ coal (Ohara, 2007).
- 0.30 kg NO_x (as NO_2)/tonne coal (Ohara, 2007).
- Approximately 3 kg PM_{10}/tonne coal[1].

Emission factors for SO_2 could be checked by comparing with total emissions given in several articles:

- Coal consumption for power generation amounted to 17.1-18.6 EJ in 2003 according to MIT (2007) and Ohara (2007). Combined with the emission factor given by Ohara (2007) total power generation related SO_2 emission would amount to approximately 14.2-15.4 Mtonnes/a.
- Total coal based power generation related SO_2 emission were reported to amount to 11 Mtonnes in 2003.

The emission factor for SO_2 seems reasonable. On the other hand there is much uncertainty about actual total annual emisisons as illustrated by the graph from Ohara (2007).

South Africa

For South Africa emission factors have been derived from Eskom's environmental performance report from 2000. Eskom is South Africa's national power company, producing > 98% of total grid delivered power[2] and > 90% of this power is produced by coal power plants. The coal power plants operated by Eskom have no desulphurisation equipment[3].

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[1] This figure is estimated in the following way: According to Wikinvest website annual soot emission from industrial sources amounts to 9,1 Mtonnes/a. According to Xu, 2008 coal firing is responsible for 70% of total industrial PM_{10} emisisons. Given the fact that approximately 65% of total coal consumption is for power generation and assuming flue gas cleaning at industrial furbnaces and public power plants is equivalent, the specific emission factor for PM_{10} amounts to (9,1 x 70% x 65%) ÷ 1.400 = 0,003 Mtonne/Mtonne coal.

[2] http://www.mbendi.co.za/indy/powr/af/sa/p0005.htm.

[3] http://www.tbcsa.travel/article/govt_gives_environmental_green_light_for_new_power_station_1.html?PHPSESSID=00dc2836a706339865502775fa15df5e.

Data for emissions per kWhe in 2003 indicate that in the years in between no changes have occurred in the coal power plant emissions and on the internet no data has been found of implementation of reduction measures for NO_x or SO_2 at the existing power plants. As stated in the indicated article the new coal power plant Eskom will be the first with desulphurisation. The 2000 emission factors therefore seem representative also for 2005. These amount to:

- 16.3 kg SO_2 per tonne coal.
- 7.3 kg NO_x per tonne coal.
- 0.72 kg PM_{10} per tonne coal.

India

Coal based power generation accounted for approximately 70% of total power generation in India in 2005. Associated emissions of NO_x, SO_2 and PM_{10} amounted to Mtonnes, 2.52 Mtonnes (CSH, 2005) and approximately 2 ktonnes[4]. Emission factors applied in Ohara, 2007 for Indian coal-fired power plants amount to:

- 0.5 kg SO_2/GJ coal.
- 0.267 kg NO_x/GJ coal.

Given a fuel consumption of approximately 5.6 EJ/year of coal an annual emission of 2.5 Mtonnes of SO_2 matches well with the specific emission factor given in Ohara (2007).

Russia

Data for SO_2, NO_x and PM_{10} emissions from Russian coal fired power plants were derived from Kakaras, 2005. Annual emissions for the Russian coal-fired power sector are given as:

- 279 ktonnes of NO_x.
- 577 ktonnes of SO_2.
- 442 tonnes of PM_{10}.
- 117.5 Mtonnes of CO_2.

Specific emission factors per unit of coal have been calculated based on the ratio between CO_2 emissions and other emissions, assuming an emission factor of 94 kg CO_2/GJ coal and a standardized LHV of 29.3 per unit of coal.

USA

Coal based power generation accounted for approximately 50% of total power generation in USA in 2005. Data for SO_2 and NO_x emissions were derived from the eGrid database of EPA (data year 2004).

In this database generation and emission data are collected on an electricity production plant level. For each plant the primary fuel is given. By selecting the plants with coal as primary fuel, we tried to select the coal fired plants only. Though a rather large number of plants showed up where biomass was also combusted (up to 97% of the total fuel). To estimate the emissions for coal we

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[4] http://cat.inist.fr/?aModele=afficheN&cpsidt=16928480.

decided to select the plants where at least 50% of the resource mix is coal. (Nearly 85% of those have at least 95% of coal in their resource mix.)
Then the total SO_2 and NO_x emissions were established to be:

- 3,595 ktonnes of NO_x.
- 10,068 ktonnes of SO_2.

PM_{10} emissions for coal fired plants in the USA are 194 kton; $PM_{2.5}$ is 87 kton per year (bron EPA[5]).

Australia

The SO_2 emissions factor for coal was retrieved from the National Inventory Report (NIR) on Submissions in 2006, reported in 2008 for the UNFCCC.

- 0.37 ton/TJ black coal.
- 0.15 ton/TJ brown coal.

For NO_x emissions the factor could be retrieved from the Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006.

- 0.384 ton/TJ black coal.
- 0.136 ton/TJ brown coal.

Together with the total coal consumption of 1,352 PJ black coal and 698 PJ brown coal (NIR) the following emissions are calculated:

- 614 ktonnes NO_x.
- 605 ktonnes SO_2.

PM_{10} emissions in Australia are 41 kton per year[6]. We have allocated these emissions entirely to coal power production. PM emissions from gas fired power plants are neglectable, utilization of oil in the Australian power sector is marginal and so will PM emissions be.

EU-25

SO_2 and NO_x emissions were derived for the EU-25 as a whole from European Environment Agency, 2008. In this report the EPER 2004 data on emissions is combined with technical data on approximately 450 power plants. Together they account for about 75 and 80% of the NO_x and SO_2 emissions.
For coal fired plants the emissions reported are:

- 1,200 ktonnes NO_x.
- 1,470 ktonnes SO_2.

Total PM_{10} emissions for energy production are 72.27 kton (EEA, 2008[7]). $PM_{2.5}$ emissions amount to 43.46 kton. We assume all PM emissions may be allocated to coal power production.

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[5] Zie http://www.epa.gov/ttn/chief/trends/trends02/pm25pm10fileguonly082108.xls.

[6] www.npi.gov.au.

[7] Annual European Community LRTAP Convention emission inventory report 1990-2006 (http://reports.eea.europa.eu/technical_report_2008_7/en).

2.3 Mining

For mining data were taken from EcoInvent 2007 database, an authoritative database for environmental impact data for industrial activities. We gladly refer to this source for further information. The extracted data are given in Table 3.

Columns with inclined text refer to specific countries within the distinguished regions.

Total global annual emissions were calculated by combining the figures given in Table 3 with the amounts of lignite and hard coal given in Table 1.

Table 3 Mining related environmental impacts, all figures per tonne of coal supplied at power station

		Hard coal																**Brown coal**
		East Asia	China	India	North America	USA	Canada	South Africa	Australia	Russia	Eastern Europe	Poland	Ukraine	Western Europe	Germany	UK	South America	
Emissions																		
CO_2	kg	3,6	*3,6*	*3,6*	3,6	*3,6*	*3,6*	3,6	3,6	3,7	3,6	*3,6*	*3,6*	3,7	*3,7*	*3,7*	3,6	11,0
CH_4	g	9,5	*9,5*	*9,5*	9,5	*9,5*	*9,5*	10,0	9,2	15,8	14,7	*14,7*	*14,7*	20,1	*20,1*	*20,1*	6,6	0,4
Dust	g																	
PM < 2.5		0,9	*0,9*	*0,9*	0,9	*0,9*	*0,9*	0,9	0,9	0,9	0,9	*0,9*	*0,9*	0,9	*0,9*	*0,9*	0,9	0,0038
PM2.5 - 10		0,2	*0,2*	*0,2*	0,2	*0,2*	*0,2*	0,2	0,2	0,2	0,2	*0,2*	*0,2*	0,2	*0,2*	*0,2*	0,2	0,0006
PM >10		2,1	*2,1*	*2,1*	2,3	*2,3*	*2,3*	2,3	2,3	2,2	2,1	*2,1*	*2,1*	2,1	*2,1*	*2,1*	2,4	
Radon-222	kBq	12,0	*12,0*	*12,0*	12,0	*12,0*	*12,0*	12,0	12,0	12,0	12,0	*12,0*	*12,0*	12,0	*12,0*	*12,0*	12,0	
CO	g	0,6	*0,6*	*0,6*	0,6	*0,6*	*0,6*	0,6	0,6	0,6	0,6	*0,6*	*0,6*	0,6	*0,6*	*0,6*	0,6	0,004
SO_2	g	12,1	*12,1*	*12,1*	12,1	*12,1*	*12,1*	12,1	12,1	12,3	12,2	*12,2*	*12,2*	12,2	*12,2*	*12,2*	12,1	0,034
NO_x	g	5,9	*5,9*	*5,9*	5,9	*5,9*	*5,9*	6,0	6,0	6,0	6,0	*6,0*	*6,0*	5,9	*5,9*	*5,9*	6,0	0,032
NMVOC	g	0,003	*0,003*	*0,003*	0,004	*0,004*	*0,004*	0,006	0,008	0,005	0,003	*0,003*	*0,003*	0,001	*0,001*	*0,001*	0,015	0,002

For several regions (East Asia, Eastern Europe, Western Europe and North America) average impact data were given. These were assumed representative for the emissions from mining in the most important producing countries in these regions, e.g. China and India in East Asia. For mining in Indonesia and Colombia environmental impact data for East Asia and Latin America, respectively, were assumed representative. The regions included in the assessment cover 2.13 Gton of coal production, which is the amount of coal used in power production (78% of the global total (IEA, 2008)).

3 Determining damage costs

3.1 Methodology

In our estimates of damage costs related to coal combustion and mining we will use extensively the values developed within the ExternE series of projects. ExternE (Externalities of Energy) is a long-term international research project funded by the EU with a goal to provide state-of-the art estimates of damage costs related to air pollution due to fuel combustion (energy and transport sectors). The last components of ExternE include NEEDS project (New Energy Externalities Development for Sustainability, implemented during the period 2004-2008).

Estimates of damage costs are available for emissions of so-called classical pollutants:
- SO_2.
- NO_x.
- VOCs.
- Fine particulate matter ($PM_{2.5}$ - with diameter below 2.5 μm).
- Coarse particulate matter (PM with diameter of between 2.5 and 10 μm).

In addition, shadow prices for CO_2 emissions causing global warming have been proposed. Methodology for estimating damage costs related to classical pollutants and CO_2 emissions differs and will be discussed separately.

3.1.1 Climate change

Damage costs of emissions of greenhouse gases are independent of location, as climate effects are global. This means that only one value is needed for all countries. However, climate damages are notoriously hard to determine as damages are spread out over a very large time. This means that parameters such as the discount value (time preference) dominate the estimates, rather than the actual damages. Within European context, this leads to a preference to use prevention costs to value greenhouse-gas damages.

Studies performed for the EU suggest that under a full flexibility EU-wide allocation of CO_2 emission permits, the marginal abatement costs oscillate around 20 Euro per tonne. These estimates are based both on top-down and bottom-up approaches. The marginal costs of abatement in individual Member States may be much higher; on the other hand, allowing trading outside the EU may lower the compliance costs to perhaps 5 Euro per tonne. Because some countries accepted stricter emission reduction targets and as studies indicated that they would also require more costly emission reductions, one can argue that the WTP in these countries may be higher than the average abatement costs and, consequently, that country-specific shadow price of CO_2 could be devised. As an example, for the Netherlands, a shadow price of 50 Euro per tonne of CO_2 has been proposed (CE, 2003). Although country-specific marginal abatement costs are available, these cannot be taken as a proxy for society's WTP per country, unless more evidence to support such values is available (ExternE, 2005).

Some studies show that a number of countries will need the cheaper Kyoto flexible mechanisms to reach the Kyoto target (Ecofys, 2004). The costs of using flexible mechanisms will be lower but it is not clear to what extent they will be used and what the marginal prices are likely to be. In the long run the EU ETS prices could be a better indicator than the current data from technical-economic studies.

Estimates of the avoidance costs change over time because of rising marginal cost curves. They also critically depend on the target chosen. With an ambitious goal of limiting global warming to 2 centigrades above the pre-industrial level, the forecasted mitigation costs for CO_2 rise to the level of 198 Euro per tonne in 2050. Within the NEEDS project, different values are recommended as estimates of damage costs for GHG for the next several decades - see Table 4.

Table 4 Recommended values for GHG (Euro 2005 per tonne CO_2)

Scenario	2005	2010	2015	2025	2035	2045	2050	2055
MDC_NoEW[1]	7	9	11	14	15	17	22	27
PP_MAC_Kyoto plus[2]	----	23.5	27	32	37	66	77	----
PP_MAC_2°[3]	----	23.5	31	51	87	146	198	----

1 Pure economic cost-benefit analysis with no equity weighting.
2 Use of agreed objectives (20% reduction of GHG by 2020).
3 Ambitious goal of 2 centigrades increase as compared to pre-industrial levels.
Source: NEEDS, 2008.

Summing up, an assessment of the costs for achieving Kyoto targets can be interpreted as a proxy for society's WTP for early action against global warming. For assessing technologies and fuel cycles in the mid to long term, the best estimate is between 5 and 20 Euro per tonne of CO_2, with the higher range reflecting the costs if emissions are controlled within Europe. By extension, it can be applied to all greenhouse gases (ExternE, 2005).

Current versus future damages

It should be noted that in this analysis we are estimating the damages of current coal power production for one year. This total figure can not be assumed representative for damages of coal power production in the future, especially concerning climate damages. Damages as well as abatement costs are expected to rise significantly in the future as CO_2 background concentrations are rising. Thus, even the same amount of emissions would lead to higher impacts when emitted in, say, 2020. According to e.g. Watkiss (2005), central estimates of damage costs double between 2010 en 2040. Stern (2006) estimates damage costs of 65 Euro/ton for the end of the 21st century in a scenario without stringent global climate policy. For abatement costs, the figures are expected to rise to almost 200 Euro/ton if we are to limit the mean temperature rise to 2 degrees (Table 4).

When applying this range, some caution has to be used. First, it should be evaluated on a case-by-case basis whether this range is applicable and whether some kind of CO_2 externality has already been internalized. Secondly, in cases where shadow price are to reflect some national or sectoral goals, country or sector-specific marginal abatement cost values could be better. However, if the objective is to reflect an overall shadow price for making small progress towards controlling GHG emissions, the overall European marginal abatement costs for CO_2 is a better approach.

Similar range of values of damage costs for greenhouse gases was recommended in another international EU-funded research project, Methodex. The values proposed within this project are 19 Euro (best estimate), 8 Euro (low) and 26 Euro (high). All values are in 2000 level of prices.

We propose to adopt a rough estimate of **20 Euro per tonne** of CO_2 at 2007 prices for all countries as the best expert estimate. While damages from CO_2 are not equivalently allocated over the various parts of the world, there is a rationale for putting up one uniform figure of € 20/ton CO_2 which relates to the fact that the preferences for CO_2 emission reduction targets seem to be less connected to damage than the other pollutants. Scandinavian countries tend to benefit from climate change but still have among the most strict targets for CO_2 emissions. Hence, citizens from developed economies tend to have an implicit preference for keeping the climate change within limits, which, in fact is relatively unrelated to potential damages. One should keep in mind that – as much further reductions are required to keep climate change impacts at a minimum acceptable level – the price of CO_2 is likely to become higher for future periods.

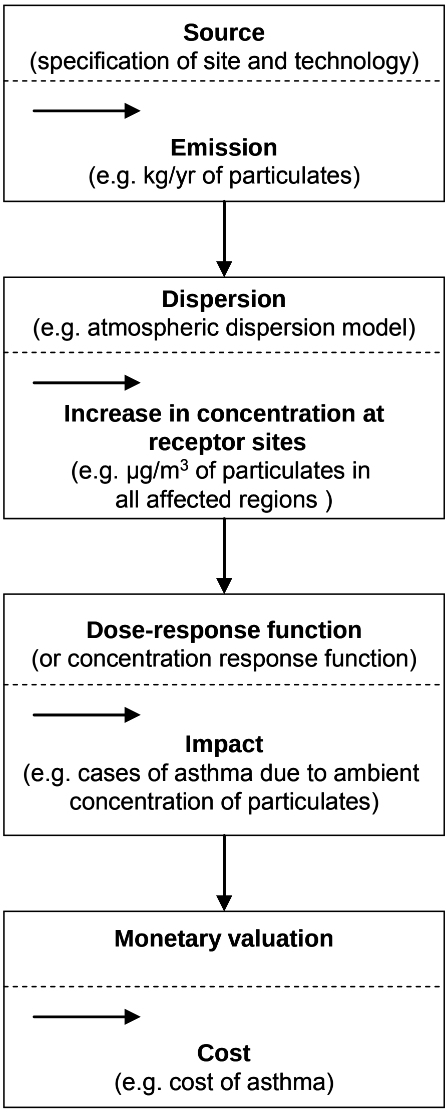
We also make the following assumptions:

- We estimate annual damage costs for 2007. As discussed before, damage costs estimates related to GHG emissions will most probably change over time, and therefore, annual estimates will also change over time. However, in our assessment we are not taking into account future damages and we are not estimating damage costs in terms of Net Present Value (NPV).
- For CH_4 emissions, a factor of 23 is applied to reflect impact of methane on global warming as compared to CO_2 (IPCC, 2001).

3.1.2 Classical pollutants

In order to be able to assess damage costs per unit of specific pollutants in monetary terms, the analysis involves several steps from pressure through physical impact to monetary valuation. A method of analysis used in ExternE is referred to as impact-pathway approach (see Figure 1).

Figure 1 Impact pathway approach



Source: Based on EC (2003).

For classical air pollutants, dispersion and chemical transformation in Europe has been modeled using the EMEP/MSC-West Eulerian model. Moreover, meteorological data are included. Source receptor matrices have been derived which allowed attributing to each unit of emission in a given region a concentration or deposition increment. With the aid of concentration response function (CRF) and the number of exposed population, physical impacts have been calculated for each region (NEEDS, 2008).

Impact of increased air pollution in terms of mortality and morbidity is reflected in higher number of certain diseases and death resulting from these diseases occurring in a population. For classical air pollutants, the reduced life time expectancy (YOLL, years of life lost) was found to be the most important endpoint. However, not only mortality but also morbidity effects are taken into account in the methodology developed within the NEEDS project and in the final estimates of damage per tonne of the specific pollutants. In addition to life expectancy reduction, the following effects are evaluated and taken into account in final calculations: restricted activity days, work loss days, hospital admissions, medication use.

In order to attach a monetary estimate to a year of life lost (YOLL), several approaches can be used. Before implementation of the NEEDS project probably the most popular approach was to relate the value of life year (VOLY) to the concept of the Value of Statistical Life (VSL); the latter can, be viewed as a stream of discounted VOLY's. However, there are serious doubts about validity of this approach. Scientific literature (environmental economics and health economics) is quite abundant in studies focusing on estimation of the Value of Statistical Life (see e.g. meta-analysis in Viscusi and Aldy, 2003). Majority of VSL estimates was derived from mortality risk premium (relation wage-payment, so called hedonic wage method). Problem with transferring such values into VOLY include the following:

1 Air pollution cannot be identified as a primary cause of an individual death, only as a contributing cause.
2 VSL fails to take into account that the magnitude of loss of life-expectancy per death is very much shorter for air pollution related deaths (around half year) than for typical accidents (30-40 years) on which VSL calculations are based (Desaigues et al., 2008).

In the NEEDS project, VOLY was valued directly using Contingent Valuation Method (CVM thus stated preferences method), asking people about WTP for 3 or 6 months longer life due to air quality improvement. This approach is quite new, as the first few questionnaires with the aim of valuing VOLY directly were developed not earlier than in the 1990's.

The VOLY questionnaire was constructed in such a way that the respondents should have been aware that they express willingness to pay not only for extension of life expectancy but also for improvement of quality of life throughout their lives which would be the result of better air quality. In this way, health and quality of life effects are to a certain extent also included in the VOLY estimate.

The survey was implemented in 9 countries (UK, France, Poland, Czech Republic, Hungary, Germany, Switzerland, Spain, and Denmark), on representative samples from populations of 1 major city in each country. The respondents answered valuation questions about implementing air pollution reduction policies which would result in increase of life expectancy by (1) 6 months and (2) 3 months. Based on the empirical results, the NEEDS team recommended a mean VOLY for EU-25 at the level of 40,000 Euro. VOLY is highly correlated with income. The mean value calculated for the group of New Member States is lower than average (33,000 Euro), and the mean value calculated from the sample for EU15 plus Switzerland is higher than average (41,000 Euro) (Desaigues et al., 2008).

In the final stage of the NEEDS project, the value of 40,000 per YOLL has been used in calculating monetary estimates of damage costs per tonne of emission of specific air pollutants. These estimates are available for emissions in 39 European and non-European countries and 5 sea regions. The results include also estimates of EU-average damage costs per tonne of specific pollutants. All values are in Euro, 2000 level of prices.

Our goal is to transfer the existing EU estimates to all countries included on our list. This is a very ambitious task when we look at the Figure 1 presenting steps in impact-pathway analysis. A lot of factors influence the final estimates, and uncertainty increases at every step. Without being able to run a full model including data on background pollution, dispersion patterns, population affected, meteorological conditions, etc. we will be able to produce only very rough estimates. Below, we will provide a description of transfer methodology used.

Transferring the VOLY estimate

The central VOLY estimate used in the NEEDS project to devise monetary values of damages is equal to 40.000 Euro. This value is used throughout the project as an estimate of the chronic YOLL, and in case of classic pollutants the loss of life years was found to be the most significant effect of pollution. Therefore, our transfer methodology will rely on transferring the VOLY estimate and devising adjustment factors for the estimates of damage costs produced within the NEEDS project.

Country-specific estimates from which the EU average was derived have been found to be highly dependent on income. Therefore, a question arises if it is legitimate to use EU-based monetary damage estimates for transferring them to countries with very different level of average personal income (approximated with GDP per capita). On the other hand, we wonder if we should allow using different VOLY valuation in different countries or regions of the world.

In our opinion, if the scope of our analysis is global, universal estimates of VOLY should be used. This practice is commonly applied in cost-benefit analysis, where one of the first steps should be to establish the scope of analysis. In projects with local significance, the best approach to valuation of environmental effects is to use local WTP or other measure reflecting preferences of local population. In projects with impact on the whole country, national estimates would be the best approach, etc. Besides, values like VOLY or VSL are especially ‘touchy’ because of human (statistical) life context. Nobody wants to attach a price tag to an individual human life – we are rather trying to find a monetary estimate of preferences related to the risk of impacts on the longevity and quality of life. Nevertheless, we believe that both VSL and VOLY should be the same for every population in our analysis, independent of socio-economic conditions.

Therefore, instead of using economic indicators to adjust the European VOLY to each country outside the EU, we will produce a global, average VOLY estimate. This VOLY estimate will be used for all countries in our analysis, which means that the original damage costs for the EU will have to be adjusted accordingly.

Within the NEEDS project, transfer errors and validity of transfers were tested using the approach of transferring WTP estimates from the sample excluding one country to this excluded country and then comparing the transferred and the empirical value. The theoretical way to do this would be to use the income elasticity's for environmental quality in which the preferences for (expenditures on) environmental quality are dependent on the level of income. Transfer tests tried in the NEEDS project included a simple value transfer using purchasing power parity (PPP) indicators and transfers with income adjustments, both assuming a unitary income elasticity and elasticity calculated based on empirical data (which was much lower than 1, in the range of 0.2-0.6). Quite surprisingly, simple unit value transfer using euro at PPP proved to be the most reliable, i.e. resulting in transfer error of plus minus 20% (NEEDS, 2007). Based on this experience, in our adjustments we will also use a simple unit value transfer using only PPP indicators. These indicators allow to a certain extent take into account differences in GDP per capita. The final adjustment factor for the EU-average VOLY will be found by applying a population-weighted average of differences in income measured through PPP indices.

Thus, the formula for a weighted average $VOLY_{WA}$ in our project is:

$$VOLY_{WA} = \frac{VOLY_{EU25} * POP_{EU25} + VOLY_A + \ldots + VOLY_Z * POP_Z}{POP_{EU25} + POP_A + \ldots + POP_z}$$

where $VOLY_{EU\text{-}25}$ equals 46,560 Euro, which corresponds to the value of 40,000 Euro adjusted for Euro inflation between 2000 and 2007 with HICP (harmonized index of consumer prices). Based on EBI data (EBI, 2008), we have calculated the consumer price change factor for Euro in this period being equal to 1,164.

$VOLY_A$ ($VOLY_z$) stands for the VOLY for country A (Z), which equals $VOLY_{EU}$ adjusted with PPP factor. Within the NEEDS project, OECD exchange rates at PPP have been used for transfer. However because not all countries in our database are OECD members, we used an indirect method of calculating PPP factors, based on data from IMF (2007) on country and EU GDP in current prices and in PPP-adjusted prices. All countries (regions) included in the analysis as well as the calculated PPP factors of adjustment are given in Table 5.

Table 5 Economic factors used for calculation of VOLY_{WA}

Country or region	**PPP factor**	**Population in millions**[8]
EU	1.00	464
People's Republic of China	3.84	1,320
United States	1.05	302
India	4.84	1,123
Russia	1.68	142
Japan	1.06	128
South Africa	2.48	48
Australia	0.91	21
TOTAL	**X**	**3,548**

Based on described above methodology and data, the value of VOLY_{WE} in 2007 prices, adjusted according to PPP and weighted using population, equals 20,689 Euro. Thus, we will adjust all the original damage costs per tonne of emission from the NEEDS project using the factor $\mathrm{VOLY}_{WEI}/\mathrm{VOLY}_{EU}$ equal to 0.44.

For estimating damage cost, a spreadsheet tool developed within the NEEDS project is used (NEEDS, 2008a). The values per tonne of emission are given in the Table 6 below. Because of our weighted-average approach, the values are uniform for all countries; the table shows both the original values proposed in the NEEDS project and the values adjusted using HICP and PPP indicators.

Table 6 Damage costs per substance (power plants), Euro per tonne (2007 prices)

	SO_2	NO_x	$PM_{2.5}$	CO_2	CH_4
Original values per tonne for EU	6,830	6,291	27,470	20	460
Values adjusted using HICP and PPP factors	3,533	3,254	14,208	20*	460*

* Values for CO_2 and CH_4 are not adjusted.

Source: NEEDS, 2008a. And own calculations.

One should keep in mind that our adjustment is based only on economic factors and that we implicitly assume that on average, physical conditions in Europe and in all other countries included in our analysis are the same. This relates in particular to background concentration of the specific pollutants and to concentration-response functions used in the Ecosense model in earlier stages of damage costs assessment (before monetary valuation). While such an assumption with respect to a particular country would be difficult to defend, we believe that overall, for the whole set of countries to which the damage costs are transferred, this is quite a plausible assumption.

3.2 Damage cost estimates

To arrive at damage cost estimates, the respective adjusted values per tonne are multiplied by the estimated emissions. We present the damage cost estimates separately for power plant emissions, mining and accidents.

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[8] Data on population is based on OECD (2008); data for EU covers EU-25 (EU-27 without Bulgaria and Romania).

3.2.1 Power plant emissions

Table 7 contains the summary of data used for power plant emissions.

Table 7 Emissions from power plants used for damage cost calculations

	Emissions				
	SO_2	NO_x	$PM_{2.5}$	CO_2	CH_4
COUNTRY/region	ktonnes	ktonnes	ktonnes	ktonnes	ktonnes
EU	1,470.00	1,200.00	43.46	889,531.52	
People's Republic of China	20,567.00	7,434.00	2,537.00	2,341,616.45	
United States	10,068.00	3,595.00	87.07	1,973,502.42	
India	2,959.00	1,580.00		562,840.07	
Russia	1,056.00	511.00	1.00	215,089.87	
Japan	23.00	21.00	11.00	212,647.68	
South Africa	1,177.00	526.00	51.00	199,634.09	
Australia	605.00	614.00	20.50	204,131.85	
Total	37,925.00	15,481.00	2,751.03	6,598,993.94	725

These emissions combined with damage per tonne values give the following damage burden results (see Table 8).

Table 8 Annual damage burden of coal combustion in power plants, billion Euro 2007

	Damage burden from coal combustion in bln Euro (10^9 Euro)					
	SO_2	NO_x	$PM_{2.5}$	CO_2	CH_4	
COUNTRY/region						
EU	5.19	3.90	0.62	17.79		27.51
People's Republic of China	72.66	24.19	36.05	46.83		179.72
United States	35.57	11.70	1.24	39.47		87.97
India	10.45	5.14	0.00	11.26		26.85
Russia	3.73	1.66	0.01	4.30		9.71
Japan	0.08	0.07	0.16	4.25		4.56
South Africa	4.16	1.71	0.72	3.99		10.59
Australia	2.14	2.00	0.29	4.08		8.51
Total	133.98	50.37	39.09	131.98	0.33	**355.75**

3.2.2 Mining

Mining emissions and damage values are summarised in the Table 9 below. There are no PM_{10} emissions in case of mining, since the main source of PM emissions are engines and machinery, which emit PM particles < 2.5 microns.

Table 9 Annual damage costs of mining, million Euro 2007

	CO_2	CH_4	$PM_{2.5}$	SO_2	NO_x	**Total**
Emissions in ktonnes	13,555	209	4	44	29	
Damage costs per tonne	20.00	460.00	14,208	3,533	3,254	
Damage value	271	96	57	155	94	**674**

It is not surprising that the values of damages related to mining emissions are much lower than those related to coal combustion, as air emissions per unit coal are expected to be much higher for combustion. Emissions to water and soil may be significant for mining, however, and those are not included in this analysis.

3.2.3 Accidents in the coal chain

In the coal power chain, accidents are quite prominent in the mining stage. In the ENSAD database (e.g. Hirschberg et al., 2004), there are more than 1,200 severe accidents (over five fatalities) related to the coal chain. In Hirschberg et al. (2004), the accident data were translated into damage cost for electricity generation making the following assumptions :

- Only accidents with more than 5 fatalities are included.
- The value of statistical life is 1.045 million Euro.
- The fraction of internalization through insurance is 80% (OECD) and 50% (non-OECD) for workplace fatalities and 50% (OECD) and 20% (non-OECD) for public fatalities.
- The allocation of damages to a kWh of electricity is based on expectation value. As incident rates are fairly high, this is probably a good estimate (see discussion in CE (2007) on risk aversion).

This leads to the following damage costs per unit of electricity generation (Table 10).

Table 10 External damages of accidents in the coal power chain (Euro per MWh)

	Occupational	Public	Total
China	0.061		0.061
OECD	0.0034	0.000061	0.003
Non-OECD (other)	0.032	0.00035	0.032

After combining these factors with data on energy production, we estimate the approximate damage value related to accidents - see Table 11.

Table 11 Global damage burden related to accidents in the coal power chain (millions Euro)

COUNTRY/region	Energy production in TWh	Occupational accidents factor	Public accidents factor	Value occupational in millions Euro	Value public in millions Euro	Total
EU	1,001	0.0034	0.000061	3.40	0.06	3.46
People's Republic of China	1,972	0.061		120.29	0.00	120.29
United States	2,154	0.0034	0.000061	7.32	0.13	7.45
India	480	0.032	0.00035	15.36	0.17	15.53
Russia	166	0.032	0.00035	5.31	0.06	5.37
Japan	309	0.0034	0.000061	1.05	0.02	1.07
South Africa	229	0.032	0.00035	7.33	0.08	7.41
Australia	201	0.0034	0.000061	0.68	0.01	0.70
Total	6,512			160.75	0.53	**161.28**

The total value of 161 million Euro is very low as compared to the values related to coal combustion and mining. One can note, however, that the value of statistical life used in the original study (Hirschberg et al., 2004) was quite low.

3.2.4 Sensitivity analysis

There can be other ways to transfer the damage cost values compared to the approach which seemed to work the best in the NEEDS project. One of them would be to use the ratio of GDP per capita at PPP factors and to assume different damage values per tonne of the specific classical air pollutants in every country. In this method we assume that richer citizens value environmental quality equiproportionally more as their incomes grow. Using this method, damage cost per tonne of NO_x for China, for example, equals the original damage cost calculated for the EU multiplied by the ratio of GDP per capita at PPP in China to GDP per capita at PPP in the EU. GDP at PPP data is taken from OECD statistics – see Table 12, and the same inflation factor (HCIP) has been used as above.

Table 12 GDP at PPP per capita and the resulting adjustment factors

	GDP per capita at PPP in USD	Adjustment factor
EU	29,849	1
China	4,091	0.137056518
USA	41,674	1.396160675
India	2,126	0.071225167
Russia	11,861	0.397366746
Japan	31,919	1.069349057
South Africa	8,477	0.283996114
Australia	33,983	1.138497102

Source: OECD statistics, http://ocde.p4.siteinternet.com/publications/doifiles/02-01-01-t2.xls.

The resulting values of damages per tonne of pollutants for every country are summarised in Table 13.

Table 13 Damage values per tonne of pollutants per country using simple GDP per capita at PPP approach

	MORBIDITY AND MORTALITY RELATED DAMAGE COSTS				
	SO_2	NO_X	$PM_{2.5}$	CO_2	CH_4
COUNTRY/region	Euro/t	Euro/t	Euro/t	Euro/t	Euro/t
EU	7,947.60	7,320.40	31,964.95	20.00	460.00
People's Republic of China	1,089.27	1,003.31	4,381.00	20.00	460.00
United States	11,096.13	10,220.46	44,628.21	20.00	460.00
India	566.07	521.40	2,276.71	20.00	460.00
Russia	3,158.11	2,908.89	12,701.81	20.00	460.00
Japan	8,498.76	7,828.07	34,181.69	20.00	460.00
South Africa	2,257.09	2,078.97	9,077.92	20.00	460.00
Australia	9,048.32	8,334.26	36,392.01	20.00	460.00

Source: Own calculations.

With this approach, we obtain the following cost of burden resulting from coal combustion for every country (Table 14).

Table 14 Annual damage burden of coal combustion in power plants using country-specific damage per tonne values, billion Euro 2007

	Damage burden from coal combustion in bln Euro (10^9 Euro)					
	SO_2	NO_X	$PM_{2.5}$	CO_2	CH_4	
COUNTRY/region						
EU	11.68	8.78	1.39	17.79		39.65
People's Republic of China	22.40	7.46	11.11	46.83		87.81
United States	111.72	36.74	3.89	39.47		191.81
India	1.67	0.82	0.00	11.26		13.76
Russia	3.33	1.49	0.01	4.30		9.14
Japan	0.20	0.16	0.38	4.25		4.99
South Africa	2.66	1.09	0.46	3.99		8.21
Australia	5.47	5.12	0.75	4.08		15.42
Total	159.14	61.67	17.99	131.98	0.33	**371.11**

Source: Own calculations.

Knowing that the impact of the estimates related to emissions from mining and from accidents on a total global value is practically negligible and equal to more or less 0.2% of the value related to combustion, we can conclude that using this alternative method of adjustment does not have a significant impact on a global estimate of damages related to coal combustion and mining. Instead of 357 billion Euro we get an estimate of approximately **372** billion Euro per year. This figure is higher, mainly, because of the higher damages for the US using this method.

While the global value does not change much with this approach, the impact of using this method on country-specific values is significant. Values for such countries like China and India are about 50% lower in this approach, which is related mostly to the fact that here we are not assuming any more a uniform value of life year (VOLY) for the whole globe. Country-specific values resulting from using such a method of adjustment would be more appropriate for comparisons with country-specific empirical studies because they reflect differences in income better than the values based on a uniform damage value per tonne approach. However we should remember that neither of these approaches is capable of producing precise values of damages.

4 Global figure

Combining all damages listed in Chapter 3, we arrive at a total annual damage figure of approximately **360** billion Euro. As discussed in Chapter 1, our estimates do not include all possible emissions or all possible damages and should therefore be considered lower limits. Especially including emissions of particulate matter from combustion for more countries might increase the estimate. The global value is not very sensitive to the type of economic value transfer that is used.

The highest damages can be attributed to coal combustion in power plants. This contributes to the total annual damage burden in over 99%. Damage burden due to mining emissions is estimated to be about 674 million Euro per year, and damage burden due to accidents - about 161 million Euro per year.

The figure for emissions damages of combustion emissions covers 90% of global coal power production for CO_2, SO_2 and NO_x emissions. The largest contribution is in fact due to SO_2 emissions, with 38%. The contribution of CO_2 emissions is 37%, NO_x contributes 14%. The contribution of $PM_{2.5}$ is low with 11%, but as mentioned above, the emissions figures are not available for India.

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