PROJECT N. 037033

EXIOPOL

A NEW ENVIRONMENTAL ACCOUNTING FRAMEWORK USING EXTERNALITY DATA AND INPUT-OUTPUT TOOLS FOR POLICY ANALYSIS

Report on chemistry and steel case studies

Report of the EXIOPOL project

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Executive Summary

Overview

This report is the report of the EXIOPOL work package II.5.a on industry externalities. The report consist of three main chapters including three case studies for different industrial sectors. The main goal of this report is to present and describe the approaches that are applied in these case studies.

The first chapter presents a screening of pollutants in order to analyse which substances should be regarded relevant for certain industrial sectors. The data sources, the monetary valuation factors and the final outcome are presented in detail. Chapter two covers the first case of the WP study. The external costs of the metal industry in Europe and especially in Germany have been estimated using the current methodology of EcoSenseWeb. Furthermore and also part of the tasks of the work package, the methodology of Polyphemus has been implemented into EcoSenseWeb and calculations have been made using this new methodology and te results have been compared. Additionally some non-environmental externalities such as risk-safety have been regarded. Chapter three estimates in similar manner the external costs of the chemical industry in Europe

The project has started in March 2007 and will run until March 2011.

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CHAPTER 1: SCREENING OF RELEVANT POLLUTANTS

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I. Introduction

The main objective of WP II.5.a is to extend the previous work in the research of externalities and to develop a solid foundation for analysis of the environmental and non-environmental externalities of the manufacturing industry. The work package aims to improve the methodology for the estimations of environmental and non-environmental external effects from industry and the application of the methodology for several specific case studies.

The first task of the work package is an analysis of externalities and burdens generated by the manufacturing sector. In course of a systematic analysis of externalities and burdens generated by industrial activities, important externalities for the industry sector will be identified. In the second step of this work package, an assessment of impacts and damage costs from pollutants will be made with the goal to extend and improve the existing methodology with pollutants from industrial emission sources. Furthermore, the currently applied Lagrangian model for atmospheric transport (EcoSense) will be improved by implementing Polyphemus, a 3D Eulerian chemical transportation model, in order to get a higher level of accuracy for the estimates of external costs.

II. Preparation of screening process

In the following, the screening process of pollutants that are relevant for the work in WP II.5.a will be described in detail. As a first step, a selection of the sectors to be analysed will be explained. Thereafter, the sources of the data used in the screening and valuation process will be presented and summarised.

II.1 Selection of sectors

For the analysis of relevant pollutants for the further work in WP II.5.a, the sectors to be examined had to be chosen. Therefore, the Description of Work for this work package says that the research should focus on "substances which are not related to energy conversion processes, but to the use of raw or bulk materials and bulk chemicals for production processes". Furthermore, in task three of the work package there is a recommendation for the sectors that could be covered in the case studies as the final part of the work package. These should "preferably be carried out in the plastic, chemical, and metal/engineering/electric and agri-food".

II.2 Data sources used for the screening process

a) Emission factors

To get data on emissions for the regarded sectors, the database of EcoInvent 2.0 was chosen. This database provides emission factors for about 4,000 processes, services and products for more than 20 industrial activities. For each of these processes, emission factors for more than 130 different pollutants are given. These emission factors are based on the production of one single unit of the regarded output. Additionally, the pollutants are classified by emissions to air, soil, water and the use of natural resources. Furthermore, for emissions to air a differentiation between population density (high, low) and atmospheric levels is given while emissions to water are differentiated by types of water (ex: lake, river, ocean, etc.) and emissions to soil are divided into agricultural and industrial sources. Thus, about 500 emission factors were analysed in this study.

EcoInvent 2.0 was developed by the Swiss Center for Life Cylce Inventories and the latest update was accomplished in 2007. Further information can be found at www.ecoinvent.org.

b) Damage factors

To enable an evaluation of the different pollutants that are emitted in the regarded production processes, damage factors are required for each of these pollutants. To have the possibility to double-check the resulting values, two different approaches were followed.

First, damage factors were taken from IMPACT2002+, a database that covers more than 1,000 pollutants and their damage factors when emitted to air, soil or water. IMPACT2002+ was developed by the Ecole Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. IMPACT2002+ links life cycle inventory results via 14 midpoint categories to damage categories. The damage factors to be found in this table are provided for ecosystem quality measured in Potentially Disappeared Fraction per square meter in one year (PDF*m^2/unit), human health measured in Disability Adjusted Life Years (DALY/unit) and climate change measured in kilograms equivalent to carbon dioxide ($kg_{eq}CO_2$/unit). Additionally the use of natural resources is measured in the energy used for the extraction in megajoule (MJ). To calculate damages to human health, estimates of dose-response slopes and severities were analysed. The transfer of contaminants into food is based on accounts for agricultural and livestock production levels. Furthermore, indoor and outdoor air emissions can be compared and the intermittent character of rainfall is considered. The effect factors to human health and the ecosystem are based on mean responses. The latest update of version 2.1 was completed in 2005. More information can be found at www.epfl.ch.

Second, a database of PRé Consultants (Netherlands) was used. This so-called Eco-Indicator 99 provides damage factors for ecosystem health (PDF*m^2/unit), human health (DALY/unit) and resources (MJ). Unlike IMPACT2002+, in Eco-Indicator 99 the effects of climate change or greenhouse effects are included into damages to human health and hence are included in the total amount of DALYs/unit for each of the pollutants. This source provides a "top-down" impact assessment method that weights the damage categories according to three different perspectives depending on time horizon, manageability etc.. These are called the Hierarchist, the Individualist and the Egalitarian perspective. Due to a lack of data for the other two approaches, data resulting from the Hierarchist perspective has been used for the calculations. Compared to the other two approache this approach has a time view between short and long term, says that proper policy can avoid many problems and includes effects on a basis of consensus. For these reasons the Hierarchist approach was chosen for the analysis. The database was updated last in 2002 and further information is given at www.pre.nl/eco-indicator99.

The use of IMPACT2002+ resulted in a list of about 400 different pollutants – categorised by the ecosystem category they are emitted to – of the 500 given in EcoInvent 2.0 that were covered with this database and that were analysed in the following screening process. Even though Eco-Indicator 99 covers a range of different pollutants than IMPACT2002+, the calculations were only done with the pollutants identified with IMPACT2002+.

c) Total production data

In order to get a complete picture of the emissions of the regarded sectors for the EU-25, production numbers were taken from the PRODCOM annual report of 2005. PRODCOM is a statistical dataset that is developed by EuroStat and that contains more than 4,500 manufactured goods. These goods are based on a standardised classification called the PRODCOM list. All products are categorised with a code that includes the

NACE code. To obtain the data, the National Statistical Institutes of all EU-25 member countries conduct a survey of enterprises within their countries.

For the following screening process, the annual data for 2005 was used as there was a lack of data in the annual report of 2006.

In the course of the analysis of the data from PROCOM and the emission factors given in EcoInvent 2.0, it was observed that not for all processes in EcoIvent 2.0 there was a total amount of output to be found in PRODCOM and vice versa: not for all given output data a production process was analysed in EcoInvent 2.0. Therefore, the screening process will only focus on the chemical (organic and inorganic), electronic, metal and plastic sectors. Data for the agri-food and engineering sectors were insufficient for a detailed study of the emitted pollutants.

II.3 Monetary evaluation factors

In order to allow for a comparison of the examined pollutants, a monetary valuation of the resulting damages to the quality of the ecosystem, to human health and the impact on climate change needs to be carried out. Only then the pollutants can be ranked by their potential damages and the pollutants can be classified into categories of high relevance and lower relevance for the regarded industrial sectors. Data for the monetary valuation of impacts on ecosystem quality and human health were taken from the integrated project NEEDS (New Energy Externalities Developments for Sustainability). The damages to the ecosystem quality are measured in Potentially Disappeared Fraction per square meter (PDF*m^2) and are valued with 0.45€/PDF*m^2 according the estimations of Ott et al. (2006). Damages to human health are measured with Disability Adjusted Life Years (DALY). Desaigues et al. (2007) calculate a value of 40.000€ for one DALY. Furthermore, the impact on climate change is measured with kilograms equivalent to one kilogram CO_2 ($kg_{eq}CO_2$) and one $kg_{eq}CO_2$ is valued 0.019€. The conversion factors for calculating the $kg_{eq}CO_2$ for all pollutants are given by the International Panel on Climate Change (IPCC).

III. Total emissions

In this section, the final results for the industrial sectors chemicals, electronics, metals and plastics will be presented. Starting with an overview of the total emissions for all regarded sectors, there will be the results for total damages to ecosystem quality, human health and climate change. In these three parts there will be both, results using IMPACT2002+ and Eco-Indicator 99 for the total emissions of the four examined sectors. Finally, the damages will be valued with the above mentioned monetary factors and listed for comparisons. This will allow for a recommendation of the pollutants of relevance for the upcoming research and the work on the case studies in task 3 of WP II.5.a. The total emissions from the industrial activities in the chemical (organic and inorganic), electronic, metal and plastic sectors are calculated by the multiplication of the emission factors for every single production process given in EcoInvent 2.0 and the total amount produced within the EU-25 from the PRODCOM statistics. Table 1 presents the total emissions ranked by their amount for the first 25 pollutants. The table has to be read with caution as the units for the pollutants might be different. An overview of the emissions can be found in the appendix (Table A1).

Table 1: Total emissions for first 25 pollutants

Pollutant	Unit	Ecocat	Total
Radon-222	kBq	air	119,113,949,088,702.0000
Carbon dioxide, fossil	kg	air	863,465,556,666.3840
Hydrogen-3, Tritium	kBq	water	274,946,139,021.0740
Coal, hard, unspecified, in ground	kg	resource	210,733,694,559.4630
Iron, 46% in ore, 25% in crude ore, in ground	kg	resource	184,245,877,042.9750
Oil, crude, in ground	kg	resource	176,532,773,700.3990
Gas, natural, in ground	Nm3	resource	170,821,274,970.3390
Coal, brown, in ground	kg	resource	91,830,616,762.3271
Hydrogen-3, Tritium	kBq	air	37,882,987,968.9759
Occupation, forest, intensive, normal	m2a	resource	18,794,840,666.0171
Radium-226	kBq	water	10,503,123,147.5721

Occupation, arable, non-irrigated	m2a	resource	8,205,520,078.2965
Aluminium, 24% in bauxite, 11% in crude ore, in ground	kg	resource	7,442,043,726.5067
Xenon-133	kBq	air	7,120,023,531.3902
Carbon-14	kBq	air	6,531,792,111.5275
Carbon monoxide, fossil	kg	air	5,497,621,502.9633
Occupation, dump site	m2a	resource	5,152,575,854.7465
Methane, fossil	kg	air	3,721,232,616.5177
Sulfur dioxide	kg	air	3,546,080,076.5215
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	kg	resource	3,460,652,023.1762
Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, inground	kg	resource	2,600,760,436.4000
Krypton-85	kBq	air	2,495,833,799.2691
Occupation, permanent crop, fruit, intensive	m2a	resource	2,432,819,595.0450
Nitrogen oxides	kg	air	2,045,478,510.5267
Gas, mine, off-gas, process, coal mining	Nm3	resource	1,911,894,644.2086
Occupation, forest, intensive	m2a	resource	1,647,246,875.4939

The table shows the particular importance of carbon dioxide, one of the so-called classical air pollutants. Although there are a number of pollutants that are classified as resources, this 'Ecocat' will not be analysed in the further process of the screening for relevant pollutants. For the analysis in WP II.5.a, it is sufficient to only analyse the damages occurring to ecosystem quality, human health and climate chance / greenhouse effect.

It is important to understand this table not as a ranking of the pollutants according to their damage potentials but as an intermediate result for the further analysis, as the table only represents data on total emissions of the analysed sectors. A high level of total emissions does not necessarily cause a high level of damages and therefore to a high amount of external costs.

IV. Total damages to ecosystem, human health and climate change

IV.1 Damages to ecosystem quality

An overview of the total damages to ecosystem quality resulting from the emissions in the examined industrial sectors can be found in this part of the study. Table 2a and 2b show the results for the first 25 pollutants using damage factors from IMPACT2002+ (2a) and Eco-Indicator 99 (2b). A complete list for both data sources can be found in the appendix (Tables A2 and A3). In general, damages to ecosystem are measured with Potentially Disappeared Fraction per square meter (PDF*m²/unit).

Table 2a: Total ecosystem damage – first 25 pollutants (IMPACT2002+)

Pollutant	Ecocat	Total PDF*m2
Aluminum	air	75,457,001,059.97
Zinc	air	56,936,244,972.02
Aluminum	soil	15,552,720,010.36
Nitrogen oxides	air	11,332,611,089.20
Zinc	soil	9,166,733,791.09
Chromium	air	8,386,003,700.81
Copper	air	7,889,216,853.59
Copper	soil	7,507,636,853.23
Mercury	air	4,765,745,033.97
Nickel	air	4,357,252,038.14
Sulfur dioxide	air	3,644,220,189.59
Ammonia	air	2,328,517,655.63
Lead	air	1,627,900,879.85
Aluminum	water	989,522,352.31
Copper	water	813,844,440.84
Arsenic	air	627,319,699.88
Chromium	soil	511,435,728.76
Zinc	water	445,629,767.52
Cadmium	air	444,490,000.96
Cobalt	air	288,562,391.57
Nickel	soil	112,318,549.33
Cadmium	soil	80,256,469.84
Antimony	water	70,951,667.49
Mercury	soil	67,608,779.95
Lead	soil	60,944,165.83
Nickel	water	52,073,612.13

Table 2a shows that IMPACT2002+ damages to the quality of the ecosystem are valued relatively high for heavy metals. Aluminium, Zinc, Chromium, Copper, Mercury, Nickel, Arsenic, Cobalt and Antimony are all within the first 25 pollutants ranked by the PDFs they cause.

The damage factors available from Eco-Indicator 99 show a slightly different result. While Aluminium is the substance causing the highest number of PDFs with IMPACT2002+, there is no damage factor given in Eco-Indicator 99. Furthermore, the damages to the ecosystem quality estimated in table 2b are clearly lower than the ones calculated in table 3a. From the tables it can be seen that both data sources give relatively high damage values to heavy metals, Nitrogen oxides and Sulfur dioxide. While the overall values are very different in both tables, the substances within the first 25 according to their effects on the ecosystem are very similar.

Table 2b: Total ecosystem damage – first 25 pollutants (Eco-Indicator 99)

Pollutant	Ecocat	Total
Zinc	air	20,547,851,336.99
Chromium	air	11,463,475,541.15
Nitrogen oxides	air	11,332,611,089.20
Nickel	air	6,940,430,640.66
Lead	air	3,996,151,579.79
Sulfur dioxide	air	3,644,220,189.59
Ammonia	air	2,316,957,005.93
Copper	air	1,211,822,316.80
Chromium VI	soil	800,145,953.03
Cadmium	air	593,309,413.67
Chromium VI	water	305,484,523.95
Chromium VI	air	265,466,665.74
Zinc	soil	209,025,762.63
Mercury	air	129,962,214.18
Copper	soil	129,887,490.56
Nickel	water	116,595,367.41
Copper	water	115,946,945.70
Arsenic	air	112,109,738.02
Zinc	water	103,151,997.25
Chromium	soil	32,384,128.53
Cadmium	water	27,778,643.26
Arsenic	water	8,856,788.66
Chromium	water	7,209,214.79
Mercury	water	2,372,635.46
Lead	water	2,350,320.02
Benzo(a)pyrene	air	2,301,668.80

IV.2 Damages to human health

The damages to human health are measured in Disability Adjusted Live Years (DALY/unit). As above the first table shows the results using IMPACT2002+ (Table 3a) and the second displays the results using Eco-Indicator 99 (Table 3b). Once again, the complete tables can be found in the appendix (Tables A4 and A5).

From table 3a it can be seen that particles with a diameter of less that 2.5 µm (PM2.5), Dioxins, Sulfur dioxide and Nitrogen oxides, out of the so-called classical air pollutants, have by far the highest damage factors to human health. Similar to the table for ecosystem quality above, IMPACT2002+ values heavy metals as dangerous to human health. Arsenic, Molybdenum, Chromium, Zinc and Mercury can be found within the ranking of the first 25 pollutants damaging human health.

Compared to the differences that could be observed analysing the outcomes for IMPACT2002+ and Eco-Indicator 99 regarding damages to the ecosystem, the damage factors to human health seem to be very similar. Only Dioxins – ranked second in table 3a – have a significant lower value in table 3b. The fact that in table 3b a number of so-called greenhouse gases appear in the list of the substances with the highest damages to human health results from the above mentioned integration of effects on climate change in the calculation of DALYs in Eco-Indicator 99. Furthermore, Molybdenum can not be found in table 3b as Eco-Indicator 99 does not provide a damage factor for this substance.

Table 3a: Total damages to human health – first 25 pollutants (IMPACT2002+)

Pollutant	Ecocat	Total
Particulates, < 2.5 um	air	295,424.23
Dioxins	air	254,062.25
Sulfur dioxide	air	196,094.17
Nitrogen oxides	air	187,760.76
Arsenic	water	25,222.83
Ammonia	air	13,719.26
Arsenic	air	8,561.95
Molybdenum	soil	5,476.17
Molybdenum	air	4,698.60
Carbon monoxide, fossil	air	4,036.00
Zinc	water	2,375.93
Chromium	air	2,123.67
Zinc	air	1,980.58
Benzo(a)pyrene	air	1,641.96
Antimony	water	1,500.03
Zinc	soil	1,237.63
Molybdenum	water	1,149.83
NMVOC, unspecified origin	air	914.14
Nitrobenzene	water	598.89
Benzene	air	582.85
Arsenic	soil	566.71
Methane, tetrachloro-, R-10	air	375.99
Barium	water	268.61
Carbon monoxide, biogenic	air	205.66
Mercury	air	169.51
Benzene, hexachloro-	air	167.73

Table 3b: Total damages to human health – first 25 pollutants (Eco-Indicator 99)

Pollutant	Ecocat	Total
Particulates, < 2.5 um	air	299,551.73
Sulfur dioxide	air	196,094.17
Nitrogen oxides	air	186,917.84
Carbon dioxide, fossil	air	183,872.17
Arsenic	water	52,241.24
Dinitrogen monoxide	air	24,329.03
Methane, fossil	air	16,540.88
Ammonia	air	13,696.19
Cadmium	air	8,514.70
Arsenic	air	5,470.06
Sulfur hexafluoride	air	4,518.22
Cadmium	water	4,145.52
Cadmium	soil	4,131.35
Radon-222	air	2,916.99
Carbon monoxide, fossil	air	1,777.83
Dioxins	air	1,556.65
Carbon-14	air	1,399.72
Methane, tetrafluoro-, R-14	air	945.26
NMVOC, unspecified origin	air	914.14
Methane, chlorodifluoro-, HCFC-22	air	910.99
Methane, tetrachloro-, R-10	air	789.27
Chromium VI	air	761.48
Methane, trifluoro-, HFC-23	air	466.79
Methane, dichlorodifluoro-, CFC-12	air	316.94
PAH, polycyclic aromatic hydrocarbons	water	193.19
Ethane, 1,2-dichloro-	air	184.03

IV.3 Effects on climate change

To calculate the effects on climate change, for each of the so-called greenhouse gases the weight of the emitted pollutant is analysed in relation to the weight of CO_2. This means that the damage of one kilogram CO_2 is valued as 1 and the damages by the other substances are put in relation to CO_2 according to the different weights. The unit for calculating the effects on climate change then is called kilogram-equivalent-to-CO_2 (kgeqCO_2). The factors for calculating the kgeqCO_2 are taken from data provided from the Intergovernmental Panel on Climate Change (IPCC). As in the first two tables, table 4 shows the results using IMPACT2002+. The complete table can be found in the appendix (Table A6). As already stated above, there is no table for the impacts on climate change using Eco-Indicator 99 as data on climate change is included in damages to human health and thus valued as DALYs.

Table 4: Total effects on climate change – first 25 pollutants (IMPACT2002+)

Pollutant	Ecocat	Total
Carbon dioxide, fossil	air	875,581,758,268.43
Dinitrogen monoxide	air	104,368,030,181.08
Methane, fossil	air	86,212,893,071.99
Sulfur hexafluoride	air	18,925,357,166.49
Carbon monoxide, fossil	air	8,676,181,072.08
Methane, chlorodifluoro-, HCFC-22	air	4,808,092,846.70
Methane, tetrafluoro-, R-14	air	3,848,551,856.36
Methane, trifluoro-, HFC-23	air	2,154,408,919.21
Methane, dichlorodifluoro-, CFC-12	air	1,484,555,326.21
Ethane, hexafluoro-, HFC-116	air	907,486,116.91
Methane, biogenic	air	847,174,107.82
Carbon dioxide, land transformation	air	842,534,236.58
Methane, tetrachloro-, R-10	air	772,807,897.57
Carbon monoxide, biogenic	air	442,107,307.21
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	258,036,842.42
Chloroform	air	114,129,952.40
Methane, chlorotrifluoro-, CFC-13	air	59,279,708.32
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	27,047,446.77
Methane, bromotrifluoro-, Halon 1301	air	12,418,547.76
Methane, trichlorofluoro-, CFC-11	air	4,213,824.36
Methane, bromochlorodifluoro-, Halon 1211	air	4,190,907.21
Methane, dichloro-, HCC-30	air	1,151,024.84
Methane, dichloro-, HCC-30	water	397,155.47
Methane, dichlorofluoro-, HCFC-21	air	118,495.04
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	107,516.70
Methane, monochloro-, R-40	air	43,207.76

Table 4 clearly shows that Carbon dioxides are causing the highest effects on climate change of all pollutants. The value is about eight times higher than the value for the damage potential of the second substance in the table – Dinitrogen monoxide (N_2O).

V. Monetary valuation and ranking of pollutants

To enable a comparison of all pollutants and their effects on all regarded environmental categories (ecosystem quality, human health and climate change), a monetary valuation is necessary. This will allow for an aggregation of the external costs to a total amount which then can be compared for all substances. In the following the external costs for each of the examined environmental categories will be calculated and an aggregation of the total external costs will be made. To continue the procedure that has been used so far, the results will first be presented using the estimates from IMPACT2002+ and thereafter the estimates following Eco-Indicator 99 will be shown. The tables present the results for the first 25 pollutants. The complete tables can once more be found in the appendix (tables A7 – A11).

One important thing to notice here is that the estimated monetary values are not meant to be final. The only aim of the monetary valuation process is to be able to rank the pollutants and to compare their impacts on ecosystem quality, human health and climate change. The final outcome of this screening process is not to deliver overall Euro values for the damages that occur but to classify the pollutants by their relative relevance for the regarded sectors.

V.1 Total external costs for ecosystem damages

The external costs resulting from damages to the ecosystem will be estimated by multiplying the total amount of PDF*m^2 with the monetary value for one PDF*m^2. This value is – as mentioned in II.3 – 0.45 Euro. The ranking of the substances does not differ from the ranking found in part III as the damages are multiplied by a constant factor.

The high level of damages to the ecosystem estimated using IMPACT2002+ for Aluminium, Zinc, Chromium, Copper, Mercury, Nickel, Arsenic, Cobalt and Antimony are still within the first 25 pollutants when ranked by the external costs the cause.

Table 5a: External costs for damages to the ecosystem (IMPACT2002+)

Pollutant	Ecocat	Euros Ecosystem Quality
Aluminum	air	34,016,016,077.8362
Zinc	air	25,666,859,233.3879
Aluminum	soil	7,011,166,180.6717
Nitrogen oxides	air	5,108,741,079.0108
Zinc	soil	4,132,363,593.0239
Chromium	air	3,780,410,468.3239
Copper	air	3,556,458,957.6006
Copper	soil	3,384,442,693.4368
Mercury	air	2,148,397,861.3158
Nickel	air	1,964,249,218.7935
Sulfur dioxide	air	1,642,814,461.4684
Ammonia	air	1,049,695,759.1571
Lead	air	733,857,716.6351
Aluminum	water	446,076,676.4191
Copper	water	366,881,073.9320
Arsenic	air	282,795,720.7076
Chromium	soil	230,555,226.5253
Zinc	water	200,889,899.2002
Cadmium	air	200,376,092.4325
Cobalt	air	130,083,926.1194
Nickel	soil	50,633,202.0371
Cadmium	soil	36,179,616.6056
Antimony	water	31,985,011.7034
Mercury	soil	30,478,038.0036
Lead	soil	27,473,629.9556
Nickel	water	23,474,784.3466

Furthermore, the results from Eco-Indicator 99 show the same difference as already stated. While Aluminium is the substance causing the highest external costs with IMPACT2002+, there are no costs given using Eco-Indicator 99 as there is no damage factor given in this source.

It can again be seen that both data sources result in relatively high costs for heavy metals, Nitrogen oxides and Sulfur dioxide. While the overall values are very different in both tables, the substances within the first 25 according to their effects on the ecosystem are very similar.

Table 5b: External costs for damages to the ecosystem (Eco-Indicator99)

Pollutant	Ecocat	Euros Ecosystem Quality
Zinc	air	9,262,971,382.7172
Chromium	air	5,167,734,773.9516
Nitrogen oxides	air	5,108,741,079.0108
Nickel	air	3,128,746,132.8101
Lead	air	1,801,465,132.1685
Sulfur dioxide	air	1,642,814,461.4684
Ammonia	air	1,044,484,218.2752
Copper	air	546,289,500.4134
Chromium VI	soil	360,705,795.6260
Cadmium	air	267,463,883.6845
Chromium VI	water	137,712,423.3958
Chromium VI	air	119,672,372.9143
Zinc	soil	94,228,813.7922
Mercury	air	58,586,966.1539
Copper	soil	58,553,280.7464
Nickel	water	52,561,191.6282
Copper	water	52,268,883.1235
Arsenic	air	50,539,069.9012
Zinc	water	46,500,920.3589
Chromium	soil	14,598,765.1434
Cadmium	water	12,522,612.3826
Arsenic	water	3,992,640.3300
Chromium	water	3,249,914.0290
Mercury	water	1,069,584.0659
Lead	water	1,059,524.2646
Benzo(a)pyrene	air	1,037,592.2932

V.2 Total external costs for impacts on human health

The external costs resulting from impacts on human health are estimated by multiplying the total amount of DALYs with the monetary value for one DALY which is 40,000 Euro (see II.3). Again, the results do not differ from the results presented in part III as there is a constant factor used to calculate the external costs.

As in the table for the damages to human health, the external costs for particles with a diameter of less that 2.5 µm (PM2.5), Sulfur dioxide and Nitrogen oxides have by far the highest costs for both approaches. Again, the major differences are that Dioxins have a significant lower value in the results for Eco-Indicator 99, Molybdenum is not in table 6b as there is no damage value given in Eco-Indicator 99 and table 6b also includes substances that are found in the ranking of impacts on climate change using IMPACT2002+ (see table 4).

An overall comparison of the results for IMPACT2002+ and Eco-Indicator 99 will be analysed in part V of this report.

Table 6a: External costs for impact on human health (IMPACT2002+)

Pollutant	Ecocat	Euros Human Health
Particulates, < 2.5 um	air	11,816,969,091.4730
Dioxins	air	10,162,490,058.7483
Sulfur dioxide	air	7,843,766,828.9332
Nitrogen oxides	air	7,510,430,595.1497
Arsenic	water	1,008,913,042.7553
Ammonia	air	548,770,252.2920
Arsenic	air	342,477,903.6888
Molybdenum	soil	219,046,854.2192
Molybdenum	air	187,944,011.4866
Carbon monoxide, fossil	air	161,440,067.4394
Zinc	water	95,037,047.0564
Chromium	air	84,946,796.3146
Zinc	air	79,223,324.9463
Benzo(a)pyrene	air	65,678,551.8359
Antimony	water	60,001,251.6367
Zinc	soil	49,505,103.6257

Molybdenum	water	45,993,303.9478
NMVOC, unspecified origin	air	36,565,414.0742
Nitrobenzene	water	23,955,674.5167
Benzene	air	23,313,943.1132
Arsenic	soil	22,668,280.4458
Methane, tetrachloro-, R-10	air	15,039,497.0144
Barium	water	10,744,218.1646
Carbon monoxide, biogenic	air	8,226,411.2400
Mercury	air	6,780,407.0029
Benzene, hexachloro-	air	6,709,149.4521

Table 6b: External costs for impact on human health (Eco-Indicator99)

Pollutant	Ecocat	Euros Human Health
Particulates, < 2.5 um	air	11,982,069,031.0653
Sulfur dioxide	air	7,843,766,828.9332
Nitrogen oxides	air	7,476,713,735.0144
Carbon dioxide, fossil	air	7,354,886,769.4548
Arsenic	water	2,089,649,728.1167
Dinitrogen monoxide	air	973,161,362.4993
Methane, fossil	air	661,635,225.3010
Ammonia	air	547,847,650.9778
Cadmium	air	340,587,907.1708
Arsenic	air	218,802,416.1717
Sulfur hexafluoride	air	180,728,636.0044
Cadmium	water	165,820,910.4989
Cadmium	soil	165,254,126.5315
Radon-222	air	116,679,580.0447
Carbon monoxide, fossil	air	71,113,135.0417
Dioxins	air	62,266,085.2125
Carbon-14	air	55,988,991.6979
Methane, tetrafluoro-, R-14	air	37,810,334.0274
NMVOC, unspecified origin	air	36,565,414.0742
Methane, chlorodifluoro-, HCFC-22	air	36,439,687.1982
Methane, tetrachloro-, R-10	air	31,570,919.9667
Chromium VI	air	30,459,119.1168
Methane, trifluoro-, HFC-23	air	18,671,543.9665
Methane, dichlorodifluoro-, CFC-12	air	12,677,542.2693

PAH, polycyclic aromatic hydrocarbons	water	7,727,479.1045
Ethane, 1,2-dichloro-	air	7,361,223.6065

V.3 Total external costs for effects on climate change

The impact on climate chance and its monetary valuation can only be estimated for data from IMPACT2002+ as these data are included into the damages to human health for Eco-Indicator99. One kgeqCO_2 is valued with 0,019 Euro, which corresponds to 19 Euro per ton of CO_2. As in the tables above the monetary valuation does not change the ranking of the substances in table 7, thus Carbon dioxides remains the pollutant causing the highest effect on climate change of all pollutants, accounting for external costs that are approximately eight times higher than those caused by Dinitrogen monoxide.

Table 7: External costs for impact on climate change

Pollutant	Ecocat	Euros Climate Change
Carbon dioxide, fossil	air	16,636,053,407.1001
Dinitrogen monoxide	air	1,982,992,573.4406
Methane, fossil	air	1,638,044,968.3679
Sulfur hexafluoride	air	359,581,786.1634
Carbon monoxide, fossil	air	164,847,440.3695
Methane, chlorodifluoro-, HCFC-22	air	91,353,764.0874
Methane, tetrafluoro-, R-14	air	73,122,485.2708
Methane, trifluoro-, HFC-23	air	40,933,769.4650
Methane, dichlorodifluoro-, CFC-12	air	28,206,551.1979
Ethane, hexafluoro-, HFC-116	air	17,242,236.2213
Methane, biogenic	air	16,096,308.0486
Carbon dioxide, land transformation	air	16,008,150.4950
Methane, tetrachloro-, R-10	air	14,683,350.0539
Carbon monoxide, biogenic	air	8,400,038.8370
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	4,902,700.0059
Chloroform	air	2,168,469.0955
Methane, chlorotrifluoro-, CFC-13	air	1,126,314.4581
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	513,901.4886
Methane, bromotrifluoro-, Halon 1301	air	235,952.4074
Methane, trichlorofluoro-, CFC-11	air	80,062.6629
Methane, bromochlorodifluoro-, Halon 1211	air	79,627.2369
Methane, dichloro-, HCC-30	air	21,869.4720
Methane, dichloro-, HCC-30	water	7,545.9540

Methane, dichlorofluoro-, HCFC-21	air	2,251.4058
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	2,042.8172
Methane, monochloro-, R-40	air	820.9474

V.4 Aggregation of external costs and final ranking of pollutants

The last step of the monetary valuation and the comparison of pollutants according to their relevance for all the analysed sectors is to aggregate the external costs for the three – or two in the case of Eco-Indicator 99 – above shown categories of impact.

The aggregated external cost values will be shown in table 8a and table 8b. Again, the overall values shown in these tables are not to be considered as a final result as the uncertainty of the emission factors, the damage factors and the monetary values is very high. It is however a representative ranking of pollutants according to the two databases used. In short, the level of the external costs examined in the screening process it is not crucial, the ranking and the relative comparison of the potential damages however is the result of this screening.

As in the sections above, only the first 25 pollutants will be displayed in the following tables and the complete tables can be found in the appendix (A12 and A13).

Table 8a: Aggregated external costs for IMPACT 2002+ – first 25 pollutants

Pollutant	Ecocat	Euros Ecosystem Quality	Euros Human Health	Euros Climate Change	Euros Total
Aluminum	air	34,016,016,077.84	5,713,881.20	0.00	34,021,729,959.04
Zinc	air	25,666,859,233.39	79,223,324.95	0.00	25,746,082,558.33
Carbon dioxide, fossil	air	0.00	0.00	16,636,053,407.10	16,636,053,407.10
Nitrogen oxides	air	5,108,741,079.01	7,510,430,595.15	0.00	12,619,171,674.16
Particulates, < 2.5 um	air	0.00	11,816,969,091.47	0.00	11,816,969,091.47
Dioxins	air	85.20	10,162,490,058.75	0.00	10,162,490,143.95
Sulfur dioxide	air	1,642,814,461.47	7,843,766,828.93	0.00	9,486,581,290.40
Aluminum	soil	7,011,166,180.67	1,853,905.83	0.00	7,013,020,086.50
Zinc	soil	4,132,363,593.02	49,505,103.63	0.00	4,181,868,696.65
Chromium	air	3,780,410,468.32	84,946,796.31	0.00	3,865,357,264.64
Copper	air	3,556,458,957.60	236,789.33	0.00	3,556,695,746.93
Copper	soil	3,384,442,693.44	276,991.38	0.00	3,384,719,684.81
Mercury	air	2,148,397,861.32	6,780,407.00	0.00	2,155,178,268.32
Dinitrogen monoxide	air	0.00	0.00	1,982,992,573.44	1,982,992,573.44
Nickel	air	1,964,249,218.79	1,058,679.26	0.00	1,965,307,898.05
Methane, fossil	air	0.00	1,919,173.97	1,638,044,968.37	1,639,964,142.34
Ammonia	air	1,049,695,759.16	548,770,252.29	0.00	1,598,466,011.45
Arsenic	water	6,823,678.56	1,008,913,042.76	0.00	1,015,736,721.32
Lead	air	733,857,716.64	507,473.68	0.00	734,365,190.31
Arsenic	air	282,795,720.71	342,477,903.69	0.00	625,273,624.40
Aluminum	water	446,076,676.42	1,280,476.55	0.00	447,357,152.97
Copper	water	366,881,073.93	367,349.94	0.00	367,248,423.87
Sulfur hexafluoride	air	0.00	0.00	359,581,786.16	359,581,786.16
Carbon monoxide, fossil	air	0.00	161,440,067.44	164,847,440.37	326,287,507.81
Zinc	water	200,889,899.20	95,037,047.06	0.00	295,926,946.26
Chromium	soil	230,555,226.53	32,374.57	0.00	230,587,601.09

Table 8b: Aggregated external costs for Eco-Indicator99 – first 25 pollutants

Pollutant	Ecocat	Euros Ecosystem Quality	Euros Human Health	Euros Total
Nitrogen oxides	air	5,108,741,079.01	7,476,713,735.01	12,585,454,814.03
Particulates, < 2.5 um	air	0.00	11,982,069,031.07	11,982,069,031.07
Sulfur dioxide	air	1,642,814,461.47	7,843,766,828.93	9,486,581,290.40
Zinc	air	9,262,971,382.72	0.00	9,262,971,382.72
Carbon dioxide, fossil	air	0.00	7,354,886,769.45	7,354,886,769.45
Chromium	air	5,167,734,773.95	0.00	5,167,734,773.95
Nickel	air	3,128,746,132.81	1,825,450.54	3,130,571,583.35
Arsenic	water	3,992,640.33	2,089,649,728.12	2,093,642,368.45
Lead	air	1,801,465,132.17	0.00	1,801,465,132.17
Ammonia	air	1,044,484,218.28	547,847,650.98	1,592,331,869.25
Dinitrogen monoxide	air	0.00	973,161,362.50	973,161,362.50
Methane, fossil	air	0.00	661,635,225.30	661,635,225.30
Cadmium	air	267,463,883.68	340,587,907.17	608,051,790.86
Copper	air	546,289,500.41	0.00	546,289,500.41
Chromium VI	soil	360,705,795.63	0.00	360,705,795.63
Arsenic	air	50,539,069.90	218,802,416.17	269,341,486.07
Sulfur hexafluoride	air	0.00	180,728,636.00	180,728,636.00
Cadmium	water	12,522,612.38	165,820,910.50	178,343,522.88
Cadmium	soil	102,242.85	165,254,126.53	165,356,369.38
Chromium VI	air	119,672,372.91	30,459,119.12	150,131,492.03
Chromium VI	water	137,712,423.40	147.89	137,712,571.29
Radon-222	air	0.00	116,679,580.04	116,679,580.04
Zinc	soil	94,228,813.79	0.00	94,228,813.79
Carbon monoxide, fossil	air	0.00	71,113,135.04	71,113,135.04
Dioxins	air	515,767.28	62,266,085.21	62,781,852.50
Mercury	air	58,586,966.15	0.00	58,586,966.15

As can be seen in the tables above, the total values for the external costs vary strongly for some cases, e.g. Aluminium, and there is only a small difference in other cases, e.g. Nitrogen oxides, when comparing the two approaches for the damage factors. One can also see that the ranking of pollutants is different in the two tables. For example Aluminium, ranked 1st in the table for damage factors given in IMPACT2002+, is not in the list of total monetary values taking damage factors from Eco-Indicator 99. On the other hand, there are some substances within the table 8b that can not be found in the list of the first 25 pollutants in table 8a, e.g. Chromium VI and Radon-222. But, as already stated, the overall monetary values should not be taken as absolute and final numbers. Moreover, they are just calculated to allow for a comparison of the different substances within one data source and across the two sources.

Thus, for a more comprehensible presentation of the substances that could be considered relevant for the examined sectors using both approaches, the two columns of the following table 10 include those pollutants that exhibit a total of external costs exceeding 1,000,000 Euro. This minimum level of external costs represents a value of less than one-tenth of a percent of the maximum level for both approaches. In the following table, the external costs for each pollutant have been added up so that there is no further differentiation between the ecosystem categories the pollutant is emitted to.

Table 9 shows that the majority of relevant pollutants are the same in both approaches. These substances – highlighted in bold letters – make up for 33 out of 52 toxic elements for IMPACT2002+ and the 41 for Eco-Indicator 99 that have a total external cost value exceeding one million Euro. The remaining 19 substances in the left table and 9 in the right table, are either not reaching this mark in the other database or, as in the case of Aluminium in Eco-Indicator 99, do not have any damage factor at all in the compared data source. In total, 60 different substances are above a value of one million of external costs and should be considered relevant in the further work of this workpackage.

Additionally, an identification of those substances that are not yet included into EcoSense has been made. These pollutants are given a gray background. It can clearly be seen that this only applies to a small number of toxic elements that are declared relevant in this table. It will be one of the next steps to analyse how to integrate these selected substances into the existing model.

Table 9: Comparison of relevant pollutants for both approaches

Relevant pollutans from IMPACT2002+	Relevant pollutant from Eco-Indicator99
Aluminum	**Nitrogen oxides**
Zinc	**Particulates, < 2.5 um**
Carbon dioxide, fossil	**Sulfur dioxide**
Nitrogen oxides	**Zinc**
Particulates, < 2.5 um	**Carbon dioxide, fossil**
Dioxins	**Chromium**
Sulfur dioxide	**Nickel**
Copper	**Arsenic**
Chromium	**Lead**
Mercury	**Ammonia**
Nickel	**Dinitrogen monoxide**
Dinitrogen monoxide	**Cadmium**
Arsenic	**Methane, fossil**
Methane, fossil	**Copper**
Ammonia	**Chromium VI**
Lead	**Sulfur hexafluoride**
Molybdenum	Radon-222
Sulfur hexafluoride	**Carbon monoxide, fossil**
Carbon monoxide, fossil	**Dioxins**
Cadmium	**Mercury**
Cobalt	Carbon-14
Methane, chlorodifluoro-, HCFC-22	**Methane, tetrafluoro-, R-14**
Antimony	**NMVOC, unspecified origin**
Methane, tetrafluoro-, R-14	**Methane, chlorodifluoro-, HCFC-22**
Benzo(a)pyrene	**Methane, tetrachloro-, R-10**
Methane, trifluoro-, HFC-23	**Methane, trifluoro-, HFC-23**
NMVOC, unspecified origin	**Methane, dichlorodifluoro-, CFC-12**
Methane, dichlorodifluoro-, CFC-12	PAH, polycyclic aromatic hydrocarbons
Benzene	**Benzene**
Methane, tetrachloro-, R-10	**Ethane, 1,2-dichloro-**
Barium	**Methane, biogenic**
Nitrobenzene	**Ethane, hexafluoro-, HFC-116**
Ethane, hexafluoro-, HFC-116	Ethylene oxide
Carbon monoxide, biogenic	**Chloroform**
Methane, biogenic	**Benzo(a)pyrene**
Carbon dioxide, land transformation	**Benzene, hexachloro-**
Metolachlor	Propylene oxide
Selenium	**Ethane, 1,1,1,2-tetrafluoro-, HFC-134a**
Carbofuran	Carbon disulfide
Benzene, hexachloro-	Hydrocarbons, aliphatic, alkanes, unspecified
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Hydrocarbons, aromatic
Ethane, 1,2-dichloro-	
Linuron	

Chromium VI **Chloroform** Benzene, chloro- Glyphosate Atrazine Acetic acid Propene Methane, chlorotrifluoro-, CFC-13 Methane, bromotrifluoro-, Halon 1301		

VI. Problems with the analysis

The analysis of relevant pollutants for the chemical, electronics, metals and plastics sector brought along some problems that are worth noticing.

One problem results from the two different sources used to assign damage factors to each of the 400 pollutants. As already mentioned above, Eco-Indicator 99 does not have a category of impacts on climate change and greenhouse effects and these are included into damages to human health. It is not clearly shown how the DALYs per unit were calculated for these pollutants.

Another major problem is the coverage of production processes and produced outputs in the different sectors. The statistics of the PRODCOM list are not covering all the processes that emission factors can be found for in EcoInvent 2.0. On the other hand, the same problem applies for output data given in the PRODCOM annual report for 2005 as the information given in this report are exceeding the number of production processes covered by EcoInvent 2.0. Furthermore, as the definition of processes and products differs between the two sources there were many cases were it was difficult to match both data sets. As a result, for some production process average values for the emissions had to be taken for the calculations as PRODCOM did not deliver a single output for each of the processes and in some of the cases an analysis was not possible. But, while there is a high number of data that could not be covered in this screening process, the most important process for the production in the regarded sectors are covered and therefore, the results of this study can be seen as a helpful tool for defining relevant pollutants for the further analysis of the sectors. Data for 974 processes is given in EcoInvent 2.0 for the covered sectors (chemicals, electronics, metals, and plastics) with 252 of these covered by data from PRODCOM, accounting for about 25%. This includes most of the important production processes within the analysed sectors.

It has already been mentioned in the sections above that the monetary values for damages to the ecosystem, especially regarding those resulting from IMPACT2002+, seem to be very high compared to the values for damages to human health. This can clearly be seen in the values resulting for heavy metals like Aluminium and Zinc. These results do not correspond to the results that were estimated in other projects like the above-mentioned NEEDS project using the EcoSense model. In this model there is also another interesting difference in the results. The ratio of Euros per ton of Nitrogen oxides for damages on human health compared to damages to the quality of the ecosystem was estimated with EcoSense to be about 6.2. In this study, this ratio is less than 1.5 indicating the high relevance of damages to the ecosystem.

Therefore, this study offers a second approach to identify the relevant pollutants. To get the same ratio as for the EcoSense model and to allow for a sensitivity analysis, the results for damages to the ecosytsem are divided by a fator of 4.21 for IMPACT2002+ and by 4.24 for Eco-Indicator 99. This factor results from the already observed ratio of about 1.5 and the 'desired' ratio of about 6.2. The calculations were done for both data sources. The new estimations only scale down the absolute amount of external costs resulting from the emissions of the regarded pollutants but do not have an impact on the ranking within the category of damages to the ecosystem. The major change can be observed when regarding the aggregated external costs for all categories. However, as shown in table 10, this 'correction' does not have an impact on the selection of pollutants that have an overall external cost value of above one million Euro.

The only changes can be found in the total number of pollutants that are classified as relevant going down from 52 to 46 substances for IMPACT2002+, while the number remains at 41 substances for Eco-Indicator 99. In total, 55 different substances can be considered relevant for the future work in this work package. The number of pollutants covered in both IMPACT2002+ and Eco-Indicator 99 falls to 32, as Chromium is not a 'relevant' pollutant in the results of Eco-Indicator 99 any more. As above, the substances that are not highlighted in bold letters either do not reach the mark of one million Euro in the other table or are not included in the other database at all. Those 35 substances that have no specially marked background are already included into the model of EcoSense. The pollutants that are marked with a grey background are not yet included into the EcoSense model. Of these 20 substances, there are seven substances which are relevant in both approaches and should be implemented into the model with a higher priority than the other 13 substances that only show up in one of the approaches. For the further analysis, the results of IMPACT2002+ will be focused on as this source has an own category for the impacts on climate change and does not include these into the estimation of damages to human health (DALY).

Finally, it has to be mentioned that the values taken for the monetary evaluation of the damages and the comparison of the pollutants for all damage categories are highly uncertain. There is no such as a definite value for a Disability Adjusted Life Year. There is a lot of literature dealing with this problem. The values that were taken for this analysis are based on the results of the studies mentioned in part II.3. However, as these values are constant across all pollutants, a recalculation using other monetary values will not change the outcome of the study. While the total external cost values will change the ranking of the substances and their relevance for the regarded sectors will not.

Table 10: Comparison of relevant pollutants for both 'corrected' approaches

Relevant pollutants from 'corrected' IMPACT2002+	Relevant pollutants from 'corrected' Eco-Indicator 99
Carbon dioxide, fossil	**Particulates, < 2.5 um**
Particulates, < 2.5 um	**Nitrogen oxides**
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	**Sulfur dioxide**
Sulfur dioxide	**Carbon dioxide, fossil**
Nitrogen oxides	**Zinc**
Aluminum	**Arsenic**
Zinc	**Chromium VI**
Dinitrogen monoxide	**Nickel**
Methane, fossil	**Dinitrogen monoxide**
Arsenic	**Ammonia**
Ammonia	**Cadmium**
Molybdenum	**Methane, fossil**
Copper	**Lead**
Sulfur hexafluoride	Cobalt-58
Carbon monoxide, fossil	**Copper**
Chromium	**Sulfur hexafluoride**
Mercury	Radon-222
Nickel	**Carbon monoxide, fossil**
Methane, chlorodifluoro-, HCFC-22	**Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin**
Methane, tetrafluoro-, R-14	Carbon-14

Benzo(a)pyrene	**Methane, tetrafluoro-, R-14**
Antimony	**NMVOC, unspecified origin**
Lead	**Methane, chlorodifluoro-, HCFC-22**
Methane, trifluoro-, HFC-23	**Methane, tetrachloro-, R-10**
NMVOC, unspecified origin	**Mercury**
Methane, dichlorodifluoro-, CFC-12	**Methane, trifluoro-, HFC-23**
Methane, tetrachloro-, R-10	**Methane, dichlorodifluoro-, CFC-12**
Benzene	PAH, polycyclic aromatic hydrocarbons
Cadmium	**Benzene**
Nitrobenzene	**Ethane, 1,2-dichloro-**
Ethane, hexafluoro-, HFC-116	**Methane, biogenic**
Carbon monoxide, biogenic	**Ethane, hexafluoro-, HFC-116**
Methane, biogenic	Ethylene oxide
Barium	**Chloroform**
Cobalt	**Benzo(a)pyrene**
Benzene, hexachloro-	**Benzene, hexachloro-**
Selenium	Propylene oxide
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	**Ethane, 1,1,1,2-tetrafluoro-, HFC-134a**
Ethane, 1,2-dichloro-	Carbon disulfide
Chromium VI	Hydrocarbons, aliphatic, alkanes, unspecified
Chloroform	Hydrocarbons, aromatic
Linuron	
Methane, chlorotrifluoro-, CFC-13	
Metolachlor	
Methane, bromotrifluoro-, Halon 1301	
Propene	

VII. Conclusion and next steps

The process of screening pollutants for four selected sectors came to the result that 52 pollutants can be seen as relevant for the production processes in these sectors and should be included into the further work in WP II.5.a. As 35 of these 55 pollutants are already covered with the existing methodology of EcoSense, 20 substances will have to be further studied and will be implemented into this model.

Another important step will be the selection of sectors for the case studies that are planned to be delivered by the end of this work package. There has been an agreement between the institutions involved in this work package to check the possibilities to include the agri-food sector into the case studies. Furthermore, the chemical sector and one of the remaining three sectors (electronics, metals and plastics) will be covered in these studies.

Regarding the further extensions to the Lagrangian transportation model of EcoSense, there will be an extension of the methodology as the 3D Eulerian chemistry transportation model of Polyphemus will be implemented into EcoSense. This will improve the accuracy of the model and is currently installed for a fully operational use.

The partners of this work package also agreed that there will not be a workshop on this subject due to lack of time and financial reasons for the project partners but there will be an extended bilateral cooperation including meetings of all partners along the work progress of WP II.5.a.

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Appendix I: Tables

Tables in the Appendix only include values above 0.01.

Table A1: Total emissions

Pollutant	Unit	Total
Radon-222	kBq	119,113,949,088,702.00
Carbon dioxide, fossil	kg	863,465,556,666.38
Hydrogen-3, Tritium	kBq	312,829,126,990.05
Coal, hard, unspecified, in ground	kg	210,733,694,559.46
Iron, 46% in ore, 25% in crude ore, in ground	kg	184,245,877,042.98
Oil, crude, in ground	kg	176,532,773,700.40
Gas, natural, in ground	Nm3	170,821,274,970.34
Coal, brown, in ground	kg	91,830,616,762.33
Occupation, forest, intensive, normal	m2a	18,794,840,666.02
Radium-226	kBq	10,583,909,188.02
Occupation, arable, non-irrigated	m2a	8,205,520,078.30
Aluminium, 24% in bauxite, 11% in crude ore, in ground	kg	7,442,043,726.51
Xenon-133	kBq	7,120,023,531.39
Carbon-14	kBq	6,531,792,111.53
Carbon monoxide, fossil	kg	5,497,621,502.96
Occupation, dump site	m2a	5,152,575,854.75
Methane, fossil	kg	3,721,232,616.52
Sulfur dioxide	kg	3,546,080,076.52
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	kg	3,460,652,023.18
Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	kg	2,600,760,436.40
Krypton-85	kBq	2,495,833,799.27
Occupation, permanent crop, fruit, intensive	m2a	2,432,819,595.05
Nitrogen oxides	kg	2,045,478,510.53
Gas, mine, off-gas, process, coal mining	Nm3	1,911,894,644.21
Occupation, forest, intensive	m2a	1,647,246,875.49
Occupation, industrial area, built up	m2a	1,441,271,563.63
Occupation, forest, intensive, short-cycle	m2a	1,399,707,770.37
Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	kg	1,221,588,896.16
Occupation, industrial area, vegetation	m2a	1,116,703,658.08
Occupation, traffic area, road network	m2a	1,097,696,903.79
Occupation, construction site	m2a	1,039,787,584.26
Occupation, mineral extraction site	m2a	1,019,007,062.73
Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	kg	894,129,106.44
Carbon dioxide, land transformation	kg	842,121,050.91
Occupation, industrial area	m2a	789,766,065.67
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	704,502,153.61
Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, in ground	kg	566,080,147.13
Particulates, < 2.5 um	kg	378,038,949.46
Dinitrogen monoxide	kg	351,969,672.49
Iodine-131	kBq	315,714,710.86
Carbon monoxide, biogenic	kg	280,231,067.58
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	kg	276,921,088.22
Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	kg	261,014,498.03
Occupation, traffic area, road embankment	m2a	228,560,577.57
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	kg	204,408,990.30
Peat, in ground	kg	186,077,980.17
Ammonia	kg	154,970,359.16
Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	kg	154,048,653.40

Occupation, traffic area, rail network	m2a	148,332,047.65
Occupation, traffic area, rail embankment	m2a	134,143,256.38
Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	kg	125,752,291.02
Aluminum	kg	97,273,287.39
Uranium-238	kBq	93,062,524.24
Polonium-210	kBq	89,801,802.22
Benzene	kg	66,410,424.67
Lead-210	kBq	53,657,107.64
Uranium	kg	48,982,924.25
Uranium alpha	kBq	48,982,333.77
Uranium-234	kBq	45,753,262.39
Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	kg	40,863,471.40
Methane, biogenic	kg	36,702,758.88
Hydrocarbons, aliphatic, alkanes, unspecified	kg	36,331,444.01
Propene	kg	36,063,969.61
Uranium-235	kBq	33,412,393.29
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	kg	33,088,855.16
Occupation, shrub land, sclerophyllous	m2a	33,024,497.03
Cumene	kg	30,052,896.53
Acetic acid	kg	29,025,282.56
Carbon disulfide	kg	22,856,862.42
Methanol	kg	18,233,611.70
Ethene	kg	16,674,431.10
Nitrobenzene	kg	16,397,802.38
Ethane	kg	15,868,231.11
Cobalt-58	kBq	14,436,704.58
Zinc	kg	13,899,499.52
Acetone	kg	13,489,899.08

Pentane	kg	13,379,481.88
Hydrocarbons, aromatic	kg	12,934,772.83
Hydrocarbons, aliphatic, alkanes, cyclic	kg	12,259,303.97
Cobalt-60	kBq	11,305,065.07
Phenol	kg	11,077,950.84
Ethane, 1,2-dichloro-	kg	7,965,595.75
Hexane	kg	7,611,783.10
Occupation, urban, discontinuously built	m2a	7,446,893.03
Propane	kg	7,424,710.56
Butene	kg	7,421,216.14
Propanol	kg	7,022,980.76
Iodine-129	kBq	6,604,296.64
Hydrogen sulfide	kg	5,995,452.01
Cesium-137	kBq	5,049,995.49
Butane	kg	4,921,167.72
Chromium VI	kg	4,748,203.21
Uranium, in ground	kg	4,711,641.08
Chromium	kg	4,234,162.94
Propylene oxide	kg	3,962,172.97
Chloroform	kg	3,804,943.90
Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	kg	3,798,672.64
Propanal	kg	3,609,843.52
Ethene, chloro-	kg	3,588,535.79
Formaldehyde	kg	3,225,483.66
Heptane	kg	2,902,543.58
Methane, chlorodifluoro-, HCFC-22	kg	2,828,009.68
Barium	kg	2,712,021.57
Xylene	kg	2,203,299.46
Ethanol	kg	2,181,665.39

Lead	kg	1,985,877.13
Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	kg	1,966,805.50
Copper	kg	1,858,138.71
Nickel	kg	1,857,469.80
Antimony-124	kBq	1,780,805.58
Cyclohexane	kg	1,694,263.57
Antimony-125	kBq	1,683,664.92
2-Methyl-2-butene	kg	1,632,273.48
Cesium-134	kBq	1,560,220.61
Toluene	kg	1,543,138.32
Metolachlor	kg	1,319,793.77
Butanol	kg	1,216,404.96
Acetaldehyde	kg	1,202,265.85
Tin, 79% in cassiterite, 0.1% in crude ore, in ground	kg	1,089,539.19
Arsenic	kg	992,740.66
Manganese-54	kBq	895,272.11
Sulfur hexafluoride	kg	804,593.50
Ethylene oxide	kg	777,839.47
Antimony	kg	695,478.47
Hydrogen peroxide	kg	687,327.19
Methane, tetrafluoro-, R-14	kg	672,261.62
Methyl formate	kg	635,500.02
Ethyl acetate	kg	632,422.46
Methyl ethyl ketone	kg	632,242.70
4-Methyl-2-pentanone	kg	540,888.74
Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	kg	536,741.11
PAH, polycyclic aromatic hydrocarbons	kg	444,444.25
Ethene, tetrachloro-	kg	435,626.53

Aldehydes, unspecified	kg	434,890.44
Methane, tetrachloro-, R-10	kg	429,319.76
Cobalt	kg	405,523.01
Formic acid	kg	385,916.79
Ethyne	kg	319,471.75
Styrene	kg	307,751.26
Benzene, ethyl-	kg	243,444.93
Butyl acetate	kg	213,888.02
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	198,486.68
Methane, trifluoro-, HFC-23	kg	179,534.02
Linuron	kg	175,450.45
Glyphosate	kg	173,186.13
Mercury	kg	170,009.01
o-Dichlorobenzene	kg	167,386.76
Methane, dichloro-, HCC-30	kg	154,339.65
Methane, dichlorodifluoro-, CFC-12	kg	140,052.03
2-Propanol	kg	130,365.05
Cadmium	kg	122,243.54
Molybdenum	kg	121,924.23
Furan	kg	109,358.34
Cinnabar, in ground	kg	88,168.81
Selenium	kg	78,737.23
Ethane, hexafluoro-, HFC-116	kg	75,933.21
Carbofuran	kg	63,718.07
Acetonitrile	kg	57,582.03
Diflubenzuron	kg	56,411.58
Atrazine	kg	56,034.29
Cobalt-57	kBq	33,375.51
2,4-D	kg	29,634.89

Barium-140	kBq	20,512.17
Trifluralin	kg	18,685.39
Cypermethrin	kg	18,539.73
Chlorothalonil	kg	18,514.23
Benzo(a)pyrene	kg	16,380.68
Iodine-133	kBq	15,718.44
Carbetamide	kg	14,462.68
Bentazone	kg	12,308.53
Napropamide	kg	12,022.02
Endosulfan	kg	11,700.36
m-Xylene	kg	9,075.34
Isoprene	kg	5,074.68
Methane, chlorotrifluoro-, CFC-13	kg	4,234.26
Vinclozolin	kg	3,486.23
Antimony-122	kBq	3,382.46
Pendimethalin	kg	3,220.93
Methane, bromochlorodifluoro-, Halon 1211	kg	3,152.72
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	2,705.84
Methane, monochloro-, R-40	kg	2,700.16
2-Methyl pentane	kg	2,518.10
Carbendazim	kg	1,911.98
Methane, bromotrifluoro-, Halon 1301	kg	1,782.58
Phenol, pentachloro-	kg	1,741.01
Pirimicarb	kg	1,155.29
Prochloraz	kg	959.71
Methane, trichlorofluoro-, CFC-11	kg	916.05
Metribuzin	kg	910.15
Acrylate	kg	892.67
Benzene, hexachloro-	kg	817.56

Beryllium	kg	798.16
Butadiene	kg	675.36
Diethylene glycol	kg	638.29
Diethyl ether	kg	637.55
Cyfluthrin	kg	622.47
Methane, dichlorofluoro-, HCFC-21	kg	564.26
Chlorpyrifos	kg	416.51
Acrylic acid	kg	377.17
t-Butyl methyl ether	kg	371.26
Deltamethrin	kg	369.13
Phosphoric acid	kg	319.47
Acrolein	kg	256.09
Zinc-65	kBq	226.23
Clomazone	kg	217.79
Aldrin	kg	212.31
Thiram	kg	206.20
Lambda-cyhalothrin	kg	198.41
Ethane, 1,1-difluoro-, HFC-152a	kg	186.63
Fluroxypyr	kg	138.84
Trinexapac-ethyl	kg	128.54
Benomyl	kg	116.22
Mecoprop	kg	111.07
Benzaldehyde	kg	104.20
Asulam	kg	55.53
Bifenox	kg	55.53
Benzene, pentachloro-	kg	44.34
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	17.90
o-Xylene	kg	15.67
Acenaphthene	kg	12.74

Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	8.68
Plutonium-alpha	kBq	2.07
Ethane, 1,1,1-trichloro-, HCFC-140	kg	1.95
Plutonium-238	kBq	0.90
Iprodion	kg	0.86
Acenaphthylene	kg	0.76
Copper, 0.52% in sulfide, Cu 0.27% and Mo 8.2E-3% in crude ore, in ground	kg	0.25

Table A2: Total ecosystem damage (IMPACT2002+)

Pollutant	Ecocat	PDF*m2
Aluminum	air	75,457,001,059.97
Zinc	air	56,936,244,972.02
Aluminum	soil	15,552,720,010.36
Nitrogen oxides	air	11,332,611,089.20
Zinc	soil	9,166,733,791.09
Chromium	air	8,386,003,700.81
Copper	air	7,889,216,853.59
Copper	soil	7,507,636,853.23
Mercury	air	4,765,745,033.97
Nickel	air	4,357,252,038.14
Sulfur dioxide	air	3,644,220,189.59
Ammonia	air	2,328,517,655.63
Lead	air	1,627,900,879.85
Aluminum	water	989,522,352.31
Copper	water	813,844,440.84
Arsenic	air	627,319,699.88
Chromium	soil	511,435,728.76
Zinc	water	445,629,767.52
Cadmium	air	444,490,000.96
Cobalt	air	288,562,391.57
Nickel	soil	112,318,549.33
Cadmium	soil	80,256,469.84
Antimony	water	70,951,667.49
Mercury	soil	67,608,779.95
Lead	soil	60,944,165.83
Nickel	water	52,073,612.13
Cobalt	water	39,081,197.89
Metolachlor	soil	28,431,111.89
Barium	soil	19,678,895.85
Carbofuran	soil	18,090,963.38
Arsenic	soil	16,063,011.53
Arsenic	water	15,136,820.23
Mercury	water	9,550,601.31
Cadmium	water	8,473,110.45
Barium	water	7,624,780.61
Benzene	water	7,250,361.99
Selenium	water	6,409,005.52

Cobalt	soil	6,394,547.66
Glyphosate	soil	5,307,533.24
Linuron	soil	5,118,292.54
Atrazine	soil	4,631,678.22
Lead	water	4,210,934.79
Antimony	air	3,951,919.74
Selenium	air	3,872,727.20
Acetic acid	air	3,005,706.80
Chromium	water	2,387,028.32
Chlorothalonil	soil	1,343,928.50
Carbendazim	soil	1,310,811.74
Propene	water	1,170,119.58
Aldrin	soil	507,019.77
Butene	water	451,410.63
Carbetamide	soil	438,663.18
Cypermethrin	soil	343,024.96
Barium	air	297,915.98
Glyphosate	soil	291,046.37
Metribuzin	soil	218,425.20
Ethane, 1,2-dichloro-	water	152,008.41
Endosulfan	soil	94,497.03
Acetic acid	water	93,701.46
Phenol	water	74,473.23
Pirimicarb	soil	72,084.36
Phenol	air	62,590.66
Methane, tetrafluoro-, R-14	air	55,412.79
Formaldehyde	water	47,112.98
Ethane, 1,2-dichloro-	air	39,406.32
Formaldehyde	air	35,680.92

Toluene	water	33,401.87
Xylene	water	25,481.71
Benzo(a)pyrene	air	23,411.73
Chloroform	air	21,296.32
2,4-D	soil	20,168.09
Benzene, ethyl-	water	17,579.82
Vinclozolin	soil	12,819.59
Benomyl	soil	8,330.99
Acetaldehyde	water	8,113.55
Bentazone	soil	7,844.64
Methanol	air	7,713.34
Cyfluthrin	soil	5,274.94
Trifluralin	soil	4,799.08
Methane, chlorodifluoro-, HCFC-22	air	4,143.24
Acetone	water	3,827.56
Methane, tetrachloro-, R-10	air	3,737.54
Prochloraz	soil	3,521.79
Fluroxypyr	soil	3,044.72
Chlorpyrifos	soil	2,480.66
Napropamide	soil	2,111.51
Methane, dichloro-, HCC-30	water	2,070.91
Lambda-cyhalothrin	soil	2,016.44
Clomazone	soil	1,351.22
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	1,337.72
Ethanol	water	1,282.45
Phenol, pentachloro-	air	1,129.16
Antimony	soil	1,070.69
Benzene	air	1,051.81
Methane, dichlorodifluoro-, CFC-12	air	1,019.53

Methanol	water	1,012.84
Propane	air	956.51
Ethene, tetrachloro-	air	778.42
Propanal	air	720.56
Deltamethrin	soil	717.28
Pendimethalin	soil	609.25
Trinexapac-ethyl	soil	600.04
Benzene, hexachloro-	air	556.35
Polychlorinated biphenyls	air	542.21
Acetone	air	539.92
Methane, dichloro-, HCC-30	air	456.62
Pentane	air	395.86
Butane	air	343.86
Acetaldehyde	air	306.48
Acrolein	air	189.21
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	189.00
Ethyl acetate	air	151.57
Methane, chlorotrifluoro-, CFC-13	air	151.22
Methyl ethyl ketone	air	120.73
Chloroform	water	116.00
Acenaphthene	water	89.20
Ethanol	air	56.72
Methane, bromotrifluoro-, Halon 1301	air	56.67
Bifenox	soil	53.09
Propene	air	46.78
Toluene	air	46.16
Butene	air	34.19
Ethyne	air	31.58
Xylene	air	30.37

Methane, bromochlorodifluoro-, Halon 1211	air	21.45
Methane, trichlorofluoro-, CFC-11	air	19.06
Benzene, pentachloro-	air	17.48
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	17.43
m-Xylene	water	13.72
Benzene, ethyl-	air	9.65
Mecoprop	soil	9.57
o-Xylene	water	7.51
Styrene	air	5.62
Methane, dichlorofluoro-, HCFC-21	air	1.51
Hexane	air	0.98
m-Xylene	air	0.72
Acenaphthylene	water	0.35
t-Butyl methyl ether	air	0.20
t-Butyl methyl ether	water	0.14
Ethane, 1,1-difluoro-, HFC-152a	air	0.09
Heptane	air	0.03
Asulam	soil	0.03
Ethane, 1,1,1-trichloro-, HCFC-140	water	0.03
Ethane, 1,1,1-trichloro-, HCFC-140	air	0.02
Acenaphthene	air	0.01
Butadiene	air	0.01

Table A3: Total ecosystem damage (Eco-Indicator 99)

Pollutant	Ecocat	Total
Zinc	air	20,547,851,336.99
Chromium	air	11,463,475,541.15
Nitrogen oxides	air	11,332,611,089.20
Nickel	air	6,940,430,640.66
Lead	air	3,996,151,579.79
Sulfur dioxide	air	3,644,220,189.59
Ammonia	air	2,316,957,005.93
Copper	air	1,211,822,316.80
Chromium VI	soil	800,145,953.03
Cadmium	air	593,309,413.67
Chromium VI	water	305,484,523.95
Chromium VI	air	265,466,665.74
Zinc	soil	209,025,762.63
Mercury	air	129,962,214.18
Copper	soil	129,887,490.56
Nickel	water	116,595,367.41
Copper	water	115,946,945.70
Arsenic	air	112,109,738.02
Zinc	water	103,151,997.25
Chromium	soil	32,384,128.53
Cadmium	water	27,778,643.26
Arsenic	water	8,856,788.66
Chromium	water	7,209,214.79
Mercury	water	2,372,635.46
Lead	water	2,350,320.02
Benzo(a)pyrene	air	2,301,668.80
Benzene	water	1,708,578.10
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	1,144,115.53
Cadmium	soil	226,803.12
Arsenic	soil	207,124.60
Mercury	soil	87,302.57
Benzene	air	75,026.26
Toluene	water	38,626.78
Lead	soil	35,857.60
Benzene, hexachloro-	air	31,610.47
Phenol, pentachloro-	air	22,663.88
Atrazine	soil	8,349.11
Carbendazim	soil	4,474.04
Trifluralin	soil	386.79
Toluene	air	311.46
PAH, polycyclic aromatic hydrocarbons	air	305.14
Thiram	soil	205.36
Bentazone	soil	204.32
Ethane, 1,2-dichloro-	water	55.49
PAH, polycyclic aromatic hydrocarbons	water	53.40
Metribuzin	soil	43.87
2,4-D	soil	3.76

Table A4: Total damages to human health (IMPACT2002+)

Pollutant	Ecocat	Total
Particulates, < 2.5 um	air	295,424.23
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	254,062.25
Sulfur dioxide	air	196,094.17
Nitrogen oxides	air	187,760.76
Arsenic	water	25,222.83
Ammonia	air	13,719.26
Arsenic	air	8,561.95
Molybdenum	soil	5,476.17
Molybdenum	air	4,698.60
Carbon monoxide, fossil	air	4,036.00
Zinc	water	2,375.93
Chromium	air	2,123.67
Zinc	air	1,980.58
Benzo(a)pyrene	air	1,641.96
Antimony	water	1,500.03
Zinc	soil	1,237.63
Molybdenum	water	1,149.83
NMVOC, unspecified origin	air	914.14
Nitrobenzene	water	598.89
Benzene	air	582.85
Arsenic	soil	566.71
Methane, tetrachloro-, R-10	air	375.99
Barium	water	268.61
Carbon monoxide, biogenic	air	205.66
Mercury	air	169.51
Benzene, hexachloro-	air	167.73
Methane, chlorodifluoro-, HCFC-22	air	148.55
Benzene	water	147.28
Methane, dichlorodifluoro-, CFC-12	air	147.06
Aluminum	air	142.85
Cadmium	water	116.55
Barium	soil	107.41
Cadmium	air	103.24
Selenium	water	101.20
Cadmium	soil	95.95
Ethane, 1,2-dichloro-	water	67.19
Methane, fossil	air	47.98
Aluminum	soil	46.35
Chromium VI	air	45.57
Ethane, 1,2-dichloro-	air	42.74
Linuron	soil	35.33
Chromium VI	water	33.38
Aluminum	water	32.01
Mercury	water	26.97
Nickel	air	26.47
Nickel	water	26.07
Propene	air	24.92
Chloroform	air	24.31
Formaldehyde	air	23.19
Methane, bromotrifluoro-, Halon 1301	air	22.68
Selenium	air	21.07
Methane, bromochlorodifluoro-, Halon 1211	air	20.31
Lead	air	12.69
Pentane	air	11.47
Antimony	air	10.58
Propylene oxide	water	10.40

Butene	air	10.01
Cumene	air	9.81
Lead	water	9.70
Metolachlor	soil	9.55
Copper	water	9.18
Propanol	air	8.36
Hexane	air	7.86
Copper	soil	6.92
Propanal	air	6.14
Copper	air	5.92
Hydrogen sulfide	air	5.01
Xylene	air	4.59
Methanol	air	4.57
Methane, chlorotrifluoro-, CFC-13	air	4.45
Ethane	air	4.28
Acetic acid	air	4.22
Benzene, chloro-	water	4.13
Propylene oxide	air	3.89
Butane	air	3.78
Carbon disulfide	air	3.70
Atrazine	soil	3.29
Heptane	air	3.23
Ethylene oxide	air	3.12
2-Methyl-2-butene	air	2.92
Propane	air	2.90
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	2.72
Aldrin	soil	2.26
Toluene	air	1.83
Chromium VI	soil	1.78

Barium	air	1.64
Nickel	soil	1.40
Cumene	water	1.38
Chromium	water	1.34
Mercury	soil	1.17
Acetone	air	1.13
Cyclohexane	air	1.05
Lead	soil	0.96
Methane, trichlorofluoro-, CFC-11	air	0.96
Trifluralin	soil	0.93
Butanol	air	0.84
Chromium	soil	0.81
Acetaldehyde	air	0.80
Phenol, pentachloro-	air	0.79
Carbofuran	soil	0.73
Aldehydes, unspecified	air	0.61
Methyl ethyl ketone	air	0.51
Ethylene oxide	water	0.49
Methane, biogenic	air	0.47
Ethanol	air	0.43
Nitrobenzene	air	0.42
4-Methyl-2-pentanone	air	0.30
Benzene, ethyl-	air	0.30
Ethyl acetate	air	0.29
Cypermethrin	soil	0.22
Ethene, tetrachloro-	air	0.19
Acetone	water	0.16
Beryllium	air	0.16
2-Propanol	air	0.16

Styrene	air	0.11
Chlorpyrifos	soil	0.11
Methane, dichloro-, HCC-30	air	0.09
Formaldehyde	water	0.08
Hydrogen sulfide	water	0.07
Prochloraz	soil	0.07
Endosulfan	soil	0.06
Chlorothalonil	soil	0.06
Ethyne	air	0.06
Methane, monochloro-, R-40	air	0.06
Toluene	water	0.05
Methane, dichloro-, HCC-30	water	0.05
2,4-D	soil	0.05
Methyl formate	air	0.05
Phenol	air	0.04
Formic acid	air	0.03
Methane, dichlorofluoro-, HCFC-21	air	0.02
m-Xylene	air	0.02
Acrolein	air	0.02
Acetonitrile	air	0.02
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	0.02
Phenol	water	0.02
Butanol	water	0.01
Isoprene	air	0.01
Benzene, ethyl-	water	0.01
Glyphosate	soil	0.01
Antimony	soil	0.01
Acetaldehyde	water	0.01
Ethanol	water	0.01
Methanol	water	0.01

Table A5: Total damages to human health (Eco-Indicator 99)

Pollutant	Ecocat	Total
Particulates, < 2.5 um	air	299,551.73
Sulfur dioxide	air	196,094.17
Nitrogen oxides	air	186,917.84
Carbon dioxide, fossil	air	183,872.17
Arsenic	water	52,241.24
Dinitrogen monoxide	air	24,329.03
Methane, fossil	air	16,540.88
Ammonia	air	13,696.19
Cadmium	air	8,514.70
Arsenic	air	5,470.06
Sulfur hexafluoride	air	4,518.22
Cadmium	water	4,145.52
Cadmium	soil	4,131.35
Radon-222	air	2,916.99
Carbon monoxide, fossil	air	1,777.83
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	1,556.65
Carbon-14	air	1,399.72
Methane, tetrafluoro-, R-14	air	945.26
NMVOC, unspecified origin	air	914.14
Methane, chlorodifluoro-, HCFC-22	air	910.99
Methane, tetrachloro-, R-10	air	789.27
Chromium VI	air	761.48
Methane, trifluoro-, HFC-23	air	466.79
Methane, dichlorodifluoro-, CFC-12	air	316.94

PAH, polycyclic aromatic hydrocarbons	water	193.19
Ethane, 1,2-dichloro-	air	184.03
Methane, biogenic	air	162.54
Ethane, hexafluoro-, HFC-116	air	152.52
Benzene	water	146.73
Arsenic	soil	109.64
Chloroform	air	103.40
Ethylene oxide	air	81.40
Benzene	air	81.36
PAH, polycyclic aromatic hydrocarbons	air	68.49
Benzene, hexachloro-	air	67.68
Benzo(a)pyrene	air	65.91
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	53.59
Propylene oxide	water	48.70
Ethylene oxide	water	46.29
Nickel	air	45.64
Carbon disulfide	air	41.37
Hydrocarbons, aliphatic, alkanes, unspecified	air	27.31
Hydrocarbons, aromatic	air	25.05
Propene	air	24.92
Ethene	air	22.99
Methane, bromochlorodifluoro-, Halon 1211	air	18.19
Methane, chlorotrifluoro-, CFC-13	air	17.64
Propylene oxide	air	13.61
Phenol, pentachloro-	air	12.82
Pentane	air	11.47
Butene	air	10.01
Methane, bromotrifluoro-, Halon 1301	air	9.90
Cumene	air	9.81

Hydrocarbons, aliphatic, alkanes, cyclic	air	9.19
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	8.49
Propanol	air	8.36
Hexane	air	7.79
Propane	air	7.67
Formaldehyde	water	7.13
Butane	air	6.91
Nitrobenzene	air	6.88
Iodine-129	air	6.34
Propanal	air	6.14
Phenol	air	5.03
Xylene	air	4.55
Methanol	air	4.38
Ethane	air	4.28
Acetic acid	air	4.22
Formaldehyde	air	3.80
Heptane	air	3.23
2-Methyl-2-butene	air	2.92
Uranium-234	air	2.53
Toluene	air	1.82
Radium-226	water	1.39
Methane, trichlorofluoro-, CFC-11	air	1.16
Cyclohexane	air	1.05
Acetone	air	0.98
Cesium-137	water	0.87
Ethyl acetate	air	0.81
Acetaldehyde	air	0.79
Ethene, chloro-	air	0.74
Acetaldehyde	water	0.65

Aldehydes, unspecified	air	0.61
4-Methyl-2-pentanone	air	0.55
Hydrogen-3, Tritium	air	0.54
Methyl ethyl ketone	air	0.51
Cobalt-60	water	0.51
Ethyne	air	0.44
Ethanol	air	0.43
Butanol	air	0.42
Benzene, ethyl-	air	0.30
Uranium-238	air	0.29
Methane, dichloro-, HCC-30	air	0.29
Cesium-134	water	0.22
Ethene, tetrachloro-	air	0.21
Polonium-210	air	0.14
Furan	air	0.14
Uranium-238	water	0.14
Hydrogen-3, Tritium	water	0.13
Lead-210	air	0.08
Uranium-235	water	0.08
Radium-226	air	0.07
Acetonitrile	air	0.07
Methane, monochloro-, R-40	air	0.06
Iodine-131	air	0.05
Uranium-234	water	0.05
Methane, dichlorofluoro-, HCFC-21	air	0.05
Methyl formate	air	0.05
2-Propanol	air	0.04
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	0.03
Formic acid	air	0.03

m-Xylene	air	0.02
Methane, dichloro-, HCC-30	water	0.02
Chloroform	water	0.02
Isoprene	air	0.01
Butadiene	air	0.01
Uranium-235	air	0.01
Ethene, chloro-	water	0.01
Styrene	air	0.01
Ethane, 1,1-difluoro-, HFC-152a	air	0.01

Table A6: Total effects on climate change (IMPACT2002+)

Pollutant	Ecocat	Total
Carbon dioxide, fossil	air	875,581,758,268.43
Dinitrogen monoxide	air	104,368,030,181.08
Methane, fossil	air	86,212,893,071.99
Sulfur hexafluoride	air	18,925,357,166.49
Carbon monoxide, fossil	air	8,676,181,072.08
Methane, chlorodifluoro-, HCFC-22	air	4,808,092,846.70
Methane, tetrafluoro-, R-14	air	3,848,551,856.36
Methane, trifluoro-, HFC-23	air	2,154,408,919.21
Methane, dichlorodifluoro-, CFC-12	air	1,484,555,326.21
Ethane, hexafluoro-, HFC-116	air	907,486,116.91
Methane, biogenic	air	847,174,107.82
Carbon dioxide, land transformation	air	842,534,236.58
Methane, tetrachloro-, R-10	air	772,807,897.57
Carbon monoxide, biogenic	air	442,107,307.21
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	258,036,842.42
Chloroform	air	114,129,952.40
Methane, chlorotrifluoro-, CFC-13	air	59,279,708.32
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	27,047,446.77
Methane, bromotrifluoro-, Halon 1301	air	12,418,547.76
Methane, trichlorofluoro-, CFC-11	air	4,213,824.36
Methane, bromochlorodifluoro-, Halon 1211	air	4,190,907.21
Methane, dichloro-, HCC-30	air	1,151,024.84
Methane, dichloro-, HCC-30	water	397,155.47
Methane, dichlorofluoro-, HCFC-21	air	118,495.04
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	107,516.70
Methane, monochloro-, R-40	air	43,207.76
Ethane, 1,1-difluoro-, HFC-152a	air	22,879.01

Table A7: External costs for damages to the ecosystem (IMPACT2002+)

Pollutant	Ecocat	Ecosystem Quality
Aluminum	air	34,016,016,077.84
Zinc	air	25,666,859,233.39
Aluminum	soil	7,011,166,180.67
Nitrogen oxides	air	5,108,741,079.01
Zinc	soil	4,132,363,593.02
Chromium	air	3,780,410,468.32
Copper	air	3,556,458,957.60
Copper	soil	3,384,442,693.44
Mercury	air	2,148,397,861.32
Nickel	air	1,964,249,218.79
Sulfur dioxide	air	1,642,814,461.47
Ammonia	air	1,049,695,759.16
Lead	air	733,857,716.64
Aluminum	water	446,076,676.42
Copper	water	366,881,073.93
Arsenic	air	282,795,720.71
Chromium	soil	230,555,226.53
Zinc	water	200,889,899.20
Cadmium	air	200,376,092.43
Cobalt	air	130,083,926.12
Nickel	soil	50,633,202.04
Cadmium	soil	36,179,616.61
Antimony	water	31,985,011.70
Mercury	soil	30,478,038.00
Lead	soil	27,473,629.96

Nickel	water	23,474,784.35
Cobalt	water	17,617,804.01
Metolachlor	soil	12,816,745.24
Barium	soil	8,871,246.25
Carbofuran	soil	8,155,406.29
Arsenic	soil	7,241,205.60
Arsenic	water	6,823,678.56
Mercury	water	4,305,411.07
Cadmium	water	3,819,678.19
Barium	water	3,437,251.10
Selenium	water	2,889,179.69
Cobalt	soil	2,882,662.08
Glyphosate	soil	2,523,839.69
Benzene, chloro-	water	2,396,656.30
Linuron	soil	2,307,326.28
Atrazine	soil	2,087,960.54
Lead	water	1,898,289.40
Antimony	air	1,781,525.42
Selenium	air	1,745,825.42
Acetic acid	air	1,354,972.63
Chromium	water	1,076,072.37
Benzene	water	871,806.89
Chlorothalonil	soil	605,842.97
Carbendazim	soil	590,913.93
Propene	water	527,489.91
Aldrin	soil	228,564.51
Butene	water	203,495.91
Carbetamide	soil	197,749.36
Cypermethrin	soil	154,635.65

Barium	air	134,300.52
Metribuzin	soil	98,466.08
Ethane, 1,2-dichloro-	water	68,525.39
Endosulfan	soil	42,599.26
Acetic acid	water	42,240.62
Phenol	water	33,572.53
Pirimicarb	soil	32,495.63
Phenol	air	28,215.87
Methane, tetrafluoro-, R-14	air	24,980.09
Formaldehyde	water	21,238.53
Ethane, 1,2-dichloro-	air	17,764.37
Formaldehyde	air	16,084.96
Toluene	water	15,057.56
Xylene	water	11,487.15
Benzo(a)pyrene	air	10,554.01
Chloroform	air	9,600.38
2,4-D	soil	9,091.78
Benzene, ethyl-	water	7,924.98
Vinclozolin	soil	5,779.07
Benomyl	soil	3,755.61
Acetaldehyde	water	3,657.59
Bentazone	soil	3,536.36
Methanol	air	3,477.17
Cyfluthrin	soil	2,377.94
Trifluralin	soil	2,163.42
Methane, chlorodifluoro-, HCFC-22	air	1,867.77
Acetone	water	1,725.46
Methane, tetrachloro-, R-10	air	1,684.88
Prochloraz	soil	1,587.62

Fluroxypyr	soil	1,372.56
Chlorpyrifos	soil	1,118.28
Napropamide	soil	951.87
Methane, dichloro-, HCC-30	water	933.56
Lambda-cyhalothrin	soil	909.01
Clomazone	soil	609.13
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	603.05
Ethanol	water	578.13
Phenol, pentachloro-	air	509.03
Antimony	soil	482.67
Benzene	air	474.16
Methane, dichlorodifluoro-, CFC-12	air	459.61
Methanol	water	456.59
Propane	air	431.20
Ethene, tetrachloro-	air	350.91
Propanal	air	324.83
Deltamethrin	soil	323.35
Pendimethalin	soil	274.65
Trinexapac-ethyl	soil	270.50
Benzene, hexachloro-	air	250.80
Polychlorinated biphenyls	air	244.43
Acetone	air	243.40
Methane, dichloro-, HCC-30	air	205.85
Pentane	air	178.45
Butane	air	155.01
Acetaldehyde	air	138.16
Acrolein	air	85.29
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	85.20
Ethyl acetate	air	68.33

Methane, chlorotrifluoro-, CFC-13	air	68.17
Methyl ethyl ketone	air	54.42
Chloroform	water	52.29
Acenaphthene	water	40.21
Ethanol	air	25.57
Methane, bromotrifluoro-, Halon 1301	air	25.55
Bifenox	soil	23.93
Propene	air	21.09
Toluene	air	20.81
Butene	air	15.41
Ethyne	air	14.24
Xylene	air	13.69
Methane, bromochlorodifluoro-, Halon 1211	air	9.67
Methane, trichlorofluoro-, CFC-11	air	8.59
Benzene, pentachloro-	air	7.88
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	7.86
m-Xylene	water	6.19
Benzene, ethyl-	air	4.35
Mecoprop	soil	4.31
o-Xylene	water	3.39
Styrene	air	2.53
Methane, dichlorofluoro-, HCFC-21	air	0.68
Hexane	air	0.44
m-Xylene	air	0.32
Acenaphthylene	water	0.16
t-Butyl methyl ether	air	0.09
t-Butyl methyl ether	water	0.06
Ethane, 1,1-difluoro-, HFC-152a	air	0.04
Heptane	air	0.01

Asulam	soil	0.01
Ethane, 1,1,1-trichloro-, HCFC-140	air	0.01
Acenaphthene	air	0.01

Table A8: External costs for damages to the ecosystem (Eco-Indicator 99)

Pollutant	Ecocat	Ecosystem Quality
Zinc	air	9,262,971,382.72
Chromium	air	5,167,734,773.95
Nitrogen oxides	air	5,108,741,079.01
Nickel	air	3,128,746,132.81
Lead	air	1,801,465,132.17
Sulfur dioxide	air	1,642,814,461.47
Ammonia	air	1,044,484,218.28
Copper	air	546,289,500.41
Chromium VI	soil	360,705,795.63
Cadmium	air	267,463,883.68
Chromium VI	water	137,712,423.40
Chromium VI	air	119,672,372.91
Zinc	soil	94,228,813.79
Mercury	air	58,586,966.15
Copper	soil	58,553,280.75
Nickel	water	52,561,191.63
Copper	water	52,268,883.12
Arsenic	air	50,539,069.90
Zinc	water	46,500,920.36
Chromium	soil	14,598,765.14
Cadmium	water	12,522,612.38
Arsenic	water	3,992,640.33
Chromium	water	3,249,914.03
Mercury	water	1,069,584.07
Lead	water	1,059,524.26
Benzo(a)pyrene	air	1,037,592.29
Benzene	water	770,227.01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	515,767.28
Cadmium	soil	102,242.85
Arsenic	soil	93,371.77
Mercury	soil	39,356.00
Benzene	air	33,821.84
Toluene	water	17,412.95
Lead	soil	16,164.61
Benzene, hexachloro-	air	14,250.00
Phenol, pentachloro-	air	10,216.88
Atrazine	soil	3,763.78
Carbendazim	soil	2,016.90
Trifluralin	soil	174.36
Toluene	air	140.40
PAH, polycyclic aromatic hydrocarbons	air	137.56
Thiram	soil	92.58
Bentazone	soil	92.11
Ethane, 1,2-dichloro-	water	25.01
PAH, polycyclic aromatic hydrocarbons	water	24.07
Metribuzin	soil	19.78
2,4-D	soil	1.70

Table A9: External costs for human health (IMPACT2002+)

Pollutant	Ecocat	Human Health
Particulates, < 2.5 um	air	11,816,969,091.47
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	10,162,490,058.75
Sulfur dioxide	air	7,843,766,828.93
Nitrogen oxides	air	7,510,430,595.15
Arsenic	water	1,008,913,042.76
Ammonia	air	548,770,252.29
Arsenic	air	342,477,903.69
Molybdenum	soil	219,046,854.22
Molybdenum	air	187,944,011.49
Carbon monoxide, fossil	air	161,440,067.44
Zinc	water	95,037,047.06
Chromium	air	84,946,796.31
Zinc	air	79,223,324.95
Benzo(a)pyrene	air	65,678,551.84
Antimony	water	60,001,251.64
Zinc	soil	49,505,103.63
Molybdenum	water	45,993,303.95
NMVOC, unspecified origin	air	36,565,414.07
Nitrobenzene	water	23,955,674.52
Benzene	air	23,313,943.11
Arsenic	soil	22,668,280.45
Methane, tetrachloro-, R-10	air	15,039,497.01
Barium	water	10,744,218.16
Carbon monoxide, biogenic	air	8,226,411.24
Mercury	air	6,780,407.00
Benzene, hexachloro-	air	6,709,149.45
Methane, chlorodifluoro-, HCFC-22	air	5,941,972.91
Benzene	water	5,891,137.34
Methane, dichlorodifluoro-, CFC-12	air	5,882,203.90
Aluminum	air	5,713,881.20
Cadmium	water	4,662,093.31
Barium	soil	4,296,401.24
Cadmium	air	4,129,443.23
Selenium	water	4,047,976.21
Cadmium	soil	3,837,831.58
Ethane, 1,2-dichloro-	water	2,687,683.34
Methane, fossil	air	1,919,173.97
Aluminum	soil	1,853,905.83
Chromium VI	air	1,822,842.80
Ethane, 1,2-dichloro-	air	1,709,575.44
Linuron	soil	1,413,081.25
Chromium VI	water	1,335,278.88
Aluminum	water	1,280,476.55
Mercury	water	1,078,705.29
Nickel	air	1,058,679.26
Nickel	water	1,042,881.46
Propene	air	996,662.87
Chloroform	air	972,488.74
Formaldehyde	air	927,565.09
Methane, bromotrifluoro-, Halon 1301	air	907,093.92
Selenium	air	842,734.90
Methane, bromochlorodifluoro-, Halon 1211	air	812,391.24
Lead	air	507,473.68
Pentane	air	458,905.89

Antimony	air	423,083.41
Propylene oxide	water	415,933.67
Butene	air	400,264.17
Cumene	air	392,544.23
Lead	water	387,974.20
Metolachlor	soil	382,044.42
Copper	water	367,349.94
Propanol	air	334,293.89
Hexane	air	314,212.33
Copper	soil	276,991.38
Propanal	air	245,469.41
Copper	air	236,789.33
Hydrogen sulfide	air	200,389.99
Xylene	air	183,789.05
Methanol	air	182,638.72
Methane, chlorotrifluoro-, CFC-13	air	177,839.12
Ethane	air	171,097.40
Acetic acid	air	168,802.02
Benzene, chloro-	water	165,194.76
Propylene oxide	air	155,571.60
Butane	air	151,281.80
Carbon disulfide	air	148,184.29
Atrazine	soil	131,635.59
Heptane	air	129,146.01
Ethylene oxide	air	124,893.85
2-Methyl-2-butene	air	116,870.78
Propane	air	116,146.27
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	108,962.57
Aldrin	soil	90,445.96

Toluene	air	73,269.93
Chromium VI	soil	71,116.68
Barium	air	65,678.77
Nickel	soil	55,851.79
Cumene	water	55,214.37
Chromium	water	53,685.59
Mercury	soil	46,906.45
Acetone	air	45,182.51
Cyclohexane	air	42,085.51
Lead	soil	38,528.42
Methane, trichlorofluoro-, CFC-11	air	38,474.08
Trifluralin	soil	37,259.63
Butanol	air	33,701.92
Chromium	soil	32,374.57
Acetaldehyde	air	31,886.71
Phenol, pentachloro-	air	31,750.38
Carbofuran	soil	29,258.19
Aldehydes, unspecified	air	24,363.54
Methyl ethyl ketone	air	20,499.54
Ethylene oxide	water	19,613.30
Methane, biogenic	air	18,858.83
Ethanol	air	17,243.57
Nitrobenzene	air	16,607.37
4-Methyl-2-pentanone	air	12,159.18
Benzene, ethyl-	air	12,089.75
Ethyl acetate	air	11,654.54
Cypermethrin	soil	8,828.31
Ethene, tetrachloro-	air	7,587.75
Acetone	water	6,389.14

Beryllium	air	6,285.77
2-Propanol	air	6,212.61
Styrene	air	4,596.77
Chlorpyrifos	soil	4,395.89
Methane, dichloro-, HCC-30	air	3,749.95
Formaldehyde	water	3,338.10
Hydrogen sulfide	water	2,712.14
Prochloraz	soil	2,648.79
Endosulfan	soil	2,581.69
Chlorothalonil	soil	2,577.80
Ethyne	air	2,548.74
Methane, monochloro-, R-40	air	2,269.61
Toluene	water	2,075.41
Methane, dichloro-, HCC-30	water	2,054.22
2,4-D	soil	1,970.61
Methyl formate	air	1,817.53
Phenol	air	1,658.08
Formic acid	air	1,063.65
Methane, dichlorofluoro-, HCFC-21	air	947.96
m-Xylene	air	876.89
Acrolein	air	786.83
Acetonitrile	air	774.79
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	752.62
Phenol	water	747.78
Butanol	water	513.16
Isoprene	air	483.14
Benzene, ethyl-	water	367.48
Glyphosate	soil	353.53
Antimony	soil	325.60

Acetaldehyde	water	295.13
Ethanol	water	259.96
Methanol	water	245.19
Vinclozolin	soil	162.32
Pendimethalin	soil	147.30
Hydrogen peroxide	water	131.96
Beryllium	water	130.98
Bentazone	soil	129.50
Benomyl	soil	126.09
Xylene	water	125.60
Radon-222	air	116.68
Chloroform	water	111.95
Furan	air	95.01
2-Methyl pentane	air	94.28
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	80.37
Carbon-14	air	55.99
Butadiene	air	52.74
Acrylic acid	air	43.32
Benzene, pentachloro-	air	37.32
Fluroxypyr	soil	28.17
Cyfluthrin	soil	24.60
Metribuzin	soil	15.65
Diethylene glycol	air	12.72
Ethane, 1,1,1-trichloro-, HCFC-140	air	9.13
Mecoprop	soil	7.56
Hydrogen peroxide	air	5.13
t-Butyl methyl ether	air	4.98
Phosphoric acid	air	3.20
Napropamide	soil	0.87

Polychlorinated biphenyls	air	0.45
Iodine-129	air	0.25
Uranium-234	air	0.10
Radium-226	water	0.06
Acenaphthene	water	0.05
t-Butyl methyl ether	water	0.04
Cesium-137	water	0.03
Hydrogen-3, Tritium	air	0.02
Cobalt-60	water	0.02
Cesium-134	water	0.01
Polonium-210	air	0.01
Ethane, 1,1-difluoro-, HFC-152a	air	0.01
Hydrogen-3, Tritium	water	0.01

Table A10: External costs for human health (Eco-Indicator 99)

Pollutant	Ecocat	Human Health
Particulates, < 2.5 um	air	11,982,069,031.07
Sulfur dioxide	air	7,843,766,828.93
Nitrogen oxides	air	7,476,713,735.01
Carbon dioxide, fossil	air	7,354,886,769.45
Arsenic	water	2,089,649,728.12
Dinitrogen monoxide	air	973,161,362.50
Methane, fossil	air	661,635,225.30
Ammonia	air	547,847,650.98
Cadmium	air	340,587,907.17
Arsenic	air	218,802,416.17
Sulfur hexafluoride	air	180,728,636.00
Cadmium	water	165,820,910.50
Cadmium	soil	165,254,126.53
Radon-222	air	116,679,580.04
Carbon monoxide, fossil	air	71,113,135.04
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	62,266,085.21
Carbon-14	air	55,988,991.70
Methane, tetrafluoro-, R-14	air	37,810,334.03
NMVOC, unspecified origin	air	36,565,414.07
Methane, chlorodifluoro-, HCFC-22	air	36,439,687.20
Methane, tetrachloro-, R-10	air	31,570,919.97
Chromium VI	air	30,459,119.12
Methane, trifluoro-, HFC-23	air	18,671,543.97
Methane, dichlorodifluoro-, CFC-12	air	12,677,542.27

PAH, polycyclic aromatic hydrocarbons	water	7,727,479.10
Ethane, 1,2-dichloro-	air	7,361,223.61
Methane, biogenic	air	6,501,582.44
Ethane, hexafluoro-, HFC-116	air	6,100,747.00
Benzene	water	5,869,100.29
Arsenic	soil	4,385,682.80
Chloroform	air	4,135,978.17
Ethylene oxide	air	3,256,164.91
Benzene	air	3,254,245.26
PAH, polycyclic aromatic hydrocarbons	air	2,739,459.48
Benzene, hexachloro-	air	2,707,373.19
Benzo(a)pyrene	air	2,636,536.57
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	2,143,690.69
Propylene oxide	water	1,948,107.90
Ethylene oxide	water	1,851,746.89
Nickel	air	1,825,450.54
Carbon disulfide	air	1,654,601.47
Hydrocarbons, aliphatic, alkanes, unspecified	air	1,092,473.08
Hydrocarbons, aromatic	air	1,001,960.32
Propene	air	996,662.87
Ethene	air	919,588.63
Methane, bromochlorodifluoro-, Halon 1211	air	727,635.75
Methane, chlorotrifluoro-, CFC-13	air	705,619.75
Propylene oxide	air	544,376.94
Phenol, pentachloro-	air	512,915.29
Pentane	air	458,905.89
Butene	air	400,264.17
Methane, bromotrifluoro-, Halon 1301	air	395,978.89
Cumene	air	392,264.58

Hydrocarbons, aliphatic, alkanes, cyclic	air	367,780.52
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	339,615.51
Propanol	air	334,293.89
Hexane	air	311,674.85
Propane	air	306,763.06
Formaldehyde	water	285,382.03
Butane	air	276,897.93
Nitrobenzene	air	275,070.99
Iodine-129	air	253,419.16
Propanal	air	245,469.41
Phenol	air	201,356.21
Xylene	air	181,850.76
Methanol	air	175,227.85
Ethane	air	171,097.40
Acetic acid	air	168,802.02
Formaldehyde	air	152,136.37
Heptane	air	129,146.01
2-Methyl-2-butene	air	116,870.78
Uranium-234	air	101,036.55
Toluene	air	72,760.16
Radium-226	water	55,720.81
Methane, trichlorofluoro-, CFC-11	air	46,535.28
Cyclohexane	air	42,085.51
Acetone	air	39,009.36
Cesium-137	water	34,974.81
Ethyl acetate	air	32,416.80
Acetaldehyde	air	31,500.13
Ethene, chloro-	air	29,776.85
Acetaldehyde	water	26,040.80

Aldehydes, unspecified	air	24,363.54
4-Methyl-2-pentanone	air	22,068.26
Hydrogen-3, Tritium	air	21,648.88
Methyl ethyl ketone	air	20,482.62
Cobalt-60	water	20,270.03
Ethyne	air	17,445.89
Ethanol	air	17,203.85
Butanol	air	16,830.07
Benzene, ethyl-	air	12,084.79
Uranium-238	air	11,617.82
Methane, dichloro-, HCC-30	air	11,422.77
Cesium-134	water	8,906.56
Ethene, tetrachloro-	air	8,398.88
Polonium-210	air	5,680.34
Furan	air	5,599.46
Uranium-238	water	5,483.24
Hydrogen-3, Tritium	water	5,049.81
Lead-210	air	3,380.99
Uranium-235	water	3,088.85
Radium-226	air	2,987.83
Acetonitrile	air	2,948.36
Methane, monochloro-, R-40	air	2,279.21
Iodine-131	air	2,062.20
Uranium-234	water	1,953.42
Methane, dichlorofluoro-, HCFC-21	air	1,948.96
Methyl formate	air	1,817.53
2-Propanol	air	1,555.76
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	1,131.08
Formic acid	air	1,063.65

m-Xylene	air	876.89
Methane, dichloro-, HCC-30	water	760.95
Chloroform	water	638.63
Isoprene	air	483.14
Butadiene	air	477.35
Uranium-235	air	435.86
Ethene, chloro-	water	305.23
Pentane	air	303.67
Styrene	air	300.40
Ethane, 1,1-difluoro-, HFC-152a	air	221.16
Chromium VI	water	147.89
2-Methyl pentane	air	94.28
Antimony-124	water	59.58
Xenon-133	air	40.66
Diethylene glycol	air	32.68
Diethyl ether	air	26.01
Cobalt-58	water	24.13
Acrylic acid	air	19.33
Krypton-85	air	14.28
Acrolein	air	13.22
Manganese-54	water	11.31
Iodine-131	water	6.65
Ethane, 1,1,1-trichloro-, HCFC-140	air	6.01
Benzaldehyde	air	5.87
t-Butyl methyl ether	air	4.92
Acenaphthene	air	4.70
Benzene, pentachloro-	air	3.73
Nickel	water	2.35
Nickel	soil	0.73

Cobalt-60	air	0.71
Cesium-137	air	0.62
Cesium-134	air	0.03
Plutonium-alpha	air	0.01
Iodine-133	air	0.01

Table A11: External costs for impact on climate change (IMPACT2002+)

Pollutant	Ecocat	Climate Change
Carbon dioxide, fossil	air	16,636,053,407.10
Dinitrogen monoxide	air	1,982,992,573.44
Methane, fossil	air	1,638,044,968.37
Sulfur hexafluoride	air	359,581,786.16
Carbon monoxide, fossil	air	164,847,440.37
Methane, chlorodifluoro-, HCFC-22	air	91,353,764.09
Methane, tetrafluoro-, R-14	air	73,122,485.27
Methane, trifluoro-, HFC-23	air	40,933,769.47
Methane, dichlorodifluoro-, CFC-12	air	28,206,551.20
Ethane, hexafluoro-, HFC-116	air	17,242,236.22
Methane, biogenic	air	16,096,308.05
Carbon dioxide, land transformation	air	16,008,150.49
Methane, tetrachloro-, R-10	air	14,683,350.05
Carbon monoxide, biogenic	air	8,400,038.84
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	4,902,700.01
Chloroform	air	2,168,469.10
Methane, chlorotrifluoro-, CFC-13	air	1,126,314.46
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	513,901.49
Methane, bromotrifluoro-, Halon 1301	air	235,952.41
Methane, trichlorofluoro-, CFC-11	air	80,062.66
Methane, bromochlorodifluoro-, Halon 1211	air	79,627.24
Methane, dichloro-, HCC-30	air	21,869.47
Methane, dichloro-, HCC-30	water	7,545.95
Methane, dichlorofluoro-, HCFC-21	air	2,251.41
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	2,042.82
Methane, monochloro-, R-40	air	820.95
Ethane, 1,1-difluoro-, HFC-152a	air	434.70

Table 12: Aggregated external costs (IMPACT2002+)

Pollutant	Ecocat	Euros Ecosystem Quality	Euros Human Health	Euros Climate Change	Euros Total
Aluminum	air	34,016,016,077.84	5,713,881.20	0.00	34,021,729,959.04
Zinc	air	25,666,859,233.39	79,223,324.95	0.00	25,746,082,558.33
Carbon dioxide, fossil	air	0.00	0.00	16,636,053,407.10	16,636,053,407.10
Nitrogen oxides	air	5,108,741,079.01	7,510,430,595.15	0.00	12,619,171,674.16
Particulates, < 2.5 um	air	0.00	11,816,969,091.47	0.00	11,816,969,091.47
Dioxins	air	85.20	10,162,490,058.75	0.00	10,162,490,143.95
Sulfur dioxide	air	1,642,814,461.47	7,843,766,828.93	0.00	9,486,581,290.40
Aluminum	soil	7,011,166,180.67	1,853,905.83	0.00	7,013,020,086.50
Zinc	soil	4,132,363,593.02	49,505,103.63	0.00	4,181,868,696.65
Chromium	air	3,780,410,468.32	84,946,796.31	0.00	3,865,357,264.64
Copper	air	3,556,458,957.60	236,789.33	0.00	3,556,695,746.93
Copper	soil	3,384,442,693.44	276,991.38	0.00	3,384,719,684.81
Mercury	air	2,148,397,861.32	6,780,407.00	0.00	2,155,178,268.32
Dinitrogen monoxide	air	0.00	0.00	1,982,992,573.44	1,982,992,573.44
Nickel	air	1,964,249,218.79	1,058,679.26	0.00	1,965,307,898.05
Methane, fossil	air	0.00	1,919,173.97	1,638,044,968.37	1,639,964,142.34
Ammonia	air	1,049,695,759.16	548,770,252.29	0.00	1,598,466,011.45
Arsenic	water	6,823,678.56	1,008,913,042.76	0.00	1,015,736,721.32
Lead	air	733,857,716.64	507,473.68	0.00	734,365,190.31
Arsenic	air	282,795,720.71	342,477,903.69	0.00	625,273,624.40
Aluminum	water	446,076,676.42	1,280,476.55	0.00	447,357,152.97
Copper	water	366,881,073.93	367,349.94	0.00	367,248,423.87
Sulfur hexafluoride	air	0.00	0.00	359,581,786.16	359,581,786.16
Carbon monoxide, fossil	air	0.00	161,440,067.44	164,847,440.37	326,287,507.81
Zinc	water	200,889,899.20	95,037,047.06	0.00	295,926,946.26
Chromium	soil	230,555,226.53	32,374.57	0.00	230,587,601.09
Molybdenum	soil	0.00	219,046,854.22	0.00	219,046,854.22
Cadmium	air	200,376,092.43	4,129,443.23	0.00	204,505,535.66
Molybdenum	air	0.00	187,944,011.49	0.00	187,944,011.49
Cobalt	air	130,083,926.12	0.00	0.00	130,083,926.12
Methane, chlorodifluoro-, HCFC-22	air	1,867.77	5,941,972.91	91,353,764.09	97,297,604.77
Antimony	water	31,985,011.70	60,001,251.64	0.00	91,986,263.34
Methane, tetrafluoro-, R-14	air	24,980.09	0.00	73,122,485.27	73,147,465.36
Benzo(a)pyrene	air	10,554.01	65,678,551.84	0.00	65,689,105.84
Nickel	soil	50,633,202.04	55,851.79	0.00	50,689,053.83
Molybdenum	water	0.00	45,993,303.95	0.00	45,993,303.95
Methane, trifluoro-, HFC-23	air	0.00	0.00	40,933,769.47	40,933,769.47
Cadmium	soil	36,179,616.61	3,837,831.58	0.00	40,017,448.19
NMVOC	air	0.00	36,565,414.07	0.00	36,565,414.07
Methane, dichlorodifluoro-, CFC-12	air	459.61	5,882,203.90	28,206,551.20	34,089,214.70

Mercury	soil	30,478,038.00	46,906.45	0.00	30,524,944.45
Arsenic	soil	7,241,205.60	22,668,280.45	0.00	29,909,486.04
Methane, tetrachloro-, R-10	air	1,684.88	15,039,497.01	14,683,350.05	29,724,531.95
Lead	soil	27,473,629.96	38,528.42	0.00	27,512,158.38
Nickel	water	23,474,784.35	1,042,881.46	0.00	24,517,665.81
Nitrobenzene	water	0.00	23,955,674.52	0.00	23,955,674.52
Benzene	air	474.16	23,313,943.11	0.00	23,314,417.27
Cobalt	water	17,617,804.01	0.00	0.00	17,617,804.01
Ethane, hexafluoro-, HFC-116	air	0.00	0.00	17,242,236.22	17,242,236.22
Carbon monoxide, biogenic	air	0.00	8,226,411.24	8,400,038.84	16,626,450.08
Methane, biogenic	air	0.00	18,858.83	16,096,308.05	16,115,166.88
Carbon dioxide, land transformation	air	0.00	0.00	16,008,150.49	16,008,150.49
Barium	water	3,437,251.10	10,744,218.16	0.00	14,181,469.26
Metolachlor	soil	12,816,745.24	382,044.42	0.00	13,198,789.66
Barium	soil	8,871,246.25	4,296,401.24	0.00	13,167,647.49
Cadmium	water	3,819,678.19	4,662,093.31	0.00	8,481,771.50
Carbofuran	soil	8,155,406.29	29,258.19	0.00	8,184,664.48
Selenium	water	2,889,179.69	4,047,976.21	0.00	6,937,155.90
Benzene	water	871,806.89	5,891,137.34	0.00	6,762,944.22
Benzene, hexachloro-	air	250.80	6,709,149.45	0.00	6,709,400.25
Mercury	water	4,305,411.07	1,078,705.29	0.00	5,384,116.36
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	603.05	80.37	4,902,700.01	4,903,383.42
Linuron	soil	2,307,326.28	1,413,081.25	0.00	3,720,407.53
Chloroform	air	9,600.38	972,488.74	2,168,469.10	3,150,558.22
Cobalt	soil	2,882,662.08	0.00	0.00	2,882,662.08
Ethane, 1,2-dichloro-	water	68,525.39	2,687,683.34	0.00	2,756,208.73
Selenium	air	1,745,825.42	842,734.90	0.00	2,588,560.32
Benzene, chloro-	water	2,396,656.30	165,194.76	0.00	2,561,851.06
Glyphosate	soil	2,523,839.69	353.53	0.00	2,524,193.22
Lead	water	1,898,289.40	387,974.20	0.00	2,286,263.60
Atrazine	soil	2,087,960.54	131,635.59	0.00	2,219,596.14
Antimony	air	1,781,525.42	423,083.41	0.00	2,204,608.83
Chromium VI	air	0.00	1,822,842.80	0.00	1,822,842.80
Ethane, 1,2-dichloro-	air	17,764.37	1,709,575.44	0.00	1,727,339.81
Acetic acid	air	1,354,972.63	168,802.02	0.00	1,523,774.65
Chromium VI	water	0.00	1,335,278.88	0.00	1,335,278.88
Methane, chlorotrifluoro-, CFC-13	air	68.17	177,839.12	1,126,314.46	1,304,221.75
Methane, bromotrifluoro-, Halon 1301	air	25.55	907,093.92	235,952.41	1,143,071.88
Chromium	water	1,076,072.37	53,685.59	0.00	1,129,757.95
Propene	air	21.09	996,662.87	0.00	996,683.96
Formaldehyde	air	16,084.96	927,565.09	0.00	943,650.05
Methane, bromochlorodifluoro-, Halon 1211	air	9.67	812,391.24	79,627.24	892,028.15
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	0.00	108,962.57	513,901.49	622,864.06
Chlorothalonil	soil	605,842.97	2,577.80	0.00	608,420.77

Carbendazim	soil	590,913.93	0.00	0.00	590,913.93
Propene	water	527,489.91	0.00	0.00	527,489.91
Pentane	air	178.45	458,905.89	0.00	459,084.34
Propylene oxide	water	0.00	415,933.67	0.00	415,933.67
Butene	air	15.41	400,264.17	0.00	400,279.59
Cumene	air	0.00	392,544.23	0.00	392,544.23
Propanol	air	0.00	334,293.89	0.00	334,293.89
Aldrin	soil	228,564.51	90,445.96	0.00	319,010.47
Hexane	air	0.44	314,212.33	0.00	314,212.77
Propanal	air	324.83	245,469.41	0.00	245,794.24
Butene	water	203,495.91	0.00	0.00	203,495.91
Hydrogen sulfide	air	0.00	200,389.99	0.00	200,389.99
Barium	air	134,300.52	65,678.77	0.00	199,979.29
Carbetamide	soil	197,749.36	0.00	0.00	197,749.36
Methanol	air	3,477.17	182,638.72	0.00	186,115.89
Xylene	air	13.69	183,789.05	0.00	183,802.74
Ethane	air	0.00	171,097.40	0.00	171,097.40
Cypermethrin	soil	154,635.65	8,828.31	0.00	163,463.96
Propylene oxide	air	0.00	155,571.60	0.00	155,571.60
Butane	air	155.01	151,281.80	0.00	151,436.81
Carbon disulfide	air	0.00	148,184.29	0.00	148,184.29
Heptane	air	0.01	129,146.01	0.00	129,146.03
Ethylene oxide	air	0.00	124,893.85	0.00	124,893.85
Methane, trichlorofluoro-, CFC-11	air	8.59	38,474.08	80,062.66	118,545.34
2-Methyl-2-butene	air	0.00	116,870.78	0.00	116,870.78
Propane	air	431.20	116,146.27	0.00	116,577.47
Metribuzin	soil	98,466.08	15.65	0.00	98,481.73
Toluene	air	20.81	73,269.93	0.00	73,290.74
Chromium VI	soil	0.00	71,116.68	0.00	71,116.68
Cumene	water	0.00	55,214.37	0.00	55,214.37
Acetone	air	243.40	45,182.51	0.00	45,425.91
Endosulfan	soil	42,599.26	2,581.69	0.00	45,180.95
Acetic acid	water	42,240.62	0.00	0.00	42,240.62
Cyclohexane	air	0.00	42,085.51	0.00	42,085.51
Trifluralin	soil	2,163.42	37,259.63	0.00	39,423.06
Phenol	water	33,572.53	747.78	0.00	34,320.31
Butanol	air	0.00	33,701.92	0.00	33,701.92
Pirimicarb	soil	32,495.63	0.00	0.00	32,495.63
Phenol, pentachloro-	air	509.03	31,750.38	0.00	32,259.40
Acetaldehyde	air	138.16	31,886.71	0.00	32,024.87
Phenol	air	28,215.87	1,658.08	0.00	29,873.95
Methane, dichloro-, HCC-30	air	205.85	3,749.95	21,869.47	25,825.26
Formaldehyde	water	21,238.53	3,338.10	0.00	24,576.63
Aldehydes, unspecified	air	0.00	24,363.54	0.00	24,363.54

Methyl ethyl ketone	air	54.42	20,499.54	0.00	20,553.96
Ethylene oxide	water	0.00	19,613.30	0.00	19,613.30
Ethanol	air	25.57	17,243.57	0.00	17,269.14
Toluene	water	15,057.56	2,075.41	0.00	17,132.97
Nitrobenzene	air	0.00	16,607.37	0.00	16,607.37
4-Methyl-2-pentanone	air	0.00	12,159.18	0.00	12,159.18
Benzene, ethyl-	air	4.35	12,089.75	0.00	12,094.10
Ethyl acetate	air	68.33	11,654.54	0.00	11,722.87
Xylene	water	11,487.15	125.60	0.00	11,612.76
2,4-D	soil	9,091.78	1,970.61	0.00	11,062.38
Methane, dichloro-, HCC-30	water	933.56	2,054.22	7,545.95	10,533.74
Benzene, ethyl-	water	7,924.98	367.48	0.00	8,292.46
Acetone	water	1,725.46	6,389.14	0.00	8,114.60
Ethene, tetrachloro-	air	350.91	7,587.75	0.00	7,938.66
Beryllium	air	0.00	6,285.77	0.00	6,285.77
2-Propanol	air	0.00	6,212.61	0.00	6,212.61
Vinclozolin	soil	5,779.07	162.32	0.00	5,941.39
Chlorpyrifos	soil	1,118.28	4,395.89	0.00	5,514.17
Styrene	air	2.53	4,596.77	0.00	4,599.31
Prochloraz	soil	1,587.62	2,648.79	0.00	4,236.42
Acetaldehyde	water	3,657.59	295.13	0.00	3,952.72
Benomyl	soil	3,755.61	126.09	0.00	3,881.70
Bentazone	soil	3,536.36	129.50	0.00	3,665.87
Methane, dichlorofluoro-, HCFC-21	air	0.68	947.96	2,251.41	3,200.05
Methane, monochloro-, R-40	air	0.00	2,269.61	820.95	3,090.55
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	7.86	752.62	2,042.82	2,803.29
Hydrogen sulfide	water	0.00	2,712.14	0.00	2,712.14
Ethyne	air	14.24	2,548.74	0.00	2,562.97
Cyfluthrin	soil	2,377.94	24.60	0.00	2,402.54
Methyl formate	air	0.00	1,817.53	0.00	1,817.53
Fluroxypyr	soil	1,372.56	28.17	0.00	1,400.74
Formic acid	air	0.00	1,063.65	0.00	1,063.65
Napropamide	soil	951.87	0.87	0.00	952.73
Lambda-cyhalothrin	soil	909.01	0.00	0.00	909.01
m-Xylene	air	0.32	876.89	0.00	877.21
Acrolein	air	85.29	786.83	0.00	872.12
Ethanol	water	578.13	259.96	0.00	838.09
Antimony	soil	482.67	325.60	0.00	808.27
Acetonitrile	air	0.00	774.79	0.00	774.79
Methanol	water	456.59	245.19	0.00	701.78
Clomazone	soil	609.13	0.00	0.00	609.13
Butanol	water	0.00	513.16	0.00	513.16
Isoprene	air	0.00	483.14	0.00	483.14
Ethane, 1,1-difluoro-, HFC-152a	air	0.04	0.01	434.70	434.75

Pendimethalin	soil	274.65	147.30	0.00	421.95
Deltamethrin	soil	323.35	0.00	0.00	323.35
Trinexapac-ethyl	soil	270.50	0.00	0.00	270.50
Polychlorinated biphenyls	air	244.43	0.45	0.00	244.88
Chloroform	water	52.29	111.95	0.00	164.25
Hydrogen peroxide	water	0.00	131.96	0.00	131.96
Beryllium	water	0.00	130.98	0.00	130.98
Radon-222	air	0.00	116.68	0.00	116.68
Furan	air	0.00	95.01	0.00	95.01
2-Methyl pentane	air	0.00	94.28	0.00	94.28
Carbon-14	air	0.00	55.99	0.00	55.99
Butadiene	air	0.00	52.74	0.00	52.74
Benzene, pentachloro-	air	7.88	37.32	0.00	45.20
Acrylic acid	air	0.00	43.32	0.00	43.32
Acenaphthene	water	40.21	0.05	0.00	40.26
Bifenox	soil	23.93	0.00	0.00	23.93
Diethylene glycol	air	0.00	12.72	0.00	12.72
Mecoprop	soil	4.31	7.56	0.00	11.88
Ethane, 1,1,1-trichloro-, HCFC-140	air	0.01	9.13	0.00	9.14
m-Xylene	water	6.19	0.00	0.00	6.19
Hydrogen peroxide	air	0.00	5.13	0.00	5.13
t-Butyl methyl ether	air	0.09	4.98	0.00	5.07
o-Xylene	water	3.39	0.00	0.00	3.39
Phosphoric acid	air	0.00	3.20	0.00	3.20
Iodine-129	air	0.00	0.25	0.00	0.25
Acenaphthylene	water	0.16	0.00	0.00	0.16
t-Butyl methyl ether	water	0.06	0.04	0.00	0.11
Uranium-234	air	0.00	0.10	0.00	0.10
Radium-226	water	0.00	0.06	0.00	0.06
Cesium-137	water	0.00	0.03	0.00	0.03
Hydrogen-3, Tritium	air	0.00	0.02	0.00	0.02
Cobalt-60	water	0.00	0.02	0.00	0.02
Asulam	soil	0.01	0.00	0.00	0.01
Cesium-134	water	0.00	0.01	0.00	0.01
Acenaphthene	air	0.01	0.00	0.00	0.01
Polonium-210	air	0.00	0.01	0.00	0.01
Hydrogen-3, Tritium	water	0.00	0.01	0.00	0.01

Table A13: Aggregated external costs (Eco-Indicator 99)

Pollutant	Ecocat	Euros Ecosystem Quality	Euros Human Health	Euros Total
Nitrogen oxides	air	5,108,741,079.01	7,476,713,735.01	12,585,454,814.03
Particulates, < 2.5 um	air	0.00	11,982,069,031.07	11,982,069,031.07
Sulfur dioxide	air	1,642,814,461.47	7,843,766,828.93	9,486,581,290.40
Zinc	air	9,262,971,382.72	0.00	9,262,971,382.72
Carbon dioxide, fossil	air	0.00	7,354,886,769.45	7,354,886,769.45
Chromium	air	5,167,734,773.95	0.00	5,167,734,773.95
Nickel	air	3,128,746,132.81	1,825,450.54	3,130,571,583.35
Arsenic	water	3,992,640.33	2,089,649,728.12	2,093,642,368.45
Lead	air	1,801,465,132.17	0.00	1,801,465,132.17
Ammonia	air	1,044,484,218.28	547,847,650.98	1,592,331,869.25
Dinitrogen monoxide	air	0.00	973,161,362.50	973,161,362.50
Methane, fossil	air	0.00	661,635,225.30	661,635,225.30
Cadmium	air	267,463,883.68	340,587,907.17	608,051,790.86
Copper	air	546,289,500.41	0.00	546,289,500.41
Chromium VI	soil	360,705,795.63	0.00	360,705,795.63
Arsenic	air	50,539,069.90	218,802,416.17	269,341,486.07
Sulfur hexafluoride	air	0.00	180,728,636.00	180,728,636.00
Cadmium	water	12,522,612.38	165,820,910.50	178,343,522.88
Cadmium	soil	102,242.85	165,254,126.53	165,356,369.38
Chromium VI	air	119,672,372.91	30,459,119.12	150,131,492.03
Chromium VI	water	137,712,423.40	147.89	137,712,571.29
Radon-222	air	0.00	116,679,580.04	116,679,580.04
Zinc	soil	94,228,813.79	0.00	94,228,813.79
Carbon monoxide, fossil	air	0.00	71,113,135.04	71,113,135.04
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	515,767.28	62,266,085.21	62,781,852.50
Mercury	air	58,586,966.15	0.00	58,586,966.15
Copper	soil	58,553,280.75	0.00	58,553,280.75
Carbon-14	air	0.00	55,988,991.70	55,988,991.70
Nickel	water	52,561,191.63	2.35	52,561,193.98
Copper	water	52,268,883.12	0.00	52,268,883.12
Zinc	water	46,500,920.36	0.00	46,500,920.36
Methane, tetrafluoro-, R-14	air	0.00	37,810,334.03	37,810,334.03
NMVOC, unspecified origin	air	0.00	36,565,414.07	36,565,414.07
Methane, chlorodifluoro-, HCFC-22	air	0.00	36,439,687.20	36,439,687.20
Methane, tetrachloro-, R-10	air	0.00	31,570,919.97	31,570,919.97
Methane, trifluoro-, HFC-23	air	0.00	18,671,543.97	18,671,543.97
Chromium	soil	14,598,765.14	0.00	14,598,765.14
Methane, dichlorodifluoro-, CFC-12	air	0.00	12,677,542.27	12,677,542.27
PAH, polycyclic aromatic hydrocarbons	water	24.07	7,727,479.10	7,727,503.18
Ethane, 1,2-dichloro-	air	0.00	7,361,223.61	7,361,223.61

Benzene	water	770,227.01	5,869,100.29	6,639,327.30
Methane, biogenic	air	0.00	6,501,582.44	6,501,582.44
Ethane, hexafluoro-, HFC-116	air	0.00	6,100,747.00	6,100,747.00
Arsenic	soil	93,371.77	4,385,682.80	4,479,054.57
Chloroform	air	0.00	4,135,978.17	4,135,978.17
Benzo(a)pyrene	air	1,037,592.29	2,636,536.57	3,674,128.86
Benzene	air	33,821.84	3,254,245.26	3,288,067.10
Ethylene oxide	air	0.00	3,256,164.91	3,256,164.91
Chromium	water	3,249,914.03	0.00	3,249,914.03
PAH, polycyclic aromatic hydrocarbons	air	137.56	2,739,459.48	2,739,597.04
Benzene, hexachloro-	air	14,250.00	2,707,373.19	2,721,623.19
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	air	0.00	2,143,690.69	2,143,690.69
Propylene oxide	water	0.00	1,948,107.90	1,948,107.90
Ethylene oxide	water	0.00	1,851,746.89	1,851,746.89
Carbon disulfide	air	0.00	1,654,601.47	1,654,601.47
Hydrocarbons, aliphatic, alkanes, unspecified	air	0.00	1,092,473.08	1,092,473.08
Mercury	water	1,069,584.07	0.00	1,069,584.07
Lead	water	1,059,524.26	0.00	1,059,524.26
Hydrocarbons, aromatic	air	0.00	1,001,960.32	1,001,960.32
Propene	air	0.00	996,662.87	996,662.87
Ethene	air	0.00	919,588.63	919,588.63
Methane, bromochlorodifluoro-, Halon 1211	air	0.00	727,635.75	727,635.75
Methane, chlorotrifluoro-, CFC-13	air	0.00	705,619.75	705,619.75
Propylene oxide	air	0.00	544,376.94	544,376.94
Phenol, pentachloro-	air	10,216.88	512,915.29	523,132.17
Pentane	air	0.00	458,905.89	458,905.89
Butene	air	0.00	400,264.17	400,264.17
Methane, bromotrifluoro-, Halon 1301	air	0.00	395,978.89	395,978.89
Cumene	air	0.00	392,264.58	392,264.58
Hydrocarbons, aliphatic, alkanes, cyclic	air	0.00	367,780.52	367,780.52
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	air	0.00	339,615.51	339,615.51
Propanol	air	0.00	334,293.89	334,293.89
Hexane	air	0.00	311,674.85	311,674.85
Propane	air	0.00	306,763.06	306,763.06
Formaldehyde	water	0.00	285,382.03	285,382.03
Butane	air	0.00	276,897.93	276,897.93
Nitrobenzene	air	0.00	275,070.99	275,070.99
Iodine-129	air	0.00	253,419.16	253,419.16
Propanal	air	0.00	245,469.41	245,469.41
Phenol	air	0.00	201,356.21	201,356.21
Xylene	air	0.00	181,850.76	181,850.76
Methanol	air	0.00	175,227.85	175,227.85
Ethane	air	0.00	171,097.40	171,097.40
Acetic acid	air	0.00	168,802.02	168,802.02

Formaldehyde	air	0.00	152,136.37	152,136.37
Heptane	air	0.00	129,146.01	129,146.01
2-Methyl-2-butene	air	0.00	116,870.78	116,870.78
Uranium-234	air	0.00	101,036.55	101,036.55
Toluene	air	140.40	72,760.16	72,900.57
Radium-226	water	0.00	55,720.81	55,720.81
Methane, trichlorofluoro-, CFC-11	air	0.00	46,535.28	46,535.28
Cyclohexane	air	0.00	42,085.51	42,085.51
Mercury	soil	39,356.00	0.00	39,356.00
Acetone	air	0.00	39,009.36	39,009.36
Cesium-137	water	0.00	34,974.81	34,974.81
Ethyl acetate	air	0.00	32,416.80	32,416.80
Acetaldehyde	air	0.00	31,500.13	31,500.13
Ethene, chloro-	air	0.00	29,776.85	29,776.85
Acetaldehyde	water	0.00	26,040.80	26,040.80
Aldehydes, unspecified	air	0.00	24,363.54	24,363.54
4-Methyl-2-pentanone	air	0.00	22,068.26	22,068.26
Hydrogen-3, Tritium	air	0.00	21,648.88	21,648.88
Methyl ethyl ketone	air	0.00	20,482.62	20,482.62
Cobalt-60	water	0.00	20,270.03	20,270.03
Ethyne	air	0.00	17,445.89	17,445.89
Toluene	water	17,412.95	0.00	17,412.95
Ethanol	air	0.00	17,203.85	17,203.85
Butanol	air	0.00	16,830.07	16,830.07
Lead	soil	16,164.61	0.00	16,164.61
Benzene, ethyl-	air	0.00	12,084.79	12,084.79
Uranium-238	air	0.00	11,617.82	11,617.82
Methane, dichloro-, HCC-30	air	0.00	11,422.77	11,422.77
Cesium-134	water	0.00	8,906.56	8,906.56
Ethene, tetrachloro-	air	0.00	8,398.88	8,398.88
Polonium-210	air	0.00	5,680.34	5,680.34
Furan	air	0.00	5,599.46	5,599.46
Uranium-238	water	0.00	5,483.24	5,483.24
Hydrogen-3, Tritium	water	0.00	5,049.81	5,049.81
Atrazine	soil	3,763.78	0.00	3,763.78
Lead-210	air	0.00	3,380.99	3,380.99
Uranium-235	water	0.00	3,088.85	3,088.85
Radium-226	air	0.00	2,987.83	2,987.83
Acetonitrile	air	0.00	2,948.36	2,948.36
Methane, monochloro-, R-40	air	0.00	2,279.21	2,279.21
Iodine-131	air	0.00	2,062.20	2,062.20
Carbendazim	soil	2,016.90	0.00	2,016.90
Uranium-234	water	0.00	1,953.42	1,953.42
Methane, dichlorofluoro-, HCFC-21	air	0.00	1,948.96	1,948.96

Methyl formate	air	0.00	1,817.53	1,817.53
2-Propanol	air	0.00	1,555.76	1,555.76
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	air	0.00	1,131.08	1,131.08
Formic acid	air	0.00	1,063.65	1,063.65
m-Xylene	air	0.00	876.89	876.89
Methane, dichloro-, HCC-30	water	0.00	760.95	760.95
Chloroform	water	0.00	638.63	638.63
Isoprene	air	0.00	483.14	483.14
Butadiene	air	0.00	477.35	477.35
Uranium-235	air	0.00	435.86	435.86
Ethene, chloro-	water	0.00	305.23	305.23
Pentane	air	0.00	303.67	303.67
Styrene	air	0.00	300.40	300.40
Ethane, 1,1-difluoro-, HFC-152a	air	0.00	221.16	221.16
Trifluralin	soil	174.36	0.00	174.36
2-Methyl pentane	air	0.00	94.28	94.28
Thiram	soil	92.58	0.00	92.58
Bentazone	soil	92.11	0.00	92.11
Antimony-124	water	0.00	59.58	59.58
Xenon-133	air	0.00	40.66	40.66
Diethylene glycol	air	0.00	32.68	32.68
Diethyl ether	air	0.00	26.01	26.01
Ethane, 1,2-dichloro-	water	25.01	0.00	25.01
Cobalt-58	water	0.00	24.13	24.13
Metribuzin	soil	19.78	0.00	19.78
Acrylic acid	air	0.00	19.33	19.33
Krypton-85	air	0.00	14.28	14.28
Acrolein	air	0.00	13.22	13.22
Manganese-54	water	0.00	11.31	11.31
Iodine-131	water	0.00	6.65	6.65
Ethane, 1,1,1-trichloro-, HCFC-140	air	0.00	6.01	6.01
Benzaldehyde	air	0.00	5.87	5.87
t-Butyl methyl ether	air	0.00	4.92	4.92
Acenaphthene	air	0.00	4.70	4.70
Benzene, pentachloro-	air	0.00	3.73	3.73
2,4-D	soil	1.70	0.00	1.70
Cobalt-60	air	0.00	0.71	0.71
Cesium-137	air	0.00	0.62	0.62
Cesium-134	air	0.00	0.03	0.03
Plutonium-alpha	air	0.00	0.01	0.01
Iodine-133	air	0.00	0.01	0.01

Table A14: Aggregated 'corrected' external costs (IMPACT2002+)

Pollutant	Unit	Ecocat	Euros Ecosystem Quality	Euros Human Health	Euros Climate Change	Euros Total
Carbon dioxide, fossil	kg	air	0.00	0.00	16,636,053,407.10	16,636,053,407.10
Particulates, < 2.5 um	kg	air	0.00	11,816,969,091.47	0.00	11,816,969,091.47
Dioxins	kg	air	20.20	10,162,490,058.75	0.00	10,162,490,078.95
Nitrogen oxides	kg	air	1,211,359,773.41	7,510,430,595.15	0.00	8,721,790,368.56
Sulfur dioxide	kg	air	389,536,154.41	7,843,766,828.93	0.00	8,233,302,983.34
Aluminum	kg	air	8,065,711,863.48	5,713,881.20	0.00	8,071,425,744.68
Zinc	kg	air	6,086,000,504.68	79,223,324.95	0.00	6,165,223,829.63
Dinitrogen monoxide	kg	air	0.00	0.00	1,982,992,573.44	1,982,992,573.44
Aluminum	kg	soil	1,662,453,536.91	1,853,905.83	0.00	1,664,307,442.74
Methane, fossil	kg	air	0.00	1,919,173.97	1,638,044,968.37	1,639,964,142.34
Zinc	kg	soil	979,845,904.95	49,505,103.63	0.00	1,029,351,008.57
Arsenic, ion	kg	water	1,617,997.39	1,008,913,042.76	0.00	1,010,531,040.14
Chromium	kg	air	896,392,496.21	84,946,796.31	0.00	981,339,292.53
Copper	kg	air	843,290,206.02	236,789.33	0.00	843,526,995.35
Copper	kg	soil	802,502,548.25	276,991.38	0.00	802,779,539.62
Ammonia	kg	air	248,898,739.88	548,770,252.29	0.00	797,668,992.18
Mercury	kg	air	509,417,624.86	6,780,407.00	0.00	516,198,031.86
Nickel	kg	air	465,753,196.69	1,058,679.26	0.00	466,811,875.94
Arsenic	kg	air	67,055,142.33	342,477,903.69	0.00	409,533,046.01
Sulfur hexafluoride	kg	air	0.00	0.00	359,581,786.16	359,581,786.16
Carbon monoxide, fossil	kg	air	0.00	161,440,067.44	164,847,440.37	326,287,507.81
Molybdenum	kg	soil	0.00	219,046,854.22	0.00	219,046,854.22
Molybdenum	kg	air	0.00	187,944,011.49	0.00	187,944,011.49
Lead	kg	air	174,008,763.33	507,473.68	0.00	174,516,237.01
Zinc, ion	kg	water	47,634,033.32	95,037,047.06	0.00	142,671,080.38
Aluminum	kg	water	105,771,526.35	1,280,476.55	0.00	107,052,002.90
Methane, chlorodifluoro-, HCFC-22	kg	air	442.88	5,941,972.91	91,353,764.09	97,296,179.88
Copper, ion	kg	water	86,993,051.27	367,349.94	0.00	87,360,401.21
Methane, tetrafluoro-, R-14	kg	air	5,923.16	0.00	73,122,485.27	73,128,408.43
Antimony	kg	water	7,584,130.01	60,001,251.64	0.00	67,585,381.65
Benzo(a)pyrene	kg	air	2,502.51	65,678,551.84	0.00	65,681,054.35
Chromium	kg	soil	54,668,131.08	32,374.57	0.00	54,700,505.65
Cadmium	kg	air	47,512,201.96	4,129,443.23	0.00	51,641,645.19
Molybdenum	kg	water	0.00	45,993,303.95	0.00	45,993,303.95
Methane, trifluoro-, HFC-23	kg	air	0.00	0.00	40,933,769.47	40,933,769.47
NMVOC	kg	air	0.00	36,565,414.07	0.00	36,565,414.07
Methane, dichlorodifluoro-, CFC-12	kg	air	108.98	5,882,203.90	28,206,551.20	34,088,864.08
Cobalt	kg	air	30,844,866.25	0.00	0.00	30,844,866.25
Methane, tetrachloro-, R-10	kg	air	399.51	15,039,497.01	14,683,350.05	29,723,246.58
Arsenic	kg	soil	1,716,999.36	22,668,280.45	0.00	24,385,279.81

Nitrobenzene	kg	water	0.00	23,955,674.52	0.00	23,955,674.52
Benzene	kg	air	112.43	23,313,943.11	0.00	23,314,055.54
Ethane, hexafluoro-, HFC-116	kg	air	0.00	0.00	17,242,236.22	17,242,236.22
Carbon monoxide, biogenic	kg	air	0.00	8,226,411.24	8,400,038.84	16,626,450.08
Methane, biogenic	kg	air	0.00	18,858.83	16,096,308.05	16,115,166.88
Carbon dioxide, land transformation	kg	air	0.00	0.00	16,008,150.49	16,008,150.49
Cadmium	kg	soil	8,578,734.27	3,837,831.58	0.00	12,416,565.85
Nickel	kg	soil	12,005,897.97	55,851.79	0.00	12,061,749.76
Barium	kg	water	815,024.22	10,744,218.16	0.00	11,559,242.38
Mercury	kg	soil	7,226,803.75	46,906.45	0.00	7,273,710.21
Benzene, hexachloro-	kg	air	59.47	6,709,149.45	0.00	6,709,208.92
Nickel, ion	kg	water	5,566,226.40	1,042,881.46	0.00	6,609,107.86
Lead	kg	soil	6,514,413.17	38,528.42	0.00	6,552,941.59
Barium	kg	soil	2,103,506.65	4,296,401.24	0.00	6,399,907.89
Benzene	kg	water	206,718.60	5,891,137.34	0.00	6,097,855.94
Cadmium, ion	kg	water	905,703.47	4,662,093.31	0.00	5,567,796.78
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	air	142.99	80.37	4,902,700.01	4,902,923.36
Selenium	kg	water	685,068.20	4,047,976.21	0.00	4,733,044.41
Cobalt	kg	water	4,177,447.78	0.00	0.00	4,177,447.78
Metolachlor	kg	soil	3,039,044.13	382,044.42	0.00	3,421,088.55
Chloroform	kg	air	2,276.40	972,488.74	2,168,469.10	3,143,234.23
Ethane, 1,2-dichloro-	kg	water	16,248.41	2,687,683.34	0.00	2,703,931.74
Mercury	kg	water	1,020,878.08	1,078,705.29	0.00	2,099,583.37
Carbofuran	kg	soil	1,933,770.17	29,258.19	0.00	1,963,028.36
Linuron	kg	soil	547,101.96	1,413,081.25	0.00	1,960,183.20
Chromium VI	kg	air	0.00	1,822,842.80	0.00	1,822,842.80
Ethane, 1,2-dichloro-	kg	air	4,212.20	1,709,575.44	0.00	1,713,787.64
Chromium VI	kg	water	0.00	1,335,278.88	0.00	1,335,278.88
Methane, chlorotrifluoro-, CFC-13	kg	air	16.16	177,839.12	1,126,314.46	1,304,169.75
Selenium	kg	air	413,961.61	842,734.90	0.00	1,256,696.51
Methane, bromotrifluoro-, Halon 1301	kg	air	6.06	907,093.92	235,952.41	1,143,052.39
Propene	kg	air	5.00	996,662.87	0.00	996,667.87
Formaldehyde	kg	air	3,813.99	927,565.09	0.00	931,379.08
Methane, bromochlorodifluoro-, Halon 1211	kg	air	2.29	812,391.24	79,627.24	892,020.77
Antimony	kg	air	422,426.62	423,083.41	0.00	845,510.03
Lead	kg	water	450,113.13	387,974.20	0.00	838,087.32
Benzene, chloro-	kg	water	568,283.46	165,194.76	0.00	733,478.22
Cobalt	kg	soil	683,522.78	0.00	0.00	683,522.78
Atrazine	kg	soil	495,087.02	131,635.59	0.00	626,722.62
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	air	0.00	108,962.57	513,901.49	622,864.06
Glyphosate	kg	soil	598,440.56	353.53	0.00	598,794.09
Acetic acid	kg	air	321,284.50	168,802.02	0.00	490,086.52
Pentane	kg	air	42.31	458,905.89	0.00	458,948.20
Propylene oxide	kg	water	0.00	415,933.67	0.00	415,933.67

Butene	kg	air	3.65	400,264.17	0.00	400,267.83
Cumene	kg	air	0.00	392,544.23	0.00	392,544.23
Propanol	kg	air	0.00	334,293.89	0.00	334,293.89
Hexane	kg	air	0.10	314,212.33	0.00	314,212.44
Chromium, ion	kg	water	255,153.03	53,685.59	0.00	308,838.62
Propanal	kg	air	77.02	245,469.41	0.00	245,546.43
Hydrogen sulfide	kg	air	0.00	200,389.99	0.00	200,389.99
Xylene	kg	air	3.25	183,789.05	0.00	183,792.30
Methanol	kg	air	824.49	182,638.72	0.00	183,463.21
Ethane	kg	air	0.00	171,097.40	0.00	171,097.40
Propylene oxide	kg	air	0.00	155,571.60	0.00	155,571.60
Butane	kg	air	36.76	151,281.80	0.00	151,318.55
Carbon disulfide	kg	air	0.00	148,184.29	0.00	148,184.29
Chlorothalonil	kg	soil	143,654.53	2,577.80	0.00	146,232.33
Aldrin	kg	soil	54,196.10	90,445.96	0.00	144,642.06
Carbendazim	kg	soil	140,114.63	0.00	0.00	140,114.63
Heptane	kg	air	0.00	129,146.01	0.00	129,146.02
Propene	kg	water	125,075.83	0.00	0.00	125,075.83
Ethylene oxide	kg	air	0.00	124,893.85	0.00	124,893.85
Methane, trichlorofluoro-, CFC-11	kg	air	2.04	38,474.08	80,062.66	118,538.78
2-Methyl-2-butene	kg	air	0.00	116,870.78	0.00	116,870.78
Propane	kg	air	102.24	116,146.27	0.00	116,248.52
Barium	kg	air	31,844.69	65,678.77	0.00	97,523.46
Toluene	kg	air	4.93	73,269.93	0.00	73,274.86
Chromium VI	kg	soil	0.00	71,116.68	0.00	71,116.68
Cumene	kg	water	0.00	55,214.37	0.00	55,214.37
Butene	kg	water	48,251.96	0.00	0.00	48,251.96
Carbetamide	kg	soil	46,889.36	0.00	0.00	46,889.36
Cypermethrin	kg	soil	36,666.45	8,828.31	0.00	45,494.76
Acetone	kg	air	57.71	45,182.51	0.00	45,240.22
Cyclohexane	kg	air	0.00	42,085.51	0.00	42,085.51
Trifluralin	kg	soil	512.98	37,259.63	0.00	37,772.61
Butanol	kg	air	0.00	33,701.92	0.00	33,701.92
Acetaldehyde	kg	air	32.76	31,886.71	0.00	31,919.47
Phenol, pentachloro-	kg	air	120.70	31,750.38	0.00	31,871.07
Methane, dichloro-, HCC-30	kg	air	48.81	3,749.95	21,869.47	25,668.23
Aldehydes, unspecified	kg	air	0.00	24,363.54	0.00	24,363.54
Metribuzin	kg	soil	23,347.80	15.65	0.00	23,363.44
Methyl ethyl ketone	kg	air	12.90	20,499.54	0.00	20,512.44
Ethylene oxide	kg	water	0.00	19,613.30	0.00	19,613.30
Ethanol	kg	air	6.06	17,243.57	0.00	17,249.63
Nitrobenzene	kg	air	0.00	16,607.37	0.00	16,607.37
Endosulfan	kg	soil	10,100.93	2,581.69	0.00	12,682.62
4-Methyl-2-pentanone	kg	air	0.00	12,159.18	0.00	12,159.18

Benzene, ethyl-	kg	air	1.03	12,089.75	0.00	12,090.78
Ethyl acetate	kg	air	16.20	11,654.54	0.00	11,670.74
Acetic acid	kg	water	10,015.89	0.00	0.00	10,015.89
Methane, dichloro-, HCC-30	kg	water	221.36	2,054.22	7,545.95	9,821.53
Phenol	kg	water	7,960.55	747.78	0.00	8,708.33
Formaldehyde	kg	water	5,035.98	3,338.10	0.00	8,374.08
Phenol	kg	air	6,690.41	1,658.08	0.00	8,348.49
Pirimicarb	kg	soil	7,705.21	0.00	0.00	7,705.21
Ethene, tetrachloro-	kg	air	83.21	7,587.75	0.00	7,670.96
Acetone	kg	water	409.13	6,389.14	0.00	6,798.27
Beryllium	kg	air	0.00	6,285.77	0.00	6,285.77
2-Propanol	kg	air	0.00	6,212.61	0.00	6,212.61
Toluene	kg	water	3,570.38	2,075.41	0.00	5,645.78
Chlorpyrifos	kg	soil	265.16	4,395.89	0.00	4,661.06
Styrene	kg	air	0.60	4,596.77	0.00	4,597.38
2,4-D	kg	soil	2,155.80	1,970.61	0.00	4,126.40
Methane, dichlorofluoro-, HCFC-21	kg	air	0.16	947.96	2,251.41	3,199.53
Methane, monochloro-, R-40	kg	air	0.00	2,269.61	820.95	3,090.55
Prochloraz	kg	soil	376.45	2,648.79	0.00	3,025.24
Xylene	kg	water	2,723.78	125.60	0.00	2,849.38
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	air	1.86	752.62	2,042.82	2,797.30
Hydrogen sulfide	kg	water	0.00	2,712.14	0.00	2,712.14
Ethyne	kg	air	3.38	2,548.74	0.00	2,552.11
Benzene, ethyl-	kg	water	1,879.13	367.48	0.00	2,246.61
Methyl formate	kg	air	0.00	1,817.53	0.00	1,817.53
Vinclozolin	kg	soil	1,370.31	162.32	0.00	1,532.63
Acetaldehyde	kg	water	867.27	295.13	0.00	1,162.40
Formic acid	kg	air	0.00	1,063.65	0.00	1,063.65
Benomyl	kg	soil	890.51	126.09	0.00	1,016.60
Bentazone	kg	soil	838.52	129.50	0.00	968.03
m-Xylene	kg	air	0.08	876.89	0.00	876.96
Acrolein	kg	air	20.22	786.83	0.00	807.05
Acetonitrile	kg	air	0.00	774.79	0.00	774.79
Cyfluthrin	kg	soil	563.85	24.60	0.00	588.44
Butanol	kg	water	0.00	513.16	0.00	513.16
Isoprene	kg	air	0.00	483.14	0.00	483.14
Antimony	kg	soil	114.45	325.60	0.00	440.05
Ethane, 1,1-difluoro-, HFC-152a	kg	air	0.01	0.01	434.70	434.72
Ethanol	kg	water	137.08	259.96	0.00	397.05
Fluroxypyr	kg	soil	325.45	28.17	0.00	353.63
Methanol	kg	water	108.26	245.19	0.00	353.46
Napropamide	kg	soil	225.70	0.87	0.00	226.57
Lambda-cyhalothrin	kg	soil	215.54	0.00	0.00	215.54
Pendimethalin	kg	soil	65.12	147.30	0.00	212.42

Clomazone	kg	soil	144.43	0.00	0.00	144.43
Hydrogen peroxide	kg	water	0.00	131.96	0.00	131.96
Beryllium	kg	water	0.00	130.98	0.00	130.98
Chloroform	kg	water	12.40	111.95	0.00	124.35
Radon-222	kBq	air	0.00	116.68	0.00	116.68
Furan	kg	air	0.00	95.01	0.00	95.01
2-Methyl pentane	kg	air	0.00	94.28	0.00	94.28
Deltamethrin	kg	soil	76.67	0.00	0.00	76.67
Trinexapac-ethyl	kg	soil	64.14	0.00	0.00	64.14
Polychlorinated biphenyls	kg	air	57.96	0.45	0.00	58.41
Carbon-14	kBq	air	0.00	55.99	0.00	55.99
Butadiene	kg	air	0.00	52.74	0.00	52.74
Acrylic acid	kg	air	0.00	43.32	0.00	43.32
Benzene, pentachloro-	kg	air	1.87	37.32	0.00	39.19
Diethylene glycol	kg	air	0.00	12.72	0.00	12.72
Acenaphthene	kg	water	9.54	0.05	0.00	9.59
Ethane, 1,1,1-trichloro-, HCFC-140	kg	air	0.00	9.13	0.00	9.13
Mecoprop	kg	soil	1.02	7.56	0.00	8.59
Bifenox	kg	soil	5.67	0.00	0.00	5.67
Hydrogen peroxide	kg	air	0.00	5.13	0.00	5.13
t-Butyl methyl ether	kg	air	0.02	4.98	0.00	5.00
Phosphoric acid	kg	air	0.00	3.20	0.00	3.20
m-Xylene	kg	water	1.47	0.00	0.00	1.47
o-Xylene	kg	water	0.80	0.00	0.00	0.80
Iodine-129	kBq	air	0.00	0.25	0.00	0.25
Uranium-234	kBq	air	0.00	0.10	0.00	0.10
t-Butyl methyl ether	kg	water	0.01	0.04	0.00	0.06
Radium-226	kBq	water	0.00	0.06	0.00	0.06
Acenaphthylene	kg	water	0.04	0.00	0.00	0.04
Cesium-137	kBq	water	0.00	0.03	0.00	0.03
Hydrogen-3, Tritium	kBq	air	0.00	0.02	0.00	0.02
Cobalt-60	kBq	water	0.00	0.02	0.00	0.02
Cesium-134	kBq	water	0.00	0.01	0.00	0.01
Polonium-210	kBq	air	0.00	0.01	0.00	0.01
Hydrogen-3, Tritium	kBq	water	0.00	0.01	0.00	0.01

Table A15: Aggregated 'corrected' external costs (Eco-Indicator 99)

Pollutant	Unit	Ecocat	Euros Ecosystem Quality	Euros Human Health	Euros Total
Nitrogen oxides	kg	air	1,205,921,570.16	7,476,713,735.01	8,682,635,305.18
Particulates, < 2.5 um	kg	air	0.00	11,982,069,031.07	11,982,069,031.07
Sulfur dioxide	kg	air	387,787,395.02	7,843,766,828.93	8,231,554,223.95
Zinc	kg	air	2,186,530,266.75	0.00	2,186,530,266.75
Carbon dioxide, fossil	kg	air	0.00	7,354,886,769.45	7,354,886,769.45
Chromium	kg	air	1,219,847,069.25	0.00	1,219,847,069.25
Nickel	kg	air	738,542,507.98	1,825,450.54	740,367,958.52
Arsenic, ion	kg	water	942,465.28	2,089,649,728.12	2,090,592,193.40
Lead	kg	air	425,236,986.41	0.00	425,236,986.41
Ammonia	kg	air	246,551,161.83	547,847,650.98	794,398,812.81
Dinitrogen monoxide	kg	air	0.00	973,161,362.50	973,161,362.50
Methane, fossil	kg	air	0.00	661,635,225.30	661,635,225.30
Cadmium	kg	air	63,135,019.29	340,587,907.17	403,722,926.46
Copper	kg	air	128,951,982.87	0.00	128,951,982.87
Chromium VI	kg	soil	85,144,831.71	0.00	85,144,831.71
Arsenic	kg	air	11,929,779.49	218,802,416.17	230,732,195.66
Sulfur hexafluoride	kg	air	0.00	180,728,636.00	180,728,636.00
Cadmium, ion	kg	water	2,955,970.59	165,820,910.50	168,776,881.09
Cadmium	kg	soil	24,134.49	165,254,126.53	165,278,261.02
Chromium VI	kg	air	28,248,739.49	30,459,119.12	58,707,858.60
Chromium VI	kg	water	32,507,104.84	147.89	32,507,252.73
Radon-222	kBq	air	0.00	116,679,580.04	116,679,580.04
Zinc	kg	soil	22,242,771.23	0.00	22,242,771.23
Carbon monoxide, fossil	kg	air	0.00	71,113,135.04	71,113,135.04
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	air	121,747.19	62,266,085.21	62,387,832.41
Mercury	kg	air	13,829,490.50	0.00	13,829,490.50
Copper	kg	soil	13,821,539.04	0.00	13,821,539.04
Carbon-14	kBq	air	0.00	55,988,991.70	55,988,991.70
Nickel, ion	kg	water	12,407,102.60	2.35	12,407,104.95
Copper, ion	kg	water	12,338,102.99	0.00	12,338,102.99
Zinc, ion	kg	water	10,976,571.73	0.00	10,976,571.73
Methane, tetrafluoro-, R-14	kg	air	0.00	37,810,334.03	37,810,334.03
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	air	0.00	36,565,414.07	36,565,414.07
Methane, chlorodifluoro-, HCFC-22	kg	air	0.00	36,439,687.20	36,439,687.20
Methane, tetrachloro-, R-10	kg	air	0.00	31,570,919.97	31,570,919.97
Methane, trifluoro-, HFC-23	kg	air	0.00	18,671,543.97	18,671,543.97
Chromium	kg	soil	3,446,047.77	0.00	3,446,047.77
Methane, dichlorodifluoro-, CFC-12	kg	air	0.00	12,677,542.27	12,677,542.27
PAH, polycyclic aromatic hydrocarbons	kg	water	5.68	7,727,479.10	7,727,484.79
Ethane, 1,2-dichloro-	kg	air	0.00	7,361,223.61	7,361,223.61

Benzene	kg	water	181,812.57	5,869,100.29	6,050,912.87
Methane, biogenic	kg	air	0.00	6,501,582.44	6,501,582.44
Ethane, hexafluoro-, HFC-116	kg	air	0.00	6,100,747.00	6,100,747.00
Arsenic	kg	soil	22,040.46	4,385,682.80	4,407,723.26
Chloroform	kg	air	0.00	4,135,978.17	4,135,978.17
Benzo(a)pyrene	kg	air	244,924.32	2,636,536.57	2,881,460.88
Benzene	kg	air	7,983.67	3,254,245.26	3,262,228.93
Ethylene oxide	kg	air	0.00	3,256,164.91	3,256,164.91
Chromium, ion	kg	water	767,144.27	0.00	767,144.27
PAH, polycyclic aromatic hydrocarbons	kg	air	32.47	2,739,459.48	2,739,491.95
Benzene, hexachloro-	kg	air	3,363.72	2,707,373.19	2,710,736.91
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	air	0.00	2,143,690.69	2,143,690.69
Propylene oxide	kg	water	0.00	1,948,107.90	1,948,107.90
Ethylene oxide	kg	water	0.00	1,851,746.89	1,851,746.89
Carbon disulfide	kg	air	0.00	1,654,601.47	1,654,601.47
Hydrocarbons, aliphatic, alkanes, unspecified	kg	air	0.00	1,092,473.08	1,092,473.08
Mercury	kg	water	252,476.00	0.00	252,476.00
Lead	kg	water	250,101.37	0.00	250,101.37
Hydrocarbons, aromatic	kg	air	0.00	1,001,960.32	1,001,960.32
Propene	kg	air	0.00	996,662.87	996,662.87
Ethene	kg	air	0.00	919,588.63	919,588.63
Methane, bromochlorodifluoro-, Halon 1211	kg	air	0.00	727,635.75	727,635.75
Methane, chlorotrifluoro-, CFC-13	kg	air	0.00	705,619.75	705,619.75
Propylene oxide	kg	air	0.00	544,376.94	544,376.94
Phenol, pentachloro-	kg	air	2,411.70	512,915.29	515,326.99
Pentane	kg	air	0.00	458,905.89	458,905.89
Butene	kg	air	0.00	400,264.17	400,264.17
Methane, bromotrifluoro-, Halon 1301	kg	air	0.00	395,978.89	395,978.89
Cumene	kg	air	0.00	392,264.58	392,264.58
Hydrocarbons, aliphatic, alkanes, cyclic	kg	air	0.00	367,780.52	367,780.52
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	air	0.00	339,615.51	339,615.51
Propanol	kg	air	0.00	334,293.89	334,293.89
Hexane	kg	air	0.00	311,674.85	311,674.85
Propane	kg	air	0.00	306,763.06	306,763.06
Formaldehyde	kg	water	0.00	285,382.03	285,382.03
Butane	kg	air	0.00	276,897.93	276,897.93
Nitrobenzene	kg	air	0.00	275,070.99	275,070.99
Iodine-129	kBq	air	0.00	253,419.16	253,419.16
Propanal	kg	air	0.00	245,469.41	245,469.41
Phenol	kg	air	0.00	201,356.21	201,356.21
Xylene	kg	air	0.00	181,850.76	181,850.76
Methanol	kg	air	0.00	175,227.85	175,227.85
Ethane	kg	air	0.00	171,097.40	171,097.40
Acetic acid	kg	air	0.00	168,802.02	168,802.02

Formaldehyde	kg	air	0.00	152,136.37	152,136.37
Heptane	kg	air	0.00	129,146.01	129,146.01
2-Methyl-2-butene	kg	air	0.00	116,870.78	116,870.78
Uranium-234	kBq	air	0.00	101,036.55	101,036.55
Toluene	kg	air	33.14	72,760.16	72,793.31
Radium-226	kBq	water	0.00	55,720.81	55,720.81
Methane, trichlorofluoro-, CFC-11	kg	air	0.00	46,535.28	46,535.28
Cyclohexane	kg	air	0.00	42,085.51	42,085.51
Mercury	kg	soil	9,290.01	0.00	9,290.01
Acetone	kg	air	0.00	39,009.36	39,009.36
Cesium-137	kBq	water	0.00	34,974.81	34,974.81
Ethyl acetate	kg	air	0.00	32,416.80	32,416.80
Acetaldehyde	kg	air	0.00	31,500.13	31,500.13
Ethene, chloro-	kg	air	0.00	29,776.85	29,776.85
Acetaldehyde	kg	water	0.00	26,040.80	26,040.80
Aldehydes, unspecified	kg	air	0.00	24,363.54	24,363.54
4-Methyl-2-pentanone	kg	air	0.00	22,068.26	22,068.26
Hydrogen-3, Tritium	kBq	air	0.00	21,648.88	21,648.88
Methyl ethyl ketone	kg	air	0.00	20,482.62	20,482.62
Cobalt-60	kBq	water	0.00	20,270.03	20,270.03
Ethyne	kg	air	0.00	17,445.89	17,445.89
Toluene	kg	water	4,110.34	0.00	4,110.34
Ethanol	kg	air	0.00	17,203.85	17,203.85
Butanol	kg	air	0.00	16,830.07	16,830.07
Lead	kg	soil	3,815.67	0.00	3,815.67
Benzene, ethyl-	kg	air	0.00	12,084.79	12,084.79
Uranium-238	kBq	air	0.00	11,617.82	11,617.82
Methane, dichloro-, HCC-30	kg	air	0.00	11,422.77	11,422.77
Cesium-134	kBq	water	0.00	8,906.56	8,906.56
Ethene, tetrachloro-	kg	air	0.00	8,398.88	8,398.88
Polonium-210	kBq	air	0.00	5,680.34	5,680.34
Furan	kg	air	0.00	5,599.46	5,599.46
Uranium-238	kBq	water	0.00	5,483.24	5,483.24
Hydrogen-3, Tritium	kBq	water	0.00	5,049.81	5,049.81
Atrazine	kg	soil	888.44	0.00	888.44
Lead-210	kBq	air	0.00	3,380.99	3,380.99
Uranium-235	kBq	water	0.00	3,088.85	3,088.85
Radium-226	kBq	air	0.00	2,987.83	2,987.83
Acetonitrile	kg	air	0.00	2,948.36	2,948.36
Methane, monochloro-, R-40	kg	air	0.00	2,279.21	2,279.21
Iodine-131	kBq	air	0.00	2,062.20	2,062.20
Carbendazim	kg	soil	476.09	0.00	476.09
Uranium-234	kBq	water	0.00	1,953.42	1,953.42
Methane, dichlorofluoro-, HCFC-21	kg	air	0.00	1,948.96	1,948.96

Methyl formate	kg	air	0.00	1,817.53	1,817.53
2-Propanol	kg	air	0.00	1,555.76	1,555.76
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	air	0.00	1,131.08	1,131.08
Formic acid	kg	air	0.00	1,063.65	1,063.65
m-Xylene	kg	air	0.00	876.89	876.89
Methane, dichloro-, HCC-30	kg	water	0.00	760.95	760.95
Chloroform	kg	water	0.00	638.63	638.63
Isoprene	kg	air	0.00	483.14	483.14
Butadiene	kg	air	0.00	477.35	477.35
Uranium-235	kBq	air	0.00	435.86	435.86
Ethene, chloro-	kg	water	0.00	305.23	305.23
Pentane	kg	air	0.00	303.67	303.67
Styrene	kg	air	0.00	300.40	300.40
Ethane, 1,1-difluoro-, HFC-152a	kg	air	0.00	221.16	221.16
Trifluralin	kg	soil	41.16	0.00	41.16
2-Methyl pentane	kg	air	0.00	94.28	94.28
Thiram	kg	soil	21.85	0.00	21.85
Bentazone	kg	soil	21.74	0.00	21.74
Antimony-124	kBq	water	0.00	59.58	59.58
Xenon-133	kBq	air	0.00	40.66	40.66
Diethylene glycol	kg	air	0.00	32.68	32.68
Diethyl ether	kg	air	0.00	26.01	26.01
Ethane, 1,2-dichloro-	kg	water	5.90	0.00	5.90
Cobalt-58	kBq	water	0.00	24.13	24.13
Metribuzin	kg	soil	4.67	0.00	4.67
Acrylic acid	kg	air	0.00	19.33	19.33
Krypton-85	kBq	air	0.00	14.28	14.28
Acrolein	kg	air	0.00	13.22	13.22
Manganese-54	kBq	water	0.00	11.31	11.31
Iodine-131	kBq	water	0.00	6.65	6.65
Ethane, 1,1,1-trichloro-, HCFC-140	kg	air	0.00	6.01	6.01
Benzaldehyde	kg	air	0.00	5.87	5.87
t-Butyl methyl ether	kg	air	0.00	4.92	4.92
Acenaphthene	kg	air	0.00	4.70	4.70
Benzene, pentachloro-	kg	air	0.00	3.73	3.73
2,4-D	kg	soil	0.40	0.00	0.40
Cobalt-60	kBq	air	0.00	0.71	0.71
Cesium-137	kBq	air	0.00	0.62	0.62
Cesium-134	kBq	air	0.00	0.03	0.03
Plutonium-alpha	kBq	air	0.00	0.01	0.01
Iodine-133	kBq	air	0.00	0.01	0.01

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CHAPTER 2: CASE STUDY FOR THE METAL INDUSTRY

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I. Introduction

The case studies for work package II.5.a will cover three different sectors: the chemical industry, the agri-food industry and the metal industry. The analysis of the external costs in this report will focus on the results for estimations of production processes within the metal industry. For this sector, the analysis has been split up into two different studies scenarios. First, a comparison of external costs of the metal sector for all European countries will be examined in order to evaluate the different effects of this sector across the European economies. Second, a more detailed study will be performed for Germany. This detailed study is based on the availability of detailed data on emissions for all economic sectors including the metal industry in Germany. As this second part of the case study will also be divided into two parts, another important part of the tasks given in work package II.5.a was completed. The existing model of EcoSenseWeb was expanded by the Eulerian model of Polyphemus in order to have an alternative chemical transportation model to the existing EMEP model and to achieve a higher level of accuracy of the estimated external costs. The results of the two different approaches applied to calculate these external costs will be compared and interpreted. Additionally, the impact of non-environmental effects of the activities within the German metal industry will be analysed. This analysis will focus on the effects of employment and risk safety and will be discussed in the end of this report.

II. Case Study 1: External costs of the metal industry in Europe

The first scenario of this case study on the external costs of the metal industry will focus on the impacts of the emissions of the metal industry in each of the EU-27 member states and on the total amount of external costs for the EU-27 as a whole. In the following sections the data sources and the estimated results will be described in detail.

II.1 Data sources used for the analysis

II.1.1 EMEP WebDab

At the official homepage, The Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe (EMEP) is described as a scientific based and policy driven programme under the Convention on

Long-range Transboundary Air Pollution (CLRTAP) for international co-operation to solve transboundary air pollution problems.[1] The data given by the EMEP internet database (WebDab) cover a total of 50 countries including the EU-27 countries, the United States, Russia and Canada. Furthermore, the EMEP database provides the possibility to focus on data for selected sectors within the chosen geographical region. This is especially interesting in this study as the analysis will only focus on the external costs resulting from one single sector, namely the metal industry. The emissions data that can be extracted from the database contain classical air pollutants, heavy metals, persistent organic pollutants (POPs) and particulate matter. In total about 40 different pollutants are given in the database. Furthermore, the database offers different formats of the data output. The user can select either national or sectoral totals, a distribution of the emission data over grid cells sized approximately 50 x 50 km², the so-called EMEP50 grid, or over grid cells sized 0.5° x 0.5°. In the following analysis of the metal industry, the EMEP50 grid will be applied in order to get the spatial resolution of the emissions. In addition, data can either be retrieved for past years back to 1980 or can be downloaded for future scenarios for the years 2010 to 2030 for every five years.[2]

In order to define the metal industry within the database, the nomenclature for reporting (NFR) had to be chosen. As the sectors of the EMEP NFR correspond to the United Nations Framework Convention on Climate Change (UNFCCC) common reporting format (CRF) the emission category 'NFR02 (level2)' was chosen. The emission data were analysed for the sectors:

- N02 2 C -- Metal production,
- N02 1 A 2 a -- Iron and steel and
- N02 1 A 2 b – Non-ferrous metals.

The first sector includes iron and steel production, ferroalloys production, aluminium production and other metals. Additionally, the latter two sectors are included in the analysis as they describe sub-categories of sector '1 A 2 – Manufacturing industries and construction'. More information on the reporting format 'NFR02' can be found in European Commission (2002). The emission data given by EMEP for all member states of the EU-27 are summarised in the following Table 1. As EMEP does not provide data for Cyprus, Lithuania, Luxemburg and Malta, these countries are not included in the estimations. The table contains only emissions of substances that could be evaluated in

[1] For more information please visit www.emep.int

[2] For more information please check www.emep-emissions.at/emission-data-webdab

monetary terms in the next steps of the analysis. A table with the total emission data for all emissions of the metal industry can be found in the Appendix (Table A1). The data collected in the EMEP WebDab consists of officially submitted emission data by the members of the CLRTAP via the secretariat of the United Nations Economic Commission for Europe (UNECE) to the EMEP project. In the 'User Guide to WebDab' the user is informed that "data might be inconsistent and/or incomplete".[3] This may have an influence on the estimated results in this case study.

II.1.2 Monetary valuation data

In order to estimate the external costs resulting from the emission of the above-mentioned substances, monetary valuation factors have to be applied. For NH_3, NMVOC, NO_x, SO_x, PM and dioxins the factors were taken from the results of research within the NEEDS project, an integrated project of the 6th Framework Programme of the European Commission. These factors have been calculated and generalized by a number of runs of the EcoSenseWeb applications. Detailed Information on the estimated Euro per ton values for damages to human health can be found in Desaigues et al. (2007), for losses of biodiversity in Ott et al. (2006) and for damages to crops in ExternE (1999) and ExternE (2005). For the heavy metals – As, Cd, Cr, Ni and Pb – the applied monetary factors are the results of projects of NEEDS and ESPREME, both within the 6th Framework Programme of the European Commission. The results were estimated with WATSON, an integrated water and soil environmental fate, exposure and impact assessment model of noxious substances, which provides Euro per ton values for damages following the ingestion.[4] Additionally OMEGA, an integrated assessment of heavy metal releases in Europe, covers the damages resulting from inhalation of substances. For mercury (Hg) the estimations of Spadaro and Rabl (2007) were applied. Finally, monetary valuation factors for Dioxins were extracted from MethodEx (2006).

An overview of the monetary valuation factors used in this part of the case study is provided in the Appendix in Tables A2 to A4. There, the factors for damages to human health, the loss of biodiversity and damages to crops by nitrate deposition and ozone are shown for all substance that valuation factors are provided for the above-mentioned literature. All values are given in Euros per ton of the emitted substance. As can be seen, the monetary factors for heavy metals only cover damages to human health.

[3] The 'User Guide to WebDab' is accessible via the official homepage of the EMEP WebDab: http://www.emep-emissions.at/emission-data-webdab/user-guide-to-webdab/

[4] WATSON: http://watson.ier.uni-stuttgart.de/

Unfortunately, there is no information on the external costs for heavy metals resulting from damages to the ecosystem provided by the data sources applied in this analysis.

Table 1: Total emissions of metal industry in Europe[5]

Unit	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	g I-Teq
Country	**NH_3**	**NMVOC**	**NO_x**	**SO_x**	**PM10**	**$PM_{2.5}$**	**PM_{co}[6]**	**As**	**Cd**	**Cr**	**Hg**	**Ni**	**Pb**	**DIOX**
Austria	0.52682	0.74906	5.38415	5.77318	1.66087	0.76250	0.89837	n.a.	0.00024	n.a.	0.00031	n.a.	0.00773	6.14631
Belgium	0.03665	3.27221	17.90125	16.73272	8.80297	6.65848	2.14449	0.00185	0.00087	0.01159	0.00068	0.00458	0.06061	15.29500
Bulgaria	n.a.	1.35872	9.72501	26.47486	n.a.	n.a.	0.00000	n.a.	0.01123	n.a.	0.00135	n.a.	0.09305	30.10920
Czech Rep.	0.17862	1.21462	10.09533	12.97976	1.74000	1.23000	0.51000	0.00035	0.00157	0.00297	0.00020	0.00115	0.02936	142.70123
Denmark	n.a.	n.a.	n.a.	n.a.	0.07974	0.02058	0.05916	0.00003	0.00002	0.00010	0.00006	0.00016	0.00101	0.20776
Estonia	0.06000	0.01000	0.01000	n.a.	0.05000	0.01000	0.04000	n.a.	n.a.	0.00018	n.a.	0.00005	n.a.	n.a.
Finland	1.19548	1.05980	4.09449	8.18884	1.75409	1.12767	0.62642	0.00072	0.00035	0.00567	0.00035	0.00585	0.00357	4.69044
France	n.a.	4.18761	23.89357	30.16396	6.37663	4.23861	2.13802	0.00230	0.00224	0.01350	0.00039	0.01554	0.04716	45.28271
Germany	0.15736	7.00766	32.57605	43.49652	28.53344	10.80822	17.72522	n.a.	0.00010	n.a.	0.00000	0.00646	0.00144	45.47000
Greece	n.a.	0.45000	4.07000	23.38000	n.a.	n.a.	0.00000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Hungary	n.a.	8.16421	6.18080	18.96363	5.02022	2.98268	2.03753	0.00032	0.00102	0.00180	0.00093	0.00149	0.02722	17.56286
Ireland	n.a.	0.01500	3.20800	4.68600	0.59052	0.51927	0.07125	0.00010	0.00018	0.00046	0.00001	0.01107	0.00024	n.a.
Italy	n.a.	3.45664	2.87600	4.15689	7.05057	5.55364	1.49693	0.00019	0.00120	0.01011	0.00269	0.00413	0.07104	78.59023
Latvia	0.00249	0.27444	3.60999	0.09964	0.41995	0.36451	0.05543	0.00042	0.00021	0.00565	0.00000	0.00009	0.00941	0.19619
Netherlands	0.05192	1.45670	7.45896	7.74805	2.02865	1.29843	0.73021	0.00029	0.00070	0.00112	0.00021	0.00086	0.02365	8.42659
Poland	n.a.	4.18000	2.23980	10.87000	7.13180	4.51680	2.61500	0.01959	0.00339	0.01227	0.00090	0.00543	0.26550	32.30017
Portugal	n.a.	0.01322	0.36910	0.45927	19.82697	18.58959	1.23738	0.00001	0.00001	0.00003	0.00001	0.00046	0.00002	0.00247
Romania	n.a.	0.29600	2.23900	3.79200	11.37030	n.a.	11.37030	0.00058	0.00112	0.011758	0.00041	0.01756	0.06366	69.33900
Slovakia	0.000196	1.06732	8.89980	13.69647	1.55871	0.82504	0.73367	0.01780	0.00039	0.00176	0.00163	0.00639	0.03692	30.93286
Slovenia	n.a.	n.a.	n.a.	1.31800	n.a.	n.a.	0.00000	0.00000	0.00055	n.a.	0.00009	n.a.	0.01100	0.00612
Spain	n.a.	4.88146	31.31937	31.20900	9.57424	5.06134	4.51290	0.01122	0.00831	0.00509	0.00279	0.03204	0.16804	94.57967
Sweden	0.02364	0.15826	2.26659	5.17516	1.46518	1.17409	0.29109	0.00026	0.00009	0.00852	0.00019	0.00195	0.00426	6.37492
UK	0.00585	2.77214	21.07650	21.70046	8.81630	5.26031	3.55598	0.00138	0.00125	0.00675	0.00106	0.01246	0.06133	47.92147

[5] No data are given for Cyprus, Lithuania, Luxemburg and Malta. Furthermore, 'n.a.' stands for not availability of data. This is mentioned in the 'User Guide to WebDab'

where it says that "data might be inconsistent and/or incomplete"

[6] PM_{co} describes the coarse fraction of PM_{10}, i.e. the difference of PM_{10} and $PM_{2.5}$.

Total	**2.23903**	**46.04506**	**199.49376**	**291.06439**	**123.85113**	**71.00177**	**52.84937**	**0.05739**	**0.03502**	**0.09935**	**0.01427**	**0.12771**	**0.98620**	**676.13520**

II.2 External costs of the metal industry in EU-27 member states

With the above-mentioned data, an estimation of the external costs of the metal industry was enabled. Therefore, the emissions provided by EMEP WebDab were converted into tons and then multiplied by the corresponding monetary factors of NEEDS, ExternE, WATSON and OMEGA. The results are summarized in the following Table 2 to Table 4 and present the external costs resulting from damages to human health, from losses of biodiversity and from damages to crops due to the deposition of nitrate compounds and due to ozone. Additionally, Table 5 sums up the results from the other tables to identify the total amount of external costs that result from the activities within the metal industry for each of the EU-27 member states and for the EU-27 in total.

The calculated total amount of external costs for the metal industry in the EU-27 member states sums up to more than €5.7 billion for 2005. In order to show the importance of the estimated external costs for the whole sector, the total value of produced output of the metal industry in the EU-27 countries can be taken as a reference value. To estimate the total value of production for the metal industry, data for two NACE sectors were extracted from the EuroStat database:

- *NACE 27:* Manufacture of basic metals
- *NACE 28:* Manufacture of fabricated metal products

The estimated values of production for the EU-27 countries are shown in Table 6. The total value sums up to more than €550 billion for 2005. From the numbers one can see that the total external costs make up for a bit more than 1% of the total value of production. The highest share of these €5.7 billion is given by NO_x, SO_x and PM2.5. The emissions of these substances are responsible for external costs of more than €1 billion each, reaching nearly €2 billion for $PM_{2.5}$ and SO_x. Together they make up for almost 92% of the total external costs. These costs result from the high level of monetary valued damages to human health they cause. While $PM_{2.5}$ only has an impact on human health, NO_x and SO_x also have minor – in some cases even positive – impacts on biodiversity and crops.

Comparing the countries of the EU-27, Table 5 also shows that Germany is responsible for the largest share of the total external costs. More than one-fifth of the total costs for Europe are generated in Germany. This fact is supported by the total emissions that are ‘produced’ in Germany as these are the highest in Europe as well as the high level of population density in Germany. Additionally, the estimated amount of external costs for Germany is supported by the fact that Germany is leading the statistics on the value of produced output as provided by EuroStat. The data – summarised in Table 6 – show that the amount given for Germany is almost two times higher than those given for the second highest values for France or Italy. However, it has to be mentioned that the estimated external costs do not necessarily correspond with the given amount of production value as can be seen for example for Italy with the second highest value of production and Belgium with the second highest amount of external costs. On the other hand, the data are sufficient to underline the importance of the German metal industry for all European countries. For that reason it is necessary to analyse the metal industry in Germany in more detail. This will be done in the following section were the external costs will be estimated using two different methodological approaches.

Table 2: External costs of metal industry due to damages to human health in millions of Euros

Country	NH3	NMVOC	NOx	SOx	PM2.5	PMco	As	Cd	Cr	Hg	Ni	Pb	DIOX
Austria	6.17	0.76	51.33	44.56	22.54	1.08	0.00	0.02	0.00	0.00	0.00	2.10	0.23
Belgium	0.80	5.13	114.08	142.95	308.09	5.72	1.09	0.08	0.28	0.01	0.02	17.80	0.57
Bulgaria	0.00	-0.07	52.34	128.80	0.00	0.00	0.00	0.86	0.00	0.01	0.00	24.48	1.11
Czech Rep.	3.00	0.71	73.72	93.91	31.01	0.51	0.18	0.13	0.03	0.00	0.00	8.03	5.28
Denmark	0.00	0.00	0.00	0.00	0.27	0.03	0.01	0.00	0.00	0.00	0.00	0.27	0.01
Estonia	0.31	0.00	0.01	0.00	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Finland	3.78	0.19	4.59	18.82	6.88	0.12	0.34	0.03	0.01	0.00	0.00	0.92	0.17
France	0.00	2.94	173.56	236.61	117.92	2.67	1.23	0.19	0.17	0.00	0.04	13.02	1.68
Germany	2.06	5.82	291.46	361.80	429.82	36.62	0.00	0.01	0.00	0.00	0.02	0.42	1.68
Greece	0.00	0.07	7.63	109.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	0.00	3.94	55.41	132.46	79.02	2.63	0.16	0.08	0.02	0.01	0.00	7.37	0.65
Ireland	0.00	0.01	9.95	20.15	6.29	0.04	0.05	0.01	0.00	0.00	0.01	0.06	0.00
Italy	0.00	1.77	18.81	29.30	160.02	2.55	0.10	0.10	0.14	0.02	0.01	19.76	2.91
Latvia	0.01	0.08	9.35	0.38	3.22	0.02	0.20	0.02	0.02	0.00	0.00	2.45	0.01
Netherlands	0.87	1.77	49.32	79.51	60.93	2.04	0.17	0.06	0.03	0.00	0.00	7.01	0.31
Poland	0.00	1.89	11.97	70.12	113.83	3.10	10.01	0.27	0.12	0.01	0.01	72.58	1.20
Portugal	0.00	0.00	0.33	1.38	319.61	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Romania	0.00	0.09	16.89	22.20	0.00	9.03	0.29	0.09	0.09	0.00	0.02	17.16	2.57
Slovakia	0.00	0.42	69.92	91.71	17.85	0.62	8.98	0.03	0.01	0.01	0.01	9.98	1.14
Slovenia	0.00	0.00	0.00	8.88	0.00	0.00	0.00	0.04	0.00	0.00	0.00	2.97	0.00
Spain	0.00	1.59	72.03	129.08	69.82	3.55	5.58	0.66	0.03	0.02	0.04	44.92	3.50
Sweden	0.14	0.05	4.98	14.07	12.62	0.10	0.12	0.01	0.03	0.00	0.00	1.11	0.24
UK	0.08	1.81	80.64	126.01	146.54	6.66	0.79	0.11	0.14	0.01	0.05	18.09	1.77
EU-27	**17.22**	**28.96**	**1,168.33**	**1,862.50**	**1,906.33**	**78.18**	**29.30**	**2.80**	**1.12**	**0.11**	**0.22**	**270.52**	**25.02**

Table 3: External costs due to losses of biodiversity in millions of Euros

Country	NH3	NMVOC	NOx	SOx
Austria	3.47	-0.06	8.45	2.80
Belgium	0.12	-0.20	19.51	5.87
Bulgaria	0.00	-0.02	2.62	0.82
Czech Rep.	0.91	-0.10	13.54	5.18
Denmark	0.00	0.00	0.00	0.00
Estonia	0.19	0.00	0.01	0.00
Finland	2.11	-0.03	3.66	3.28
France	0.00	-0.23	23.68	12.46
Germany	0.94	-1.42	48.96	25.23
Greece	0.00	0.00	0.58	0.44
Hungary	0.00	-0.38	6.30	4.91
Ireland	0.00	0.00	1.32	0.71
Italy	0.00	-0.26	3.25	0.77
Latvia	0.01	-0.01	2.30	0.01
Netherlands	0.18	-0.09	7.68	2.45
Poland	0.00	-0.21	2.22	2.32
Portugal	0.00	0.00	0.07	0.02
Romania	0.00	-0.01	0.94	0.22
Slovakia	0.00	-0.06	9.59	4.55
Slovenia	0.00	0.00	0.00	0.67
Spain	0.00	-0.12	14.41	2.96
Sweden	0.03	-0.01	2.34	2.93
UK	0.00	-0.08	12.41	4.58
EU-27	**7.96**	**-3.30**	**183.82**	**83.20**

Table 4: External costs due to damages to crops by deposition of nitrate compounds and ozone in millions of Euros

Country	NH3	NMVOC	NOx	SOx
Austria	-0.05	0.09	3.07	-0.39
Belgium	-0.01	1.50	-2.08	-0.54
Bulgaria	0.00	0.05	3.34	-0.05
Czech Rep.	-0.02	0.17	4.03	-0.56
Denmark	0.00	0.00	0.00	0.00
Estonia	0.00	0.00	0.00	0.00
Finland	0.00	0.03	0.19	-0.09
France	0.00	0.94	19.69	-1.96
Germany	-0.01	1.96	15.05	-3.09
Greece	0.00	0.01	0.88	-0.12
Hungary	0.00	0.70	3.47	-0.30
Ireland	0.00	0.00	0.72	-0.27
Italy	0.00	0.67	1.45	-0.24
Latvia	0.00	0.01	0.43	0.00
Netherlands	-0.01	0.56	-1.66	-0.26
Poland	0.00	0.48	0.53	-0.11
Portugal	0.00	0.00	0.04	-0.01
Romania	0.00	0.01	0.66	-0.02
Slovakia	0.00	0.10	4.08	-0.27
Slovenia	0.00	0.00	0.00	-0.09
Spain	0.00	0.41	9.36	-1.15
Sweden	0.00	0.01	0.32	-0.15
UK	0.00	0.86	-0.70	-1.00
EU-27	**-0.11**	**8.57**	**62.88**	**-10.68**

Table 5: Sum of external costs of metal industry in EU-27 in millions of Euros

Country	NH3	NMVOC	NOx	SOx	PM2.5	PMco	As	Cd	Cr	Hg	Ni	Pb	DIOX	total
Austria	9.58	0.79	62.84	46.97	22.54	1.08	0.00	0.02	0.00	0.00	0.00	2.10	0.23	**146.15**
Belgium	0.92	6.43	131.52	148.29	308.09	5.72	1.09	0.08	0.28	0.01	0.02	17.80	0.57	**620.81**
Bulgaria	0.00	-0.04	58.29	129.57	0.00	0.00	0.00	0.86	0.00	0.01	0.00	24.48	1.11	**214.28**
Czech Rep.	3.88	0.77	91.28	98.53	31.01	0.51	0.18	0.13	0.03	0.00	0.00	8.03	5.28	**239.64**
Denmark	0.00	0.00	0.00	0.00	0.27	0.03	0.01	0.00	0.00	0.00	0.00	0.27	0.01	**0.60**
Estonia	0.50	0.00	0.02	0.00	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.59**
Finland	5.88	0.18	8.44	22.01	6.88	0.12	0.34	0.03	0.01	0.00	0.00	0.92	0.17	**45.00**
France	0.00	3.65	216.93	247.10	117.92	2.67	1.23	0.19	0.17	0.00	0.04	13.02	1.68	**604.60**
Germany	2.99	6.36	355.47	383.94	429.82	36.62	0.00	0.01	0.00	0.00	0.02	0.42	1.68	**1,217.34**
Greece	0.00	0.08	9.10	110.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**119.29**
Hungary	0.00	4.26	65.18	137.07	79.02	2.63	0.16	0.08	0.02	0.01	0.00	7.37	0.65	**296.45**
Ireland	0.00	0.01	11.98	20.59	6.29	0.04	0.05	0.01	0.00	0.00	0.01	0.06	0.00	**39.04**
Italy	0.00	2.18	23.51	29.84	160.02	2.55	0.10	0.10	0.14	0.02	0.01	19.76	2.91	**241.14**
Latvia	0.02	0.08	12.08	0.40	3.22	0.02	0.20	0.02	0.02	0.00	0.00	2.45	0.01	**18.51**
Netherlands	1.04	2.24	55.35	81.70	60.93	2.04	0.17	0.06	0.03	0.00	0.00	7.01	0.31	**210.88**
Poland	0.00	2.15	14.72	72.33	113.83	3.10	10.01	0.27	0.12	0.01	0.01	72.58	1.20	**290.33**
Portugal	0.00	0.00	0.43	1.38	319.61	1.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**322.53**
Romania	0.00	0.09	18.49	22.40	0.00	9.03	0.29	0.09	0.09	0.00	0.02	17.16	2.57	**70.24**
Slovakia	0.00	0.45	83.58	95.98	17.85	0.62	8.98	0.03	0.01	0.01	0.01	9.98	1.14	**218.66**
Slovenia	0.00	0.00	0.00	9.47	0.00	0.00	0.00	0.04	0.00	0.00	0.00	2.97	0.00	**12.48**
Spain	0.00	1.87	95.81	130.89	69.82	3.55	5.58	0.66	0.03	0.02	0.04	44.92	3.50	**356.68**
Sweden	0.18	0.05	7.64	16.86	12.62	0.10	0.12	0.01	0.03	0.00	0.00	1.11	0.24	**38.95**
UK	0.08	2.59	92.36	129.60	146.54	6.66	0.79	0.11	0.14	0.01	0.05	18.09	1.77	**398.77**
total EU-27	**25.07**	**34.23**	**1,415.02**	**1,935.02**	**1,906.33**	**78.18**	**29.30**	**2.80**	**1.12**	**0.11**	**0.22**	**270.52**	**25.02**	**5,722.96**

Table 6: Total production values of metal industry in millions of Euros, 2005

country	*NACE 27* Manufacture of basic metals	*NACE 28* Manufacture of fabricated metal products	Total
Austria	11,141	9,617	**20,758**
Belgium	17,715	1,584	**19,299**
Bulgaria	2,128	61	**2,189**
Cyprus	55	271	**326**
Denmark	1,155	5,834	**6,989**
Estonia	16	557	**573**
Finland	849	5,476	**6,325**
France	32,417	55,979	**88,396**
Germany	78,446	97,580	**176,026**
Greece	423	3,882	**4,305**
Hungary	2,561	285	**2,846**
Ireland	523	1,592	**2,115**
Italy	4,884	86,817	**91,701**
Latvia	314	244	**558**
Lithuania	2	448	**450**
Luxembourg	2,616	694	**3,310**
Netherlands	712	15,483	**16,195**
Poland	7,335	172	**7,507**
Portugal	1,892	4,774	**6,666**
Romania	4,223	190	**4,413**
Slovakia	3,219	1,492	**4,711**
Slovenia	123	2,129	**2,252**
Spain	26,256	39,226	**65,482**
Sweden	13,123	195	**13,318**
UK	2,212	3,853	**6,065**
EU-27	**214,341**	**338,434**	**552,775**

Source: EuroStat

III. Case Study 2: External costs of the metal industry in Germany

As already stated above, the second part of this case study will be a more detailed analysis of the external costs of the metal industry in Germany. Two different approaches were applied in order to estimate the external costs of this sector. Both of these approaches are chemical transportation models that were implemented into the existing methodology of EcoSenseWeb. First, the external costs were estimated using the current EMEP model. In this relatively straight-forward approach, data on the total emissions of the metal industry were used as input into EcoSenseWeb application and the impacts for all European countries and for Germany were calculated using source-receptor matrices. Second, the external costs of the metal industry were estimated with an alternative approach to the source-receptor matrices, using the Polyphemus Model. The estimations within this approach required data on the total emissions for all sectors in all European countries in order to create a background scenario. Against this background scenario, emission data for the metal industry in Germany were subtracted and the external costs of the metal industry in Germany were calculated. The following section will describe the two approaches in more detail.

III.1 EcoSenseWeb model

III.1.1 Description of the general model

EcoSenseWeb is an integrated computer system developed for the assessment of environmental impacts and resulting external costs from electricity generation systems and other industrial activities. Based on the Impact Pathway Approach (IPA) developed in the ExternE-Project series on External Costs of Energy funded by the European Commission, EcoSenseWeb provides relevant data and models required for an integrated impact assessment related to pollutants. Modules for the assessment of emissions to air, soil and water are also included, comprising so called classical airborne pollutants, heavy metals, greenhouse gases and radio nuclides. Furthermore, different impact categories are considered including human health, crops yield loss, damage to building materials, loss of biodiversity and climate change.

One of the major objectives of the EcoSenseWeb development was to produce a user friendly system that is capable of performing a highly standardised impact assessment procedure with a minimum of data required as input from the user. Only the technical data of the facility to be analysed have to be added by the user. All other data are provided by the system. However, it is obvious that the approach of providing all important data and models to the user limits the flexibility of the system. Although the various modules of the system have a potential for high flexibility, the current EcoSenseWeb version is limited to a set of standard applications that can very easily be carried out. A basic decision during the design phase of the system with respect to an easy handling was the selection of a single co-ordinate system. The European wide grid used by the "Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe" (EMEP) with the spatial resolution of approximately 50 x 50 km2 (EMEP50 grid) was applied. The EcoSenseWeb and the calculation of external costs follow as far as possible the so called Impact Pathway Approach (IPA).[7]

The IPA starts with the emission of a pollutant at the location of the source into the environment. It models the dispersion and chemical transformation in the different environmental media. Introducing receptor and population date it identifies the exposure of the receptors and calculates the impacts. These impacts are then weighted and aggregated into external costs. According to the IPA with the aid of CRF (concentration response functions) and the number of population physical impacts are then calculated for each grid cell. Population data are taken from SEDAC 2006 - Gridded Population of the World. Finally, the impacts are weighted and aggregated by means of monetary valuation of each physical impact in order to derive external costs per unit of emission. Emission weighted European averages which can be used for evaluation of emissions located in the EU-27 are also provided. These values can be used for up- and downstream process for which the location can not be identified. Since they are emission weighted it is the best approximation if the location within Europe is not known.

Results are available for emissions in 39 European and non-European countries and 5 sea regions. Furthermore, with a Northern Hemispheric model by Tarrasón (2006) external costs due to impacts to human health outside Europe caused by emissions of classical pollutants in Europe have been estimated and, with the same model, external costs for emissions in 5 North African countries have been calculated.

[7] The link to the online tool EcoSenseWeb is http://EcoSenseWeb.ier.uni-stuttgart.de/

After registration one will find most relevant information at the page itself (i.e. background reports and User

Manual, etc) in the section "News".

III.1.2 The EMEP model

This approach describes the currently used chemical transportation model applied in EcoSenseWeb. With regard to the classical pollutants, parameterised results from an Eulerian dispersion and chemical transformation model from The Norwegian Meteorological Institute (MET.NO), see Tarrasón (2008) have been derived based on source receptor matrices (SRM). These SRM allow attributing a concentration or deposition increment in each of the 50 x 50 km^2 EMEP grid cells all over Europe to each unit of emission in one region. Europe is divided into 66 regions, i.e. some larger countries are subdivided into sub-regions.

As stated above, the parameterised results for classical pollutants have been derive based on SRM. To get these SRM, a reduction of each pollutant by 15% for each source of emission within a corresponding sub-region is modelled separately, i.e. for a 15% reduction of an airborne pollutant (e.g. NO_x) within a country / sub-region of Europe (e.g. Belgium = BE) based on meteorological conditions (e.g. in the year 2000) and background emissions of e.g., the year 2010, a model run was performed by MET.NO. The result is a matrix covering the resulting concentration of different pollutants in each of the 50 x 50 km^2 grid cell of the EMEP grid. This matrix contains the results in terms of concentrations of a primary (NO_x) or secondary (nitrates and ozone, increased sulphates, etc.) air pollutants on the grid. The chemical reactions and interactions are quite complex. For example, a reduction of NO_x emissions leaves in regions where NH_3 is in the air, e.g. due to agricultural processes, more background NH_3 for reaction with SO_2 which was already in the background emitted, and therefore, increases the concentration of sulphates at some locations, etc.

The estimations of the SRM have been done in two ways:

- for pollutants from all sources, i.e. all SNAP sectors (i.e., including transport, industry, domestic firing systems, but also combustion plants), and
- for pollutants (primary particles, SO_2 and NO_x) from for SNAP sector 1 (combustion in power plants) only.

For the calculation of site specific and marginal damages the IPA was applied for each source of emission, e.g. a coal fired power station and the corresponding emissions from the stack. Marginal damages have to be calculated because the creation of secondary pollutants like sulfates, nitrates and ozone depends also on the background concentration of NO_x, SO_2, NH_3, NMVOC, etc. Therefore, two scenarios have to be calculated, one background and one with additional, or reduced emissions. Furthermore, two set of SRM are available. One corresponds to conditions in 2010 and second corresponds to anticipated conditions in 2020. In general the emissions in 2020 are lower than in 2010. Because of non-linearity of the chemistry the creation of secondary pollutants and hence the marginal damage per unit of emission differs between the two scenarios. It has to be emphasised that because of non-linear atmospheric chemistry and because of different background concentrations of e.g. NO_x and NMVOC, especially with regard to ozone there can occur large differences in [Euro per tonne] values. Negative external costs can occur for NO_x emission in 2010 but also for a view cells in 2020 values.

For heavy metals, formaldehyde, dioxins and several radionuclide species values for impact assessment and external costs are taken from other studies. Regarding heavy metals values for the pathway inhalation are taken from OMEGA, whereas for As, Cd, Pb due to ingestion, they are newly calculated with the WATSON model. For Hg, the value is taken from Spadaro and Rabl (2007). The evaluation of greenhouses gases is a very contentious issue because the assessment of the impacts is highly uncertain. Moreover, since the impacts are spread all over the whole world and into the future, the monetary evaluation is dependent on value choices, like discounting and equity weighting. Nonetheless, with regard to impact assessment and external costs evaluation of energy technologies the recommendations have a decisive and crucial influence on the results and corresponding decisions. Therefore, different approaches based on impact assessment as well as on the standard price approach have been used to provide a reasonable range of estimates of the external costs.

Further information on the methodology, the design and the use of EcoSenseWeb is provided by Preiss and Klotz (2007), Preiss et al. (2008) and further reports to be found on the website of EcoSenseWeb.

III.1.3 The Polyphemus Model

This approach describes an alternative to chemical transportation model discussed in the section above. The modelling here relies on the direct use of an Eulerian formulation instead of a parameterized model derived from such a formulation. The Eulerian model applied for the case study is mainly relying on the following modules:

- An Eulerian transport framework which has been applied for different situations (Mallet 2007)

- The RACM chemistry mechanism to represent gaseous chemistry (Stockwell 1997), slightly upgraded to manage aerosol interactions.
- The SIREAM aerosol model to represent aerosol phase processes (Debry 2007)
- An aqueous phase module (Tombette 2007) to represent chemical processes in cloud droplets.

Some interfaces have been developed to allow the use of Polyphemus results within the EcoSenseWeb model.

III.2 Estimation of external costs using the EMEP model

III.2.1 Background information and data sources

Data on the total emissions of the metal industry in Germany were estimated by a spatial distribution of the emissions data provided by the Federal Environment Agency. The main goal of spatial distribution is to dissolve national emission values on a desired grid. Therefore, the source-specific emissions are allocated across the grid using certain indicators. The grid used within this case study corresponds to the 50 x 50 km^2 resolution of the EMEP grid. In order to get the share of the emissions for each grid cell, intersections of the EMEP grid cells with the grid cells of the national administrative units need to be established. The necessity of these intersections results from the fact that the distribution parameters are mostly only available on administrative units. These parameters are socio-economic data which are taken as indicators for the emission activity, e.g. number of employees discerned by industrial sectors, number of animals discerned by species, land use discerned by ways of use, etc. This is done using geographical information systems (GIS).

Figure 1 displays the procedure of distributing the emissions. This distribution was accomplished using a gridding tool, a tool which was developed in order to fulfil the reporting obligations of the Federal Environment Agency to EMEP. The Agency provides a database system to keep track of emission data to meet the divers' obligations of reporting. Thus, this central system of emissions (ZSE) presents the source of emission data. An intersection that has only been developed for this case has been applied, enabling the extraction of the emission data from ZSE and the further work with the gridding tool. The further work with the distribution parameters was accomplished with SuDa, an access database application like the gridding tool. SuDa is applied to keep and process the distribution parameters. All these proceedings are shown in Figure 1.

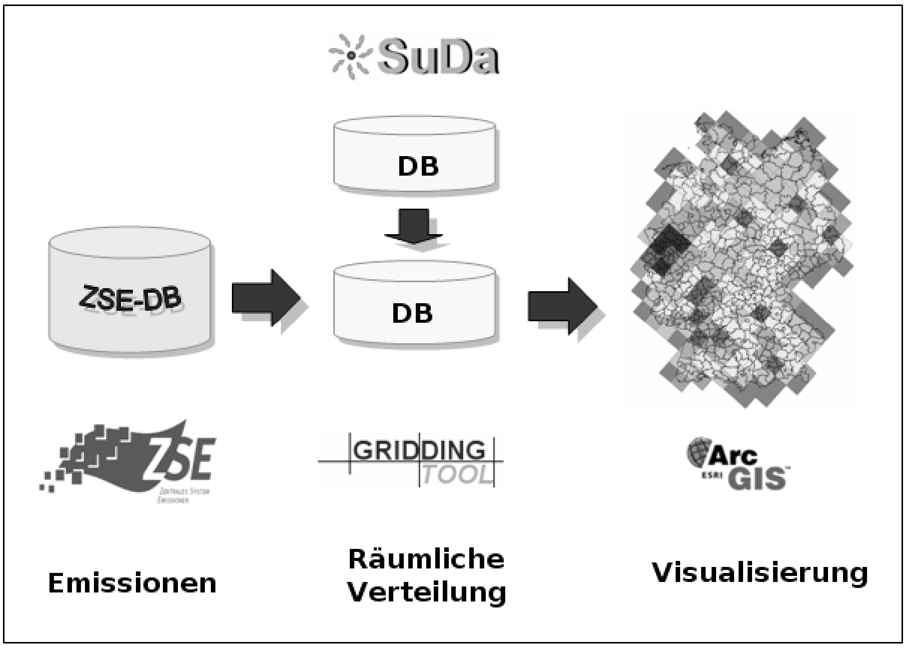


Figure 1: Proceedings of extraction emission data from databases

The most important data sources for socio-economic indicators are:

- Regionalstatistik (2007)
- Yearbook of the European energy and resource economy (see Glückauf (1993-2005))
- Statistical Yearbook of the Federal Statistical Office (see Destatis (1991-2005))
- Straßenverkehrszählung; Jahresfahrleistung und mittlere DTV-Werte covering data on traffic (see BVZ (2000))
- Raffenerielesitung (see MWV (2005))

The spatial distribution of the metal industry was achieved using emission data from ZSE and employment data from Regionalstatistik (2007). Therefore, the emissions were resolved into administrative units, i.e. districts, using the employment data for the metal industry. These emissions on district level were used as the basis for the distribution in the EMEP grid. Relevant indicators for the metal industry are the employment data for the sub-sectors iron processing industry, foundries, non-ferrous metal processing and non-ferrous metal tools production. Figure 2 presents an example for the spatial distribution of the emissions of lead from all sources.

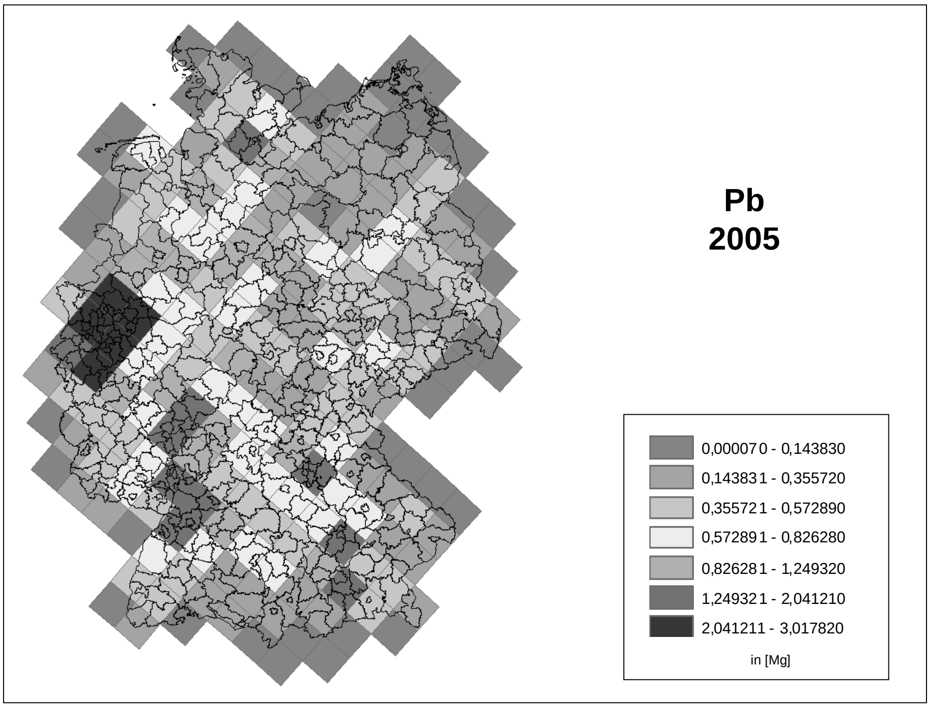


Figure 2: Spatial resolution of emissions of lead from all sources

As the data described above cover the 50 x 50 km² grid cell of the EMEP grid it had to be adjusted to the corresponding sub-regions within EcoSenseWeb. This was possible as the sub-regions cover a well-defined size and geographical region. Thus, each sub-region can be identified by a certain number of different EMEP grid cells. The emission data for the EMEP grid cells that could be assigned to one of the four sub-regions of Germany were aggregated in order to get the total emissions for these sub-regions. In cases where two sub-regions of Germany are sharing the same EMEP cell, the given emissions were distributed evenly between the sub-regions to get an approximation of the emissions.

Figure 3 shows the map of Germany with its four sub-regions as they are used within the EcoSenseWeb model. As can be seen in the figure, the sub-regions do not have the same size and thus do not cover the same amount of cells. The squares within the map represent the 50 x 50 km² grid cells of the EMEP grid. Additionally, Figure 4 displays the distribution of metal processing companies across Germany. The map was provided by EPER Germany. A triangle on this map of Germany identifies the location of a metal processing company. Finally, Figure 5 shows the density of the German population in 2000. This map was provided by SEDAC - Gridded Population of the World.[8]

[8] For more information please visit http://sedac.ciesin.columbia.edu/gpw/index.jsp

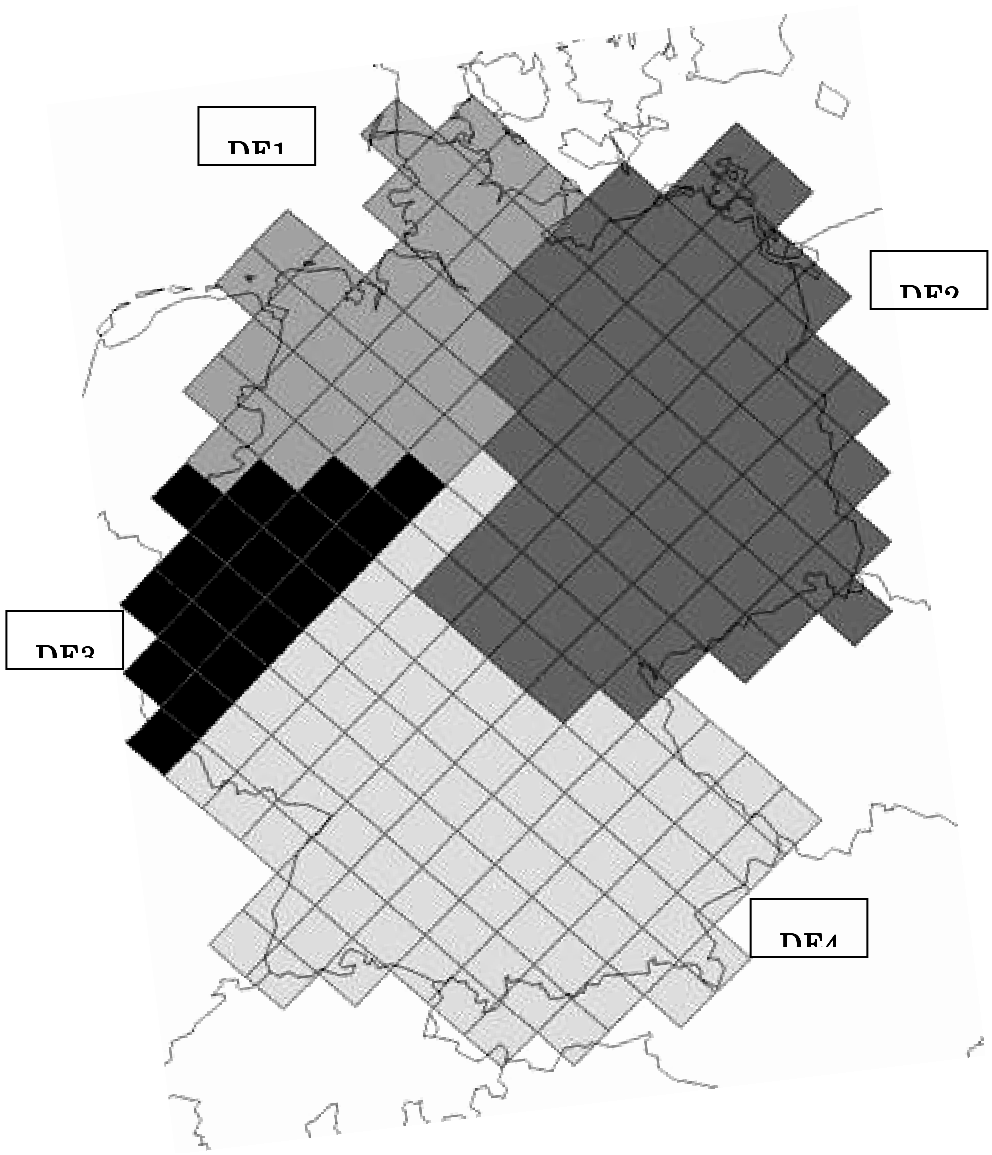
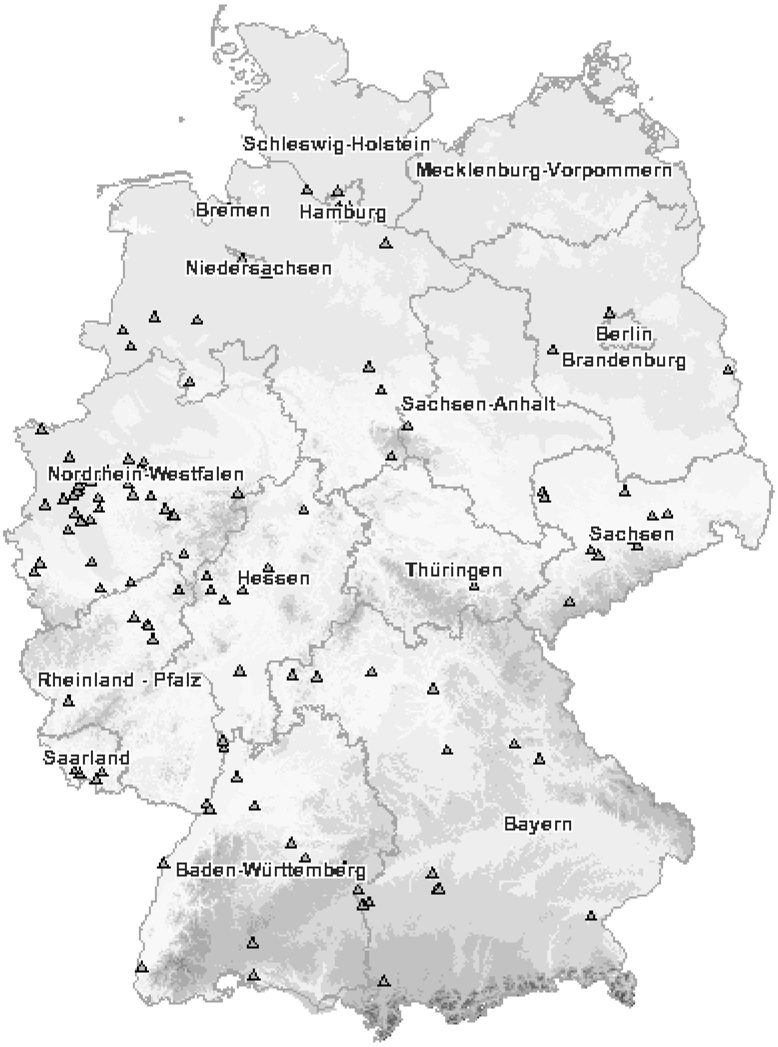


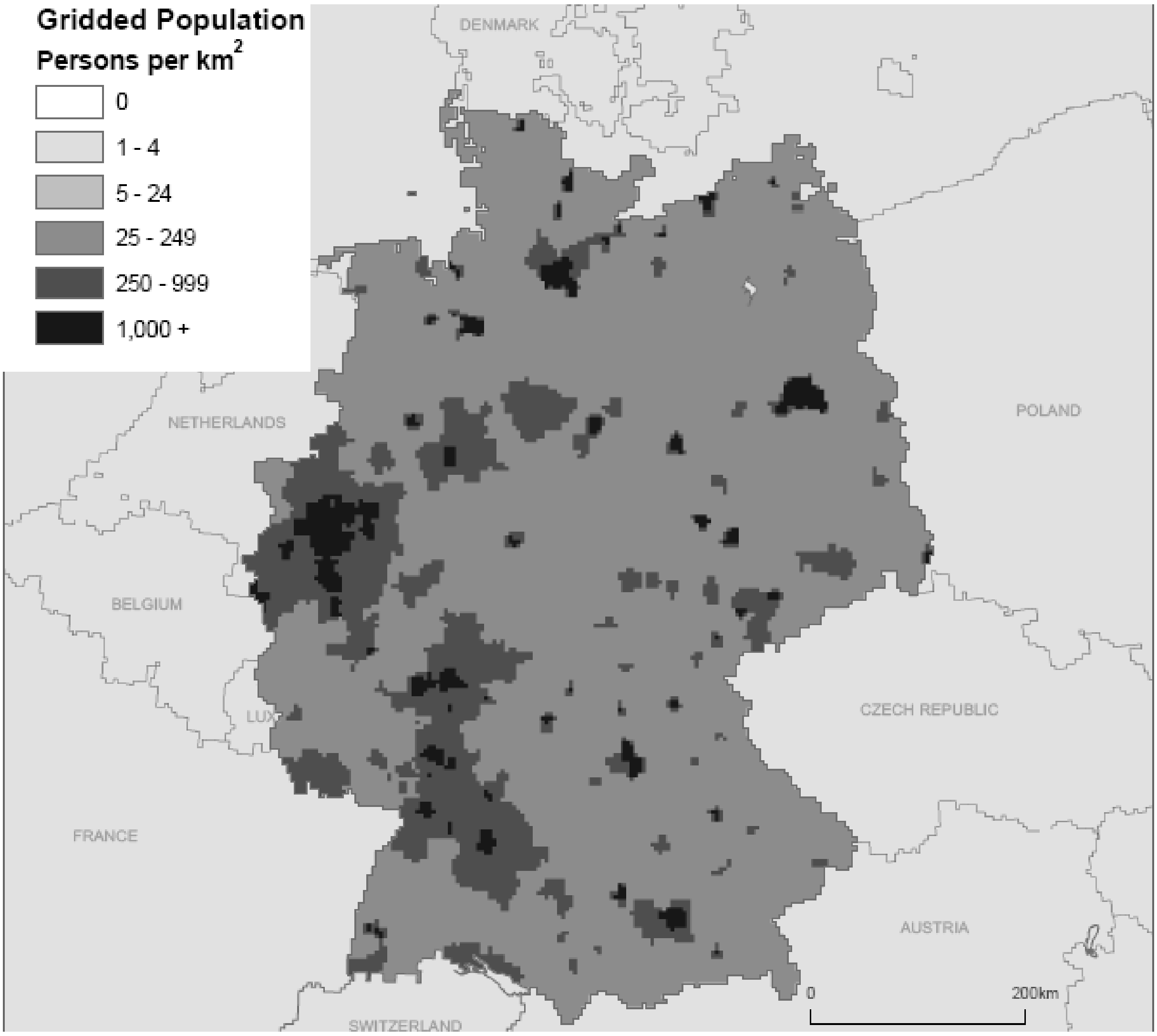
Figure 3: Map of Germany with EMEP grid and sub-regions

Furthermore, the map shows that some of the grid cells cover parts of neighbouring countries. However, as the meteorological data and the source-receptor matrices are given only for the 66 sub-regions, there is no problem arising when one sub-region is covering other countries alongside Germany as the resulting external costs are the same for the whole sub-region. Furthermore, it is possible to extract the external costs affecting only Germany from the results delivered by EcoSenseWeb.



Source: EPER Germany

Figure 4: Distribution of metal processing companies in Germany, 2004



Source: SEDAC - Gridded Population of the World

Figure 5: Population density of Germany, 2000

III.2.2 Total emissions of German metal industry

The total emissions of the metal industry in Germany can be seen in Table 7. The emissions in this table are given in an aggregated form for Germany and for the four sub-regions Germany is divided into by the methodology used in EcoSenseWeb. It is shown that the sub-region DE3 – despite being the smallest of the four sub-regions – is responsible for the majority of the emissions of the metal industry in Germany. An explanation for this is delivered by the two maps above. Figure 3 shows that the sub-region DE3 covers the west of Germany, including the Ruhr are which is – as Figure 4 shows – the area where most of the German metal processing companies are located and also – as Figure 5 shows – the region with the highest population density compared to the other sub-regions.

Table 7: Total emissions of metal industry for Germany and sub-regions, 2005

Pollutant	NO_x (as NO_2)	NMVOC	SO_x (as SO_2)	NH_3	PM_{10}	$PM_{2.5}$	Pb	Cd	Hg	Cu	Ni	Zn	DIOX
Unit	*Gg*	*Gg*	*Gg*	*Gg*	*Gg*	*Gg*	*Mg*	*Mg*	*Mg*	*Mg*	*Mg*	*Mg*	*g I-Teq*
DE1	3.736	0.980	5.287	0.018	3.427	1.297	0.167	0.012	0.000142	0.292	0.765	1.099	5.640
DE2	3.657	0.947	5.196	0.013	3.373	1.270	0.166	0.012	0.000141	0.291	0.763	1.095	5.552
DE3	17.591	4.567	23.295	0.057	16.031	5.863	0.547	0.040	0.000465	0.957	2.509	3.603	25.738
DE4	6.958	1.899	11.298	0.066	6.438	2.641	0.528	0.038	0.000449	0.924	2.421	3.477	11.195
Germany total	**31.942**	**8.393**	**45.077**	**0.154**	**29.269**	**11.071**	**1.408**	**0.102**	**0.001197**	**2.464**	**6.458**	**9.274**	**48.125**

III.2.3 Estimations and Results

The following presentation of the results of the calculations with EcoSenseWeb is divided into two parts. First, the results for 'all countries' will be shown, i.e. all external costs were estimated including those that arise in other countries than Germany. Second, the external costs that occur only in Germany will be regarded separately. Thus, the share of external costs that affect only Germany compared to the overall external costs affecting all countries can be estimated.

a) All countries

In order to calculate the total external costs for the metal industry in Germany, the external costs were calculated for each of the four sub-sectors Germany is divided into by the model of EcoSenseWeb. Thus as shown above, the emission data were adjusted from the approximately 50 x 50 km^2 grid cell of the EMEP grid to the corresponding sub-regions within EcoSenseWeb. In a second step, these external costs were aggregated to receive the total external costs for the German metal industry.

The estimations of the external costs of the metal industry in Germany were accomplished for six of the classical airborne pollutants (NO_x, SO_x, NMVOC, NH_3, PM_{10} and $PM_{2.5}$), four heavy metals (Cadmium, Nickel, Lead and Mercury) and Dioxins. Data for other than these substances were either not provided by the ZSE or can not yet be processed by the current methodology of EcoSenseWeb. The results of the calculations with EcoSenseWeb are summarised in the following tables.

Before presenting the external costs, the methodology of EcoSenseWeb allows for an analysis of the endpoints of the impacts on human health. Table 8 shows the most important damages to human health measured in the number of cases that occur. Furthermore, a differentiation of the cause of the impacts is made by differing between PM_{10} and SIA_{10} for cases of infant mortality or $PM_{2.5}$ and $SIA_{2.5}$ for 'chronic' YOLLs which can be compared to DALYs. 'Acut' YOLLs only result from emission of ozone. These endpoints are then valued in monetary terms to receive the external costs. As can be seen from the table, the effects on human health are highest for DE3.

Table 8: Number of cases of endpoints for damages to human health

health end point sub-region	Infant Mortality PM_{10}	Infant Mortality SIA_{10}	'chronic' YOLL $PM_{2.5}$	'chronic' YOLL $SIA_{2.5}$	'Acut' YOLL SOMO35
DE1	0.08	0.11	482.50	981.70	2.37

DE2	0.10	0.12	555.90	1,047.00	0.48
DE3	0.99	0.69	5,123.00	6,053.00	-5.30
DE4	0.25	0.34	1,675.00	3,028.00	4.54
Germany total	**1.41**	**1.25**	**7,836.40**	**11,109.70**	**2.09**

Table 9 presents the total external costs of the metal industry in Germany divided into the four sub-regions. As can be seen, the total values for the 'regional scale' and the 'regional + hemispherical scale' respectively differ strongly across sub-regions. Data in both cases represent the sum of damages to materials, damages on crops and damages on human health. Analogous to the amount of emissions, these differences can also be explained by the geographical coverage of the sub-region and – more important – by the different size of the covered population within the sub-region. As can be seen from the maps above, the sub-region of DE3 covers the west of Germany, including the Ruhr area where most of the mining and metal processing is to be found and where the population density is higher than in the other sub-regions of Germany and therefore, the highest amount of external costs is generated. It can also be observed that in all of the four sub-regions more than 95% of the external costs in the regional scale result from damages to human health.

In Table 10 the estimated external costs for the four sub-regions of Germany have been aggregated to get the total external costs of the activities in the metal industry in Germany. The table shows that the external costs for 2004 sum up to more than €1.2 billion for all European countries. The greatest share of this amount can be assigned to external costs resulting from the emission of particulate matter, SO_x and NO_x. Here again, damages to human health form the greatest share of the overall external costs.

The difference in the results for Germany compared to those estimated in section II.1 follows from a difference in the emission data. The data provided by the EMEP WebDab and those provided by the ZSE differ from each other. They do not differ strongly – as can be seen in Table 1 and Table 7 but these differences might be enough to explain the resulting gap.

b) Germany

The results provided by EcoSenseWeb allow for a more detailed analysis of the estimated external costs. The results for the 'regional scale' were not only provided in aggregated form for all countries, but can also be examined for each of the included countries separately. Thus, the external costs of the metal industry in Germany that only occur within the German borders can be extracted and analysed. Unfortunately, while this is also possible for the damages to biodiversity, expressed by external costs of eutrophication and acidification, it is not possible for the external costs caused by micro-pollutants such as heavy metals and dioxins. Therefore, the analysis of the external costs within Germany will only focus on the classical air pollutants.

Analogous to the procedure for the external costs occurring in all countries of Europe, the external costs of the German metal industry that only arise within Germany will first be presented for the four sub-regions before the total amount of external costs will be shown. Table 11 describes the external costs within the four sub-regions of Germany. As above, the highest value of external costs generated by the metal industry can be found for the west of Germany. The share of damages caused by all pollutants within the German borders compared the overall damages lies between 45% for sub-region DE1 and 65% for sub-region DE3. These shares can again be explained by the different numbers of the affected population of Germany in the respective sub-regions as can be seen in Figure 5.

The aggregated external costs for Germany of the German metal industry are presented in Table 12. This sum of the external costs of the four sub-regions reflects a share of 60% of the external costs that affect all European countries. While this means that most of the damages occur in Germany, about 40% of the external costs arise in other European countries. These countries do not directly benefit from the production processes of the German metal industry – e.g. employment and wages, profits of companies, taxes, etc. – but they are directly affected by the emissions of the German metal industry and the consequential impacts on human health and biodiversity.

The external costs divided by country are presented in Table 13. As can be seen, the Netherlands show the highest value for external costs, followed by France, Poland and Belgium. Aside from Poland, this result is not surprising as the external costs of sub-region DE3 clearly exceed those of the other regions. As the maps in Figure 3 to Figure 5 show, this region borders with Belgium and the Netherlands and has a short distance to France. The sub-region includes the Ruhr area with the highest density of both metal processing companies and population. The damages to human health, materials and crops measured in Euros for these countries can also be extracted from the results calculated by EcoSenseWeb. For Poland, the border with sub-region DE2 with some metal industry companies in 'Sachsen' (Saxony) – see Figure 4 – has a major influence on the resulting numbers.

The damages sum up to more than €75 million in the Netherlands and exceed €60 million in France, €50 million in Poland and €40 million in Belgium. The table also provides data for countries outside the EU-27, summarised as 'other countries'. A detailed picture of the external costs in these countries that among others include Russia, Switzerland and Norway, can be found in the Appendix (Table A5). The difference in the overall sum shown in Table 13 and Table 10 results from the fact that damages due to acidification and eutrofication as well as damages caused by micro-pollutants are not included in the calculations for the tables. However, the results presented in Table 13 provide a useful overview of the external costs occurring in other countries than in Germany.

Table 9: All countries: External costs in million of Euros of the metal industry in Germany, by sub-regions

DE1	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM	Cd	Hg	Ni	Pb	Dioxins
Reg/Hemis. Scale	97.90	39.22	25.94	1.11	0.23	28.93	31.40					
Regional Scale	95.38	37.75	25.46	0.76	0.23	28.73	31.19					
of which: human health	91.33	35.92	23.43	0.56	0.23	28.73	31.19					
Acidification / Eutrophication	7.40	2.55	4.97	-0.21	0.09							
Non-classical pollutants	0.31							0.001	0.001	0.003	0.100	0.21
Total regional scale	**103.09**	**40.30**	**30.42**	**0.55**	**0.32**	**28.73**	**31.19**	**0.001**	**0.001**	**0.003**	**0.100**	**0.21**

DE2	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM	Cd	Hg	Ni	Pb	Dioxins
Reg/Hemis. Scale	105.35	39.84	27.55	1.33	0.12	33.31	36.52					
Regional Scale	102.89	38.39	27.07	0.99	0.12	33.11	36.32					
of which: human health	99.54	36.60	25.80	0.71	0.12	33.11	36.32					
Acidification / Eutrophication	5.96	2.20	3.87	-0.16	0.04							
Non-classical pollutants	0.31							0.001	0.001	0.003	0.100	0.21
Total regional scale	**109.16**	**40.60**	**30.94**	**0.83**	**0.16**	**33.11**	**36.32**	**0.001**	**0.001**	**0.003**	**0.100**	**0.21**

DE3	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM	Cd	Hg	Ni	Pb	Dioxins
Reg/Hemis. Scale	731.93	223.29	153.44	8.74	1.14	306.03	345.35					
Regional Scale	720.56	216.81	151.14	7.11	1.14	305.10	344.40					
of which: human health	707.10	208.80	147.50	5.28	1.14	305.10	344.40					
Acidification / Eutrophication	36.15	12.41	24.25	-0.83	0.32							
Non-classical pollutants	1.30							0.002	0.004	0.010	0.328	0.95
Total regional scale	**758.01**	**229.21**	**175.38**	**6.28**	**1.46**	**305.10**	**344.40**	**0.002**	**0.004**	**0.010**	**0.328**	**0.95**

DE4	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM	Cd	Hg	Ni	Pb	Dioxins
Reg/Hemis. Scale	304.77	109.19	85.21	2.77	0.93	100.19	106.63					
Regional Scale	299.61	106.05	84.30	2.09	0.93	99.77	106.20					
of which: human health	290.30	102.80	78.72	1.60	0.93	99.77	106.20					
Acidification / Eutrophication	20.91	8.10	12.68	-0.43	0.56							
Non-classical pollutants	0.75							0.002	0.004	0.010	0.317	0.41
Total regional scale	**321.27**	**114.15**	**96.98**	**1.67**	**1.48**	**99.77**	**106.20**	**0.002**	**0.004**	**0.010**	**0.317**	**0.41**

Table 10: All countries: Total external costs in million of Euros of the metal industry in Germany

Germany total	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM	Cd	Hg	Ni	Pb	Dioxins
Reg/Hemis. Scale	1,239.95	411.54	292.15	13.95	2.41	468.46	519.89					
Regional Scale	1,218.44	399.00	287.96	10.95	2.41	466.71	518.11					
of which: human health	1,188.27	384.12	275.45	8.15	2.42	466.71	518.11					
Acidification / Eutrophication	70.43	25.27	45.76	-1.62	1.02							
Non-classical pollutants	2.66							0.004	0.010	0.026	0.845	1.78
Total regional scale	**1,291.53**	**424.26**	**333.73**	**9.33**	**3.43**	**466.71**	**518.11**	**0.004**	**0.010**	**0.026**	**0.845**	**1.78**

Table 11: Germany: External costs in million of Euros of the metal industry in Germany, by sub-regions

DE1	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM
Regional Scale	43.58	13.23	9.75	0.17	0.11	18.19	20.33
of which: human health	42.99	13.25	9.18	0.12	0.11	18.19	20.33
Acidification / Eutrophication	2.97	0.01	1.82	-0.01	0.06		
Total regional scale	**46.54**	**13.24**	**11.56**	**0.16**	**0.17**	**18.19**	**20.33**

DE2	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM
Regional Scale	54.54	17.78	11.10	0.27	0.06	22.57	25.32
of which: human health	54.20	17.8	10.8	0.21	0.06	22.57	25.32
Acidification / Eutrophication	2.51	1.06	1.49	-0.07	0.00		
Total regional scale	**57.06**	**18.84**	**12.59**	**0.20**	**0.06**	**22.57**	**25.32**

DE3	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM
Regional Scale	473.05	131.76	71.67	2.78	0.80	231.80	266.10
of which: human health	472.30	131.80	71.25	2.42	0.80	231.80	266.10
Acidification / Eutrophication	20.94	8.59	12.49	-0.39	0.25		
Total regional scale	**493.99**	**140.35**	**84.17**	**2.39**	**1.05**	**231.80**	**266.10**

DE4	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM
Regional Scale	242.74	100.66	45.95	2.78	0.80	83.57	92.52
of which: human health	242.20	100.70	45.74	2.42	0.80	83.57	92.52
Acidification / Eutrophication	18.78	7.72	11.20	-0.39	0.25		

Total regional scale	**261.52**	**108.38**	**57.15**	**2.39**	**1.05**	**83.57**	**92.52**

Table 12: Germany: Total external costs in million of Euros of the metal industry in Germany

Germany total	all pollutants	SO_X	NO_X	NMVOC	NH_3	$PM_{2.5}$	PM
Regional Scale	744.74	217.71	133.82	3.83	1.51	343.16	387.97
of which: human health	741.79	217.88	131.26	3.27	1.51	343.16	387.97
Acidification Eutrophication	37.91	14.82	21.95	-0.70	0.71		
Total regional scale	**782.64**	**232.53**	**155.77**	**3.13**	**2.22**	**343.16**	**387.97**

Table 13: External costs divided by country, EcoSenseWeb

Country	Euros
Germany	744.74
Netherlands	75.67
France	62.12
Poland	52.64
Belgium	41.29
United Kingdom	29.14
Czech Republic	27.15
Italy	26.51
Austria	15.77
Hungary	9.46
Denmark	9.05
Romania	8.70
Sweden	5.52
Slovakia	5.35
Spain	3.34
Slovenia	2.87
Bulgaria	2.00
Luxembourg	1.88
Greece	1.69
Lithuania	1.67
Finland	0.94
Latvia	0.88
Ireland	0.70
Portugal	0.45
Estonia	0.36
Malta	0.05
Cyprus	0.04
EU-27	**1,129.98**
other countries	67.56

III.3 Estimation of external costs using the Polyphemus model

III.3.1 Background information and data sources

As this scenario required more complex calculations, the general approach will be discussed in the following before the estimations will be shown in detail. The first necessary step to examine the external costs of the metal industry was to create a base scenario covering all economic sectors for all European countries. In order to get these results data were taken from EMEP. As already summarised in section I.1.1, the database of EMEP covers about 50 countries and includes 40 different pollutants. Furthermore, the database allows for an analysis of the emission by economic activity. With this large amount of data, the creation of a base scenario including all sectors and all countries for this case study was enabled and a first simulation for the background concentration of the regarded pollutants of Polyphemus was conducted.

The simulations have been performed with data for the year 2005. The domain which has been considered extends in space from 12.5°W to 29.5°E in longitude and from 35.0°N to 72°N in latitude. A constant grid resolution of 0.5° has been taken along longitude and latitude. Five vertical levels, defined in a z-coordinate system, cover the lower troposphere from the ground to 3000m. The data used for this simulation are:

- Meteorological data from the ECMWF, with a horizontal resolution of 0.36° x 0.36° and a time resolution of three hours.
- Emissions data from EMEP for all sectors (SNAP classification) for all countries except Germany. For Germany, to ensure a full agreement between the background simulation and the scenario simulation, emissions data from the ZSE have been used. The emissions are vertically and temporally distributed (Sartelet 2007).
- The boundary conditions (in space and time) are derived from results of the Climate-Chemistry Model LMDz-INCA[9]
- For land use coverage the USGS (United States Geological Survey) land cover map (24 categories) is used.
- Photolysis rates are computed off-line with the FAST-J photolysis algorithm (Barnard 2004)

The second simulation uses the same data set except for the emissions. In this case the emissions of the metal industry sector are not included. Both simulations provide concentration and deposition fields with an hourly frequency. The results are post processed to fit in an EcoSenseWeb compliant format.

III.3.2 Results and comparison to EMEP model

In order to get an estimation of the external costs of the metal industry in Germany, the emission data from this sector were analysed separately. As this data were also

[9] For further information see, http://web.lmd.jussieu.fr/~hourdin/AMMA/MODELS/lmdz-inca.pdf and http://www-lsceinca.cea.fr/talks_posters/readme_inca_aerosol.pdf

taken out of the database provided by EMEP, it covers the same pollutants and distributes them on the same 50km x 50 km grid as the data that were used in the first simulation mentioned above. In order to examine the total external costs resulting from the production processes within the metal industry of Germany, the total emissions from that sector were subtracted from the 'all-sector-all-countries' case. The external costs for this second scenario were calculated and compared with the results of the 'all-sectors-all-countries' scenario. The difference between the two results can be assigned to the activities within the metal industry in Germany.

This complete elimination of the emissions of one sector might not be regarded as a marginal change, but compared to the overall emissions in Germany, emissions of the metal industry only make up for about 7%. While this is not necessarily a definition of marginality, it shows that an elimination of the metal industry would only have a minor influence on the total emissions in Germany. Table 14 presents the comparison of emissions of the metal industry to those for all sectors in Germany for NO_x, SO_x and $PM_{2.5}$. These pollutants are responsible for almost 95% of the external costs estimated with the EMEP model in III.2.3.2.

Table 14: Share of emissions from metal industry in overall emissions for Germany

Pollutant	Metal industry	all sectors	share
NO_x	31.94	1,446.65	**2.21%**
SO_x	45.08	573.51	**7.86%**
$PM_{2.5}$	11.07	114.85	**9.64%**

As a result, the external costs of the activities within the metal industry in Germany were estimated and allow for future comparisons with the external costs of other important sectors and for cross-country comparisons of respective sectors.

As already stated above, the methodology of Polyphemus enabled a calculation of the external costs of the German metal industry as a whole and had not to be done for the sub-regions of Germany first. Furthermore, the estimations were only enforced for all pollutants at the same time. Thus, it is not possible to extract the share that a single pollutant contributes to the total external costs.

The results of the calculations with the model of Polyphemus are summarised in the following table. As for the results presented for the estimations with the EMEP model, the results are divided into two parts. First, the external costs for the observation of all countries covered by the methodology are shown. In this case, the external costs sum up to more than €1.1 billion, with damages to human health representing clearly the major source of the external costs. Comparing these numbers to the total external costs estimated in the sections above there is a difference of €126 million, which can be assigned to the different – and more precise – model of Polyphemus.

The second have of the table displays the external costs that only occur inside the borders of Germany. This means that external costs of about €840 million only arise due to damages to the health of the German population and due to acidification and eutrophication. Analogous to the results for all countries, there is a difference to the estimated external costs with the EMEP approach. However, while this difference for the first case resulted from a higher value of external costs from the EMEP model, now the opposite is the case. The external costs within Germany are higher for the estimations with Polyphemus, by almost €62 million. Again, the more precise model of Polyphemus led to this difference.

Table 15: Total external costs in millions of euros estimated with Polyphemus

All countries	**all pollutants**
Damages to human health	1,129.0
Acidification Eutrophication	36.2
Total regional scale	**1,165.2**

Germany	**all pollutants**
Damages to human health	823.4
Acidification Eutrophication	20.9
Total regional scale	**844.3**

As for the calculations based on the EMEP model, it is possible to divide the resulting external costs by country they occur. This will allow for an insight at the damages the activities (metal industry) within one country (Germany) cause in other countries.

Once again, it can be seen that the highest external costs outside Germany occur in the Netherlands, France, Poland and Belgium. As for the results shown in the sections above, the reason for the high level of external costs in these countries is the common border with a sub-region of Germany were there is a certain amount of metal industry to be found, namely the Ruhr area in the west and the industrial activities in Saxony in the east.

The numbers given by Polyphemus again differ from those estimated by applying the EMEP model. For Germany the external cost values are higher, while for the other countries those numbers are lower than those summarised in Table 13. This is once more a result of the more precise methodology applied in Polyphemus.

Table 16: External costs divided by country, Polyphemus

Country	Euros
Germany	824.15
Netherlands	68.87
France	58.89
Poland	34.76
Belgium	31.26
United Kingdom	20.27
Czech Republic	15.65
Italy	13.43
Austria	7.73
Denmark	5.14
Hungary	5.07
Romania	4.69
Spain	3.68
Sweden	3.08
Slovakia	3.06
Luxembourg	2.66
Slovenia	1.18
Lithuania	1.06
Bulgaria	0.75
Greece	0.64
Latvia	0.43
Finland	0.34
Ireland	0.33

Portugal	0.32
Estonia	0.12
Malta	0.02
Cyprus	0.00
EU-27	**1,107.59**
other countries	23.79

III.4 Comparison of composition of results

III.4.1 External cost values

The results of the two approaches have already been compared in the last section. It has been shown that there are differences in the total external costs estimated with the two chemical transportation models. These differences were mostly assigned to the higher level of preciseness of the methodology provided by Polyphemus. On the other hand, the differences also result from a slight difference in the emission data used for the estimations. In order to get a more detailed understanding were the differences occur an analysis of the external costs resulting from damages to human health will be regarded. These costs form the largest share of the total external costs for both approaches.

In the following figure, the external costs of damages to human health are divided into different categories according to the classification and the aerodynamic diameter of pollutants. These categories correspond to primary particulate matter of less than 10 µm in aerodynamic diameter (PPM_{10}), primary particulate matter of less than 2.5 µm ($PPM_{2.5}$), secondary inorganic aerosols of both classes of aerodynamic diameter (SIA_{10} and $SIA_{2.5}$) as well as Ozone (SOMO35).

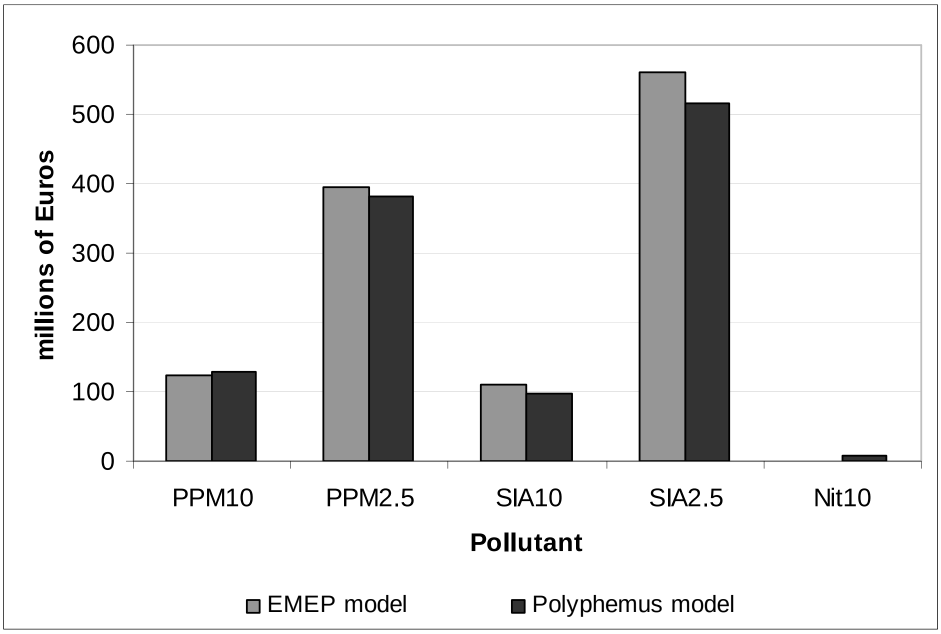


Figure 6: Detailed analysis of external costs due to damages to human health

As can be seen from the figure, the external costs estimated by the EMEP model are higher than those estimated by Polyphemus in three out of the five categories. While for PPM_{10} the costs given by Polyphemus are slightly higher, for SOMO35 they are clearly exceeding those of EMEP. Here, the value calculated for SOMO35 is about €0.8 million – a value too small to be presented in the figure. Generally speaking, the differences can easily be seen in Figure 6 but the amount of the deviation is less than €60 million, which is about 5% of both of the totals estimated in the sections above (see Tables 10 and 14). Thus, the other half of the €126 million estimated in section III.3.2 results from differences in the external costs of acidification and eutrofication and micro-pollutants. Unfortunately, these categories can not be analysed in further detail.

Another interesting observation can be made when comparing two different approaches within the EMEP model. While the estimations so far have been based on the SIA_E_PPM approach, meaning that the toxicity of primary and secondary particles is assumed to be equal, there is another approach – SIA_D_PPM – assuming different levels of toxicity of both groups of particles. The results of both approaches are presented in Figure 7. For SIA_D_PPM, there is no direct calculation for secondary inorganic aerosols, but the external costs of nitrates and sulfates are calculated separately. As the monetary values underlying these calculations are lower than those applied in SIA_E_PPM, the monetary values for primary particulate matter have to be higher in order to get the results that correspond to each other. Thus, the bars for PPM_{10} and

$PPM_{2.5}$ are higher for the SIA_D_PPM approach. The overall results of the two approaches are about €1.2 billion for SIA_E_PPM and about €1.1 billion for SIA_D_PPM. The values for SOMO35 do not appear in the figure, as their sum of about €0.8 million is too little compared to the other values.

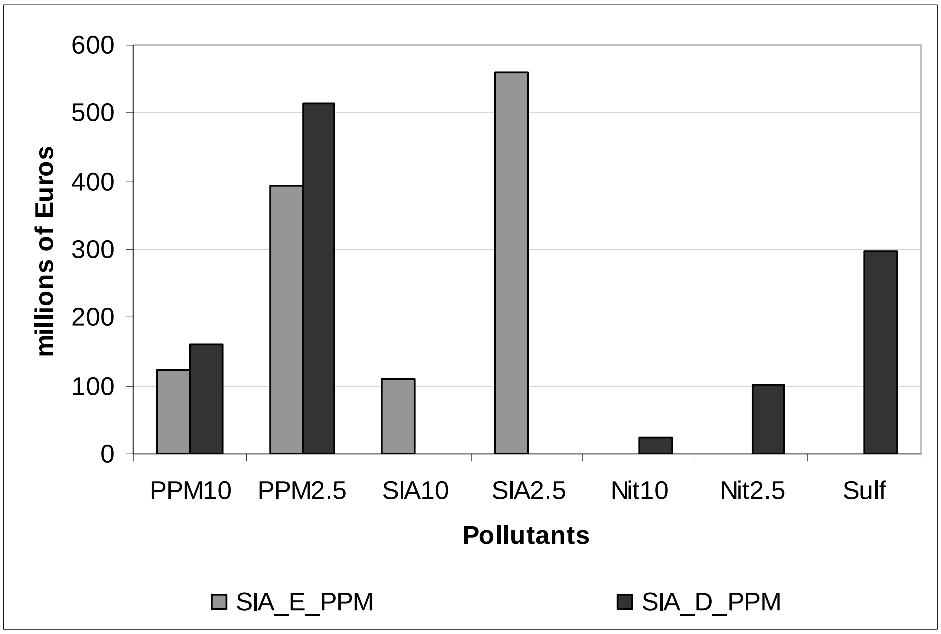


Figure 7: Comparison of two approaches of the EMEP model

III.4.2 Changes in air quality

In the following figures, changes in the air quality are shown by presenting the changes in concentrations of $PM_{2.5}$, SOMO35 and secondary inorganic aerosols (SIA). As these changes in the concentrations result from the complete elimination of all emissions from the metal industry, i.e. the complete elimination of all activities of that sector, a higher level of change in the concentration means a higher level of improvement of the quality of the air and vice versa. Thus, these figures provide information on how much the air quality changes compared to the scenario including the metal industry, showing how much the quality of the air is influenced by the emissions of the metal industry.

Furthermore, a comparison of the results of the two approaches used for the calculations with EcoSenseWeb, EMEP and Polyphemus, is accomplished. From the figures it can be seen that the results of Polyphemus provide a more precise picture of the changes in the concentration of $PM_{2.5}$, SOMO35 and SIA. The concentration changes of $PM_{2.5}$ for EMEP – as shown in Figure 8 – are more or less evenly distributed within Germany and also within its neighbouring countries, showing the highest improvements of the air quality in western Germany, where the metal industry is most active in Germany as shown in the sections above. Thus, the results shown here can be interpreted as straight forward: The influence of the metal industry on the quality of the air regarding $PM_{2.5}$ is highest in the region where the metal industry is present the most. The region with most of the activities of that sector benefits the most of an elimination of that sector regarding the quality of the air.

While the overall results from Polyphemus are very similar to those described above, Figure 9 shows a clearly higher level of concentration changes in western Germany compared to the rest of the country. This is an outcome of the different and more precise chemical transportation model applied in this approach as it is described in section III.1.3.

The same principle works for Figures 10 and 11 showing the chances in concentrations for secondary inorganic aerosols. Here again, the results given by the Polyphemus model provide a more detailed picture of the different changes in the quality of the air.

The analysis of the changes in the concentration of ozone (Figures 12 and 13) is represented by SOMO35, the sum of means over 35 ppb (parts per billion at daily maximum 8-hour). However, the results are different from those presented above. As can be seen, the area where most of the emissions have been reduced by the elimination of the metal industry shows a strong increase in the concentration of SOMO35 while in the areas where fewer emissions have been reduced the concentration of SOMO35 decreases. The latter effect is especially strong at the 'borders' to those areas with an increase in SOMO35 and diminishes with the distance to this area.

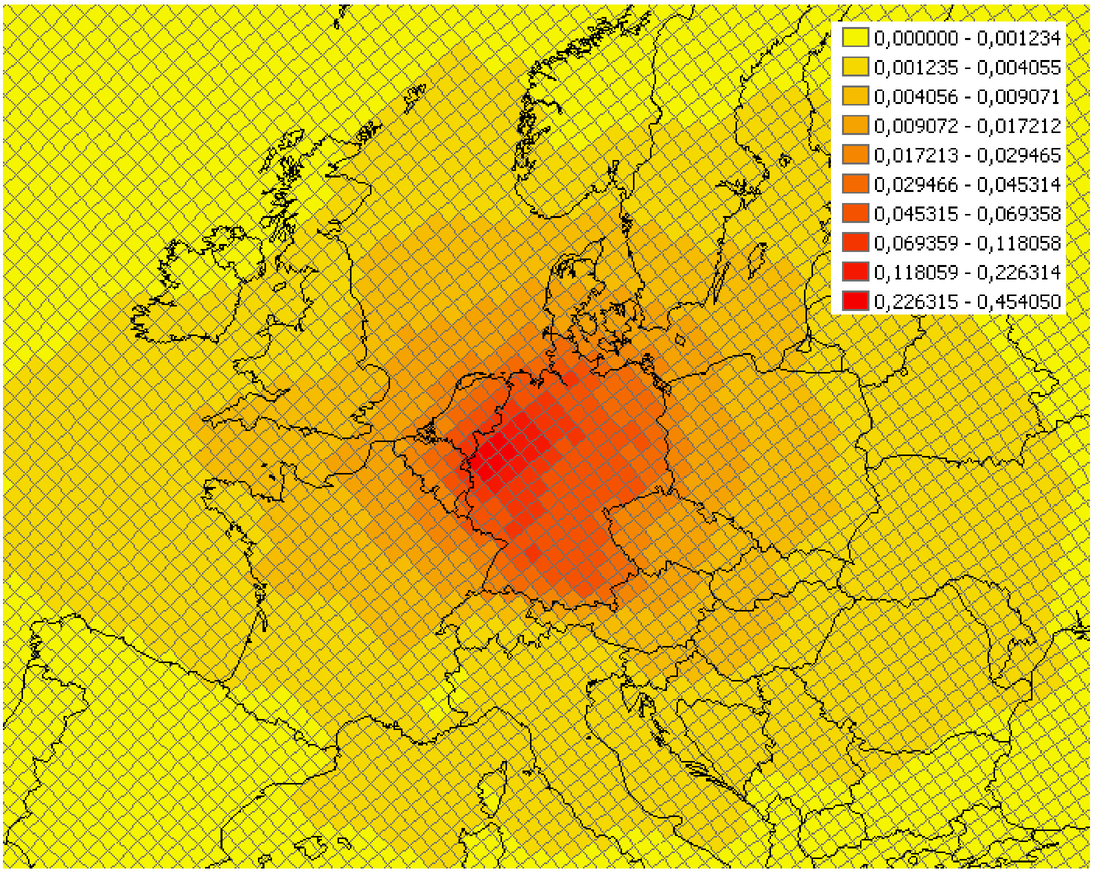


Figure 8: $PM_{2.5}$ concentration in Europe in µg/m³, EMEP model

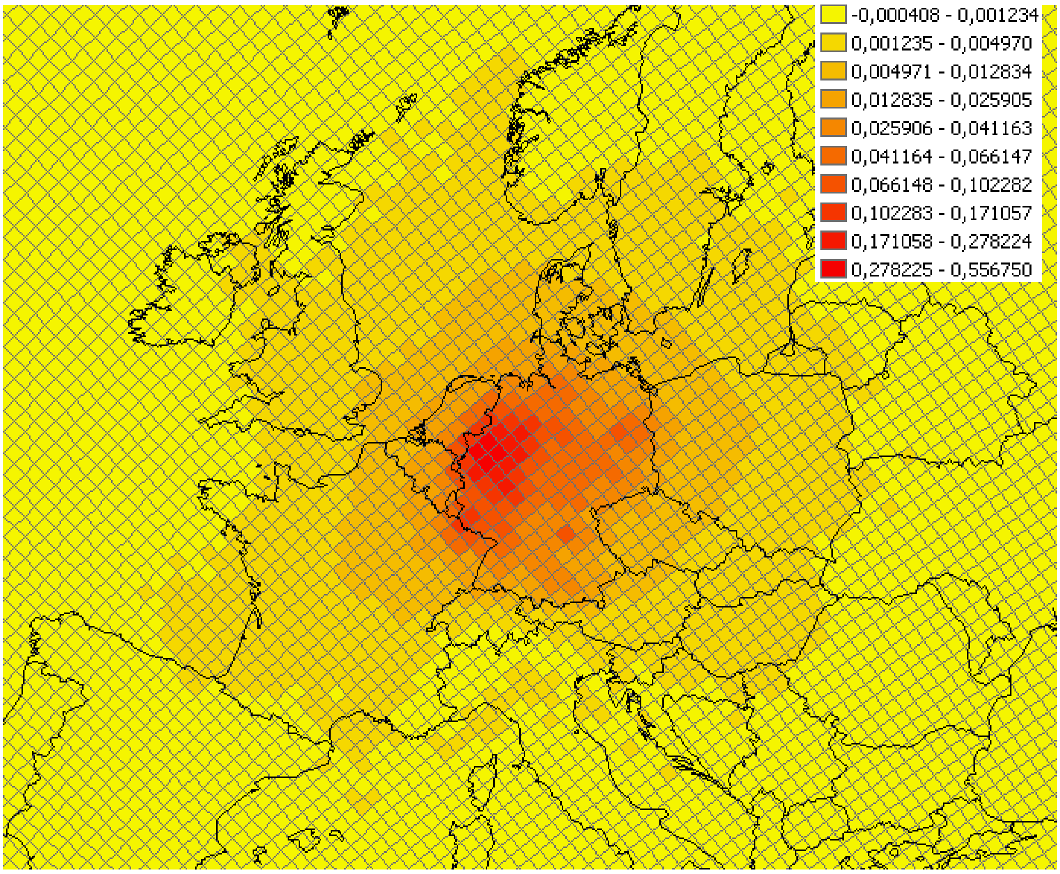


Figure 9: $PM_{2.5}$ concentration in Europe in µg/m³, Polyphemus model

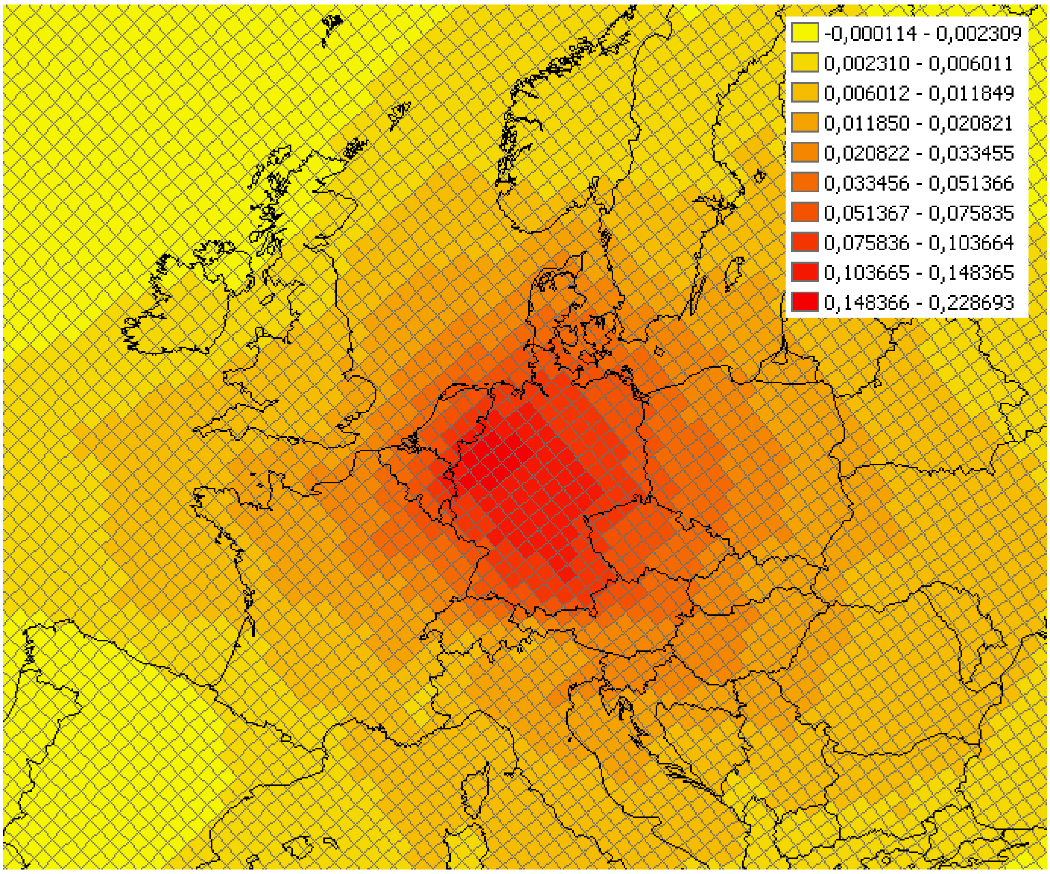


Figure 10: SIA concentration in Europe in µg/m³, EMEP model

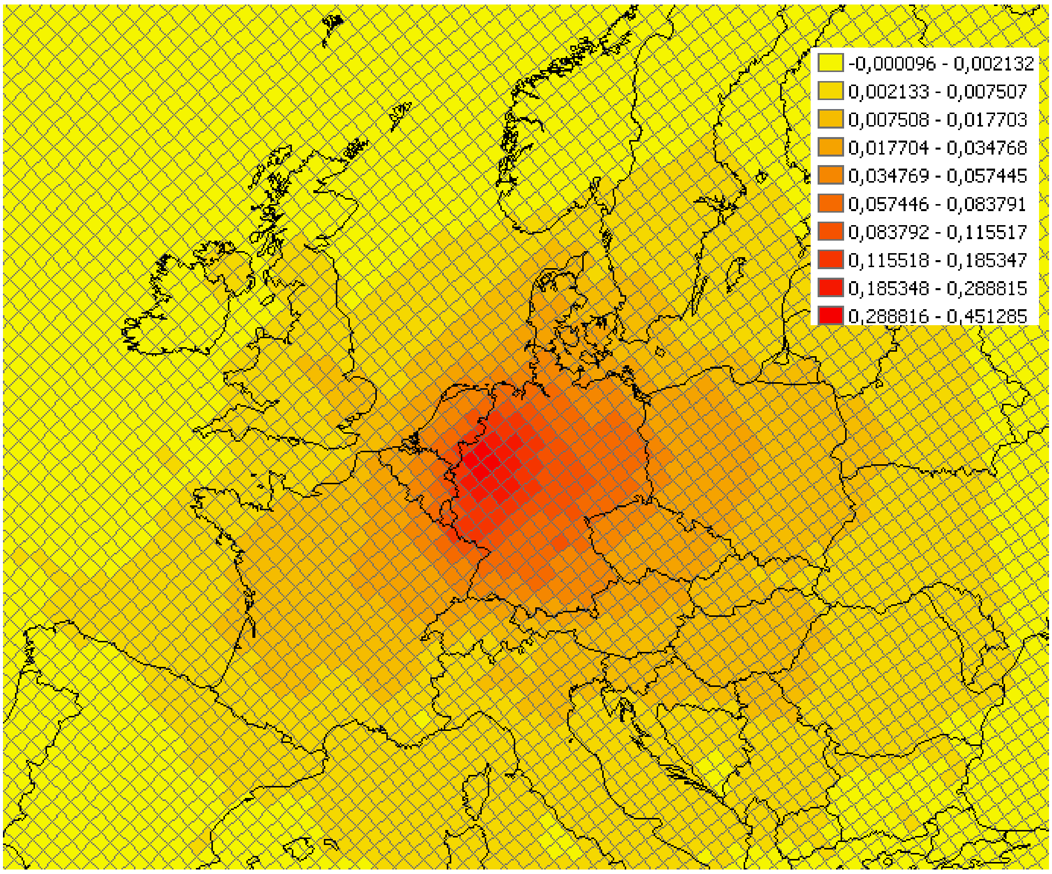


Figure 11: SIA concentration in Europe in µg/m³, Polyphemus model

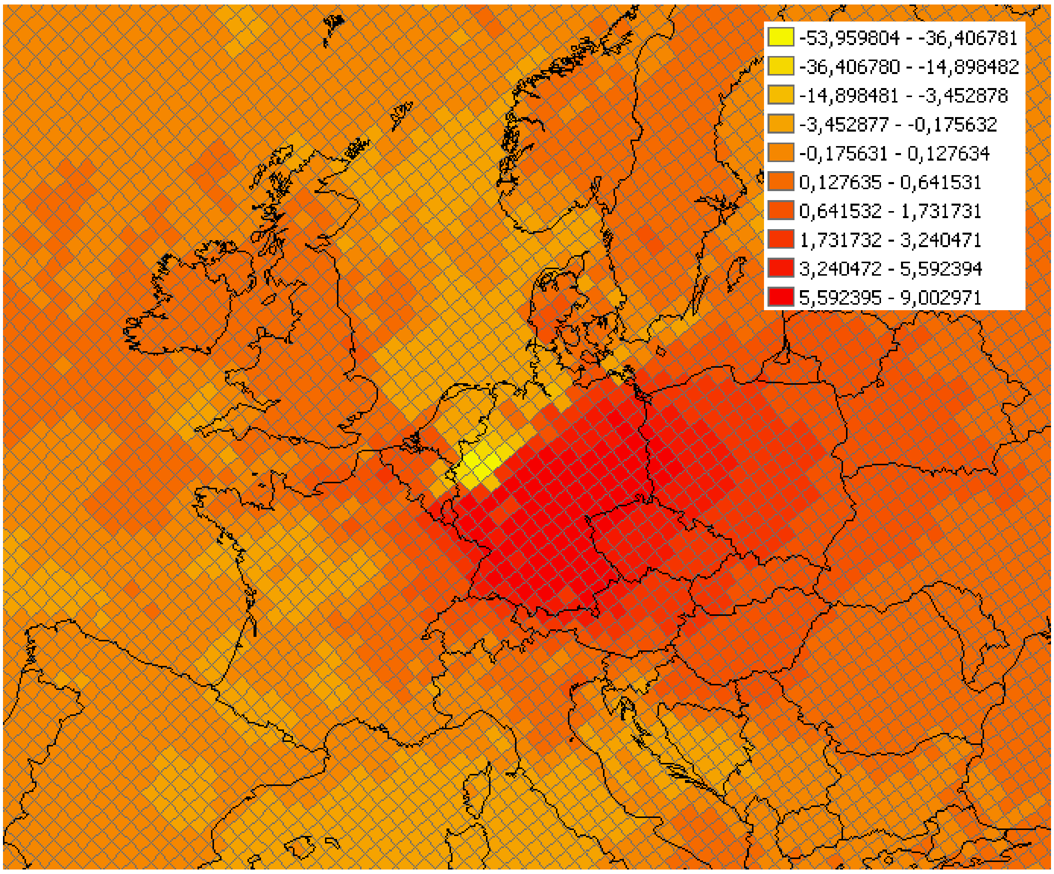


Figure 12: SOMO35 concentration in Europe in ppb/day, EMEP model

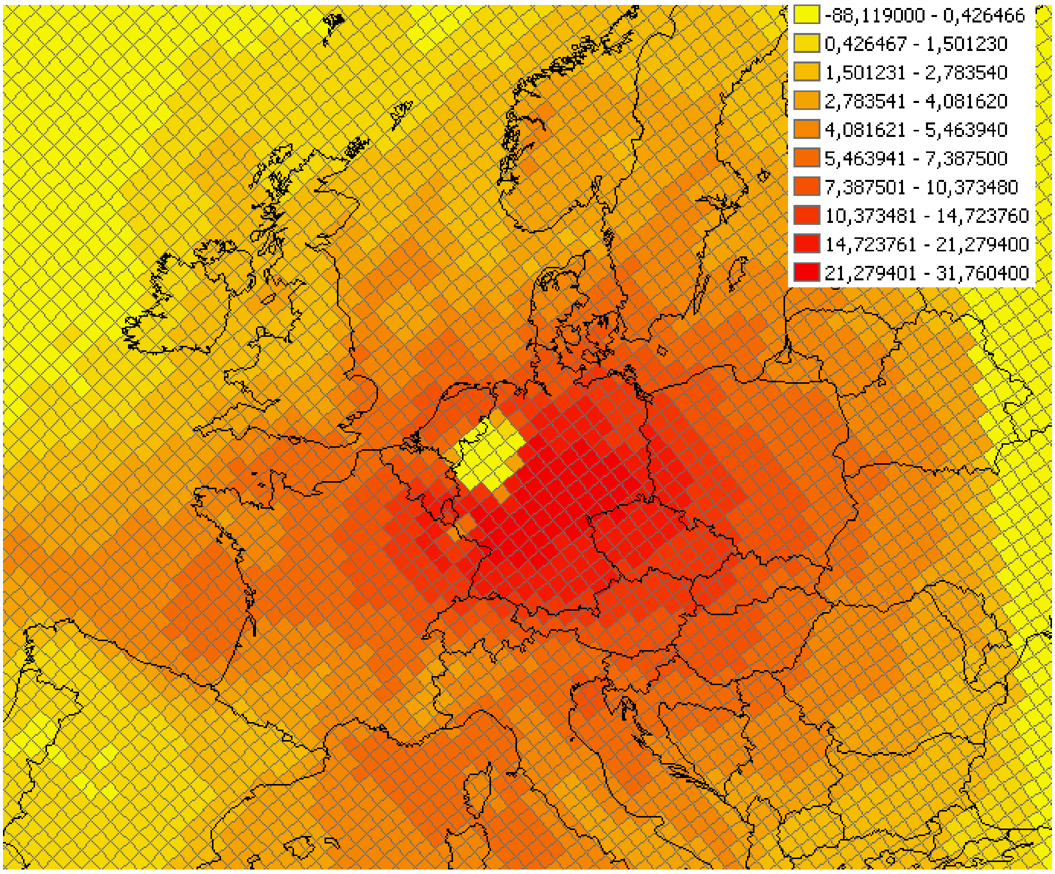


Figure 13: SOMO35 concentration in Europe in ppb/day, Polyphemus model

IV. Integration of other relevant pollutants

As the estimation of external costs for the metal industry only focused on the classical air pollutants, some heavy metals and dioxins, there are a large number of pollutants not covered. In order to include some more substances in the analysis in this case study, the results of Part 1 of the report on the work of work package II.5.a will be taken into account. There, a number of pollutants were classified as being relevant for the estimations of external costs in the sectors chemical, electronic, engineering, plastic, agri-food and metal industry. These relevant pollutants will be integrated into the analysis of the external costs of the metal industry in the following sections. As the methodology used in this section is very different from those applied in the sections above, there will not be an aggregation of the results.

IV.1 General Approach

The approach applied for the integration of further relevant substances in the estimations of the external costs of the activities of the metal industry in Europe is in most steps identical to the approach followed in Part 1. Data on the emissions of the production processes within the metal industry have been extracted from EcoInvent 2.0 and multiplied with the numbers of total output given by the EuroStat statistics of PRODCOM. The processes covered included:

- Pig iron
- Aluminium product manufacturing, average metal working,
- Aluminium alloy,
- Steel product manufacturing, average metal working,
- Steel, electric, un- and low-alloyed,
- ferrochromium, high-carbon and
- ferromanganese, high-coal.

These are certainly not all processes within the metal industry, but data provided by PRODCOM only allowed for an analysis of these processes. The covered processes correspond to the sectors chosen within the EMEP WebDab as shown in section II.1.1.

The resulting total emissions of the metal industry then have been evaluated with damage factors given by IMPACT2002+ before the impacts on the ecosystem, on human health and on climate change have been valued with monetary factors in order to get the amount of external costs caused by each pollutant. The calculation of impacts on climate change is an extension of the analysis as these impacts have not yet been analysed with the applied methodologies of EcoSenseWeb and Polyphemus. It is important to mention that although the analysis in Part 1 also applied the damage costs of EcoIndicator 99, research in this case study will only include damage factors provided by IMPACT2002+.

The resulting relevant pollutants for the above-mentioned sectors as estimated in Part 1 are shown in Table 17. As the original results included the classical air pollutants, some heavy metals and dioxins which already have been regarded in the sections above, these will not be covered in this section. Therefore, these substances are not shown in Table 17 and only those of interest for the further work are presented here. Additionally, the substances Metolachlor and Linuron have been excluded from the further analysis as damages caused by this pollutant only occur from emissions into soil. The work in this case study will only focus on emissions into the air. Furthermore, the table also presents the estimated emissions for the above mentioned production processes.

A comparison of the emissions for those pollutants that already have been covered shows, that the emissions calculated with EcoInvent 2.0 and PRODCOM are very different from those given by the EMEP WebDab. While there are emissions of some pollutants that are higher for the EMEP data, the overall average shows that emissions calculated with EcoInvent 2.0 and PRODCOM are about 4.3 times higher than those given by the EMEP WebDab. As a consequence the external costs will be higher than those estimated in the sections above. This makes a comparison of the results very difficult and thus, an aggregation of the estimated external costs in order to get the total external costs of the metal industry is not possible. However, the methodology applied in the estimations for the additional pollutants was made to present a possible way of expanding the current methodology by other relevant pollutants.

Table 17: Other relevant pollutants and their total emissions

Pollutant	Unit	Emissions
Aluminum	kg	30,601,825.0
Antimony	kg	4,427.0
Barium	kg	27,120.7
Benzene	kg	1,279,570.7
Benzene, hexachloro-	kg	741.6
Benzo(a)pyrene	kg	9,212.2
Carbon dioxide, fossil	kg	280,558,683,777.5
Carbon disulfide	kg	5,047,653.3
Carbon monoxide, biogenic	kg	202,026,760.5
Carbon monoxide, fossil	kg	2,677,566,836.1
Carbon-14	kBq	2,635,929,152.1
Chloroform	kg	34.3
Chromium VI	kg	52,954.5
Cobalt	kg	22,438.9
Cobalt-58	kBq	44.4
Copper	kg	378,667.3
Dinitrogen monoxide	kg	5,134,747.4
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	66.0
Ethane, 1,2-dichloro-	kg	50,018.9
Ethane, hexafluoro-, HFC-116	kg	53,764.0
Ethylene oxide	kg	401.9
Hydrocarbons, aliphatic, alkanes, unspecified	kg	61,201,445.1
Hydrocarbons, aromatic	kg	2,946,748.4
Methane, biogenic	kg	19,051,149.0
Methane, bromotrifluoro-, Halon 1301	kg	637.0
Methane, chlorodifluoro-, HCFC-22	kg	4,578.1
Methane, chlorotrifluoro-, CFC-13	kg	0.0
Methane, dichlorodifluoro-, CFC-12	kg	1,737.4
Methane, fossil	kg	738,493,262.7
Methane, tetrachloro-, R-10	kg	372.2
Methane, tetrafluoro-, R-14	kg	483,774.0
Methane, trifluoro-, HFC-23	kg	0.7
Molybdenum	kg	2,538.1
Nitrobenzene	kg	0.0
PAH, polycyclic aromatic hydrocarbons	kg	238,941.9

Propene	kg	230,343.2
Propylene oxide	kg	408.0
Radon-222	kBq	48,198,356,659,727.2
Selenium	kg	12,453.7
Sulfur hexafluoride	kg	649,974.0

IV.2 Estimation of external costs from additional pollutants

The estimation of external costs resulting from emissions of the above-mentioned additional substances follows the approach applied in the screening process fro relevant pollutants. First, the respective damage factors for each of the pollutants were taken out of the database of IMPACT2002+. With these damage factors the impacts on the ecosystem, on human health and on climate change were estimated. Thus, for each pollutant the Potentially Disappeared Fraction per m^2 (PDF), the Disability Adjusted Life Years (DALY) and the kilograms equivalent to carbon dioxide ($kg_{eq}CO_2$) were calculated. Based on the research within the NEEDS project – Preiss et al. (2008) – monetary values for PDFs, DALYs and $kg_{eq}CO_2$ are available. The values were updated compared to those applied in Part 1 and are summarised in Table 18.

Table 18: Monetary valuation factors[10]

Impact	Ecosystem Quality	Human Health	Climate Change
Euros	0,47 € / PDF	40,000 € / DALY	21 € / $t_{eq}CO_2$

With these factors, a monetary valuation of the damages estimated with IMPACT2002+ was enabled. The results of the calculation of the external costs for these additional relevant substances are presented in Table 19. The data presented in this table was 'corrected' as it was proposed in Part 1. The ratio between damages to human health and damages to the ecosystem for NOx was adjusted to be 6.2. This value corresponds to results of calculations with EcoSenseWeb for the NEEDS project. In order to get this ratio, the value for damages to the ecosystem had to be divided by about 4.48. As this division was done for all resulting external costs due to damages to the

[10] Please note that the monetary evaluation factors have been updated according to latest research results and thus do not correspond with the factors applied in Chapter 1.

ecosystem quality, the ranking within this category did no change. However, the total amount of external costs and thus the ranking of the total costs were changed.

From the results in Table 19 it can be seen that the additional 40 substances sum up to an amount of more than €13.5 billion. This amount would have to be added to the estimated amount of €5.7 billion in section II.2 in order to get a total amount of the external costs of the metal industry in Europe. However, as already stated above, an aggregation of these two sums is not feasible due to the different sources of data and the different approaches within the estimations. Thus, these sums can only be taken as a rough approximation of the potential external costs of the metal industry. The large difference in the estimated sums could be interpreted in a way that there is a need for an extension of the current methodology of EcoSenseWeb and Polyphemus applied n the sections above.

Table 19: External costs for additional pollutants in millions of Euros

Pollutant	Unit	Euros Ecosystem	Euros Human Health	Euros Climate Change	Euros Total
Aluminum	kg	6,253.01	1.67	0.00	**6,254.68**
Carbon dioxide, fossil	kg	0.00	0.00	5,891.73	**5,891.73**
Copper	kg	362.15	0.09	0.00	**362.24**
Methane, fossil	kg	0.00	0.38	356.69	**357.07**
Sulfur hexafluoride	kg	0.00	0.00	303.02	**303.02**
Carbon monoxide, fossil	kg	0.00	78.29	88.36	**166.65**
Methane, tetrafluoro-, R-14	kg	0.00	0.00	57.91	**57.91**
Molybdenum	kg	0.00	47.08	0.00	**47.08**
Benzo(a)pyrene	kg	0.00	36.55	0.00	**36.55**
Dinitrogen monoxide	kg	0.00	0.00	31.92	**31.92**
Ethane, hexafluoro-, HFC-116	kg	0.00	0.00	13.44	**13.44**
Carbon monoxide, biogenic	kg	0.00	5.91	6.67	**12.57**
Methane, biogenic	kg	0.00	0.01	9.20	**9.21**
Benzene, hexachloro-	kg	0.00	6.06	0.00	**6.06**
Cobalt	kg	3.84	0.00	0.00	**3.84**
Benzene	kg	0.00	1.09	0.00	**1.09**
Chromium VI	kg	0.00	0.74	0.00	**0.74**
Methane, dichlorodifluoro-, CFC-12	kg	0.00	0.07	0.39	**0.46**
Methane, bromotrifluoro-, Halon 1301	kg	0.00	0.32	0.09	**0.41**
Selenium	kg	0.12	0.25	0.00	**0.37**
Methane, chlorodifluoro-, HCFC-22	kg	0.00	0.01	0.16	**0.17**
Antimony	kg	0.08	0.08	0.00	**0.16**
Barium	kg	0.01	0.02	0.00	**0.04**
Methane, tetrachloro-, R-10	kg	0.00	0.01	0.01	**0.03**
Carbon disulfide	kg	0.00	0.02	0.00	**0.02**
Propene	kg	0.00	0.02	0.00	**0.02**
Ethane, 1,2-dichloro-	kg	0.00	0.01	0.00	**0.01**
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	0.00	0.00	0.00	**0.00**
Methane, trifluoro-, HFC-23	kg	0.00	0.00	0.00	**0.00**
Ethylene oxide	kg	0.00	0.00	0.00	**0.00**
Propylene oxide	kg	0.00	0.00	0.00	**0.00**
Radon-222	kBq	0.00	0.00	0.00	**0.00**
Chloroform	kg	0.00	0.00	0.00	**0.00**
Carbon-14	kBq	0.00	0.00	0.00	**0.00**
Cobalt-58	kBq	0.00	0.00	0.00	**0.00**
Hydrocarbons, aliphatic, alkanes, unspecified	kg	0.00	0.00	0.00	**0.00**
Hydrocarbons, aromatic	kg	0.00	0.00	0.00	**0.00**
Methane, chlorotrifluoro-, CFC-13	kg	0.00	0.00	0.00	**0.00**
Nitrobenzene	kg	0.00	0.00	0.00	**0.00**
PAH, polycyclic aromatic hydrocarbons	kg	0.00	0.00	0.00	**0.00**
total		**6,619.22**	**178.70**	**6,759.59**	**13,557.51**

V. Non-environmental effects

Non-environmental describe external effects that occur in the process of production and which do not have an impact on the environment due to the emission of pollutants but which have an impact on other issues as the situation of employment or the safety of the employees with respect to accidents. However, as the three main characteristics of external costs are the facts that these costs are not internalised in the accounting of the respective firms, that there is no compensation payment from the polluter to the affected persons and that there is no such as a market which regulates the height of compensation payments and other relevant prices. Thus, these characteristics of externalities lead to the problem, that the costs resulting from non-environmental effects of employment and risk-safety can not be regarded as external costs as such because they either can not be valued in monetary terms or because there exists a market and a compensation payment. This is the case regarding the effects of changes in the employment within a certain sector. Labour can be seen as a good - supplied by households and demanded by firms - which is marketed within the labour market. This market brings together firms searching for workers and workers looking for vacancies. Therefore, the good labour is 'traded' within this market and changes in the employment situation within a firm or of an individual can not be regarded as an externality. The now unemployed person will use the labour market to find a new job, as will the firm looking for a replacement. This also applies in case a firm gets bankrupt, moves to another country or another major negative event concerning the employees. Now, a large number of people become unemployed and start looking for a job on the labour market not necessarily on within the home country. Labour is a marketed good and changes can not be regarded as external effects.

Furthermore, there is a compensation payment. The producer or employer directly compensates the workers via the wages that are paid. This price for a certain unit of labour is – besides other factors – directly connected to the situation at the workplace. A higher risk of accidents at the workplace and a higher risk of sudden unemployment will in general lead to higher level of wages demanded by employees. Following this argumentation, one could try to estimate the value of the effects, resulting from these non-environmental effects, via the wage structure within certain industries and certain companies. But, as stated above, the situation of risk-safety and employment are not the only factors influencing the final level of wages. Among others, the required level of education, the economic situation of the industry or the economy as a whole, the age of the worker, the responsibilities of the employee, the internal wage structure of the company and the affiliation to collective wage agreements are important factors in the determination of the wages. Thus, it is a very complex approach to evaluate the external effects at the workplace of a certain company with a comparison of the wages that are paid in this company and the ones that are paid in similar companies or across the total economic sector. In order to facilitate the analysis in this case study, only the effects on risk safety will be summarised and there will only be a rough estimation of the potential economic losses due to damage costs resulting from accidents within the metal industry.

The overall economic losses – especially those of accidents – are difficult to estimate, as they can never be calculated exactly (see NewExt 2004). The losses of accidents are estimated in several different ways and depend on the underlying definitions. Additionally, these losses can be classified in three parts:

- direct losses that are immediately visible and countable,
- indirect losses that result from the physical destruction of assets and
- secondary costs that weaken the economy of the regarded country.

The major problem arising is the lack of clear statements of these components.

V.1 Effects on risk-safety

It has already been stated in the introduction to this chapter on the non-environmental effects that these can not be treated as external effects due to the existing compensation via wages. This section will focus on the effects on the safety situation within the metal industry. There will be two different ways of analysing the effects on risk safety in this sector. First, there will be an overview of some literature covering the risk safety within the metal industry and second, the statistics on work-days lost and fatal accidents within this sector will be regarded and damage costs due to these accidents will be estimated.

V.1.1 Overview of studies on risk safety in metal industry

Risks of safety that do not only address workers in the metal industry but greater parts of the population should also be included in this analysis. One of these problems was observed by the International Atomic Energy Agency (IAEA) and focuses on metal scrap. In a publication from 2005, the IAEA wants to reduce risks in the scrap metal industry. In the paper several examples of careless use of contaminated metal scrap are described. Furthermore, hints are provided how to identify contaminated metals and training options are offered.

Workers within the metal industry face many different risks of injuries and accidents as can be seen in different studies. Bull (2007) studied the effect of mandatory eye protection for workers in the metal industry in Norway as these are reported to have the highest incidence work-related eye injuries in the country. The Safety & Health in Foundries Targets initiative (SHIFT, 2004) provides statistics on the accidents in the foundry industry in the UK. The data given by SHIFT show, that the accident rate of the foundry industry was significantly higher in 2002 than the industry average or that of comparable industries like manufacturing and construction. Furthermore, it is shown that the incidence rate of the molten metal industry has been decreasing from 1996/7 to 2002/3. Further interesting numbers are provided by Table 21 where the incidences are divided into sub industries. It can be observed that casting of iron and of other non-ferrous metals includes the highest risks of accidents for workers.

Table 21: Incidences Rates of the sub industries of the Molten Metal Sector

Sector	Accidents/ 100,000 employees
Casting of iron	4625
Casting of steel	2039
Casting of light metals	1722
Casting of other non ferrous metals	3853
All Molten Metals	2163

Source: SHIFT (2004)

Statistics on accidents concerning the metal industry are also provided by the Workplace Safety & Health Advisory Committee (WSHAC) of Singapore. Soon (2007) presents data on the metalworking industry contributing to about 63% of all accidents within the manufacturing sector. In their report they analyse cases of fatal accidents, accidents leading to permanent disablement and those leading to temporary disablement. The latter mostly resulted in lost workdays between four and 20 days. While the injuries resulted from the presence of heavy machinery such as power presses, the fatal accidents often resulted from falling objects. Further major problems were deafness resulting from industrial noise and industrial dermatitis. The figures shown in the report clearly identify the metalworking industry as the one with the highest number of accidents.

In an earlier study by Das and Chaudhury (1995) the authors analysed accidents in the aluminium smelting industry in India observing 2,100 workers. In their results, they show that most of the accidents are caused by the extreme temperatures that are required for the smelting process. The injuries resulted from contact with hot materials. One result was that over the three years of observation more than 11,000 man-days were lost on average every year. Another study from the beginning of the millennium by Räsänen et al (2000) analyses the differences in the perception of the hygiene of the workplace between younger and older employees. As a general outcome, they come to the conclusion that most of the workers in Finish metal manufacturing were not satisfied with the noise and the cleanliness of their air in their company. On the other hand they were satisfied with the lighting and the chemical safety of their workplace.

For the United States, the Mine Safety and Health Administration (MSHA, 2007) provides detailed information and data on the diverse injuries reported in the mining of metallic and non-metallic minerals. In this report, which is also found at the US Department of Labour, the different reported injuries within the sector of mining are collected and valued with a certain amount of lost work days.

V.1.2 Work-days lost and fatal accidents in European metal industry

Data on accidents causing lost work-days or having fatal consequences for workers in the European metal industry are collected and reported by EuroStat. However, data for 2005 are not given for all countries of the EU-27. Thus, the following Table 22 only reports data for the EU-15 countries, namely: Austria, Belgium, Denmark, Germany, Spain, Finland, France, Greece, Ireland, Italy, Luxemburg, the Netherlands, Portugal, Sweden and the UK. The data show that in the observed countries almost 25% of the reported work-days lost within the whole manufacturing sector occur in the production, processing and manufacturing of metals. In Luxemburg every third accident causing a minimum of 4 days of absence from work can be addressed to the metal industry. The same ratio can be taken from Table 23 where the number of fatal accidents within the metal industry and the total manufacturing sector is given. Again, 25% of all reported fatal accidents occur in this part of the manufacturing sector. In Austria and Greece, half of all accidents resulting in the death of a worker occur in the metal industry. In Belgium, Spain, Italy and Sweden it is still one third of the total amount of fatal accidents. Only Denmark, Finland, France and the UK show ratios that are clearly below the average for these 15 countries. To compare the situation of risk safety in the metal industry, Table 24 shows the accidents resulting in work-days lost and those resulting fatal as a percentage of the total number of accidents for all sectors within the

EU-15 economies. With a ratio of 5.95% and 4.51% the metal industry clearly shows the greatest share of all subsectors of the manufacturing sector for both categories of incidents. Regarding accidents that lead to work-days lost only the food and tobacco subsector has a share of more than four percent of the total amount for all sectors. Fatal accidents only occur in the food and tobacco industry and the glass and ceramic industry with a share of more than two percent. Thus, the metal industry clearly is the most insecure subsector of the manufacturing sector.

Tables 25 and 26 show that while the total number of work-days lost and fatal accidents in the metal industry and the whole manufacturing sector has been declining for most of the years between 1993 and 2005, the ratio for the two types of accidents has always been around 25%. This indicates on the one hand that there have been significant improvements in the safety standards of the workplace in the manufacturing sector including the metal industry. But on the other hand, the metal industry has been a place where every fourth incident occurred throughout the observed period from 1993 to 2005.

V.1.3 Estimation of monetary effects due to accidents

The above-mentioned examples show that the risk safety for workers in the metal industry is difficult to ensure. While some numbers were present a decrease in the number of accidents, it is still the industrial sector causing most of the incidents. The use of heavy machinery, hot temperatures for melting processes, insecure storing of products, noise and insufficient protection all lead to these problems. It can be assumed that the wages partly compensate for these risks but the overall level is not very high due to the limited requirements of education for the job. Another problem is the already mentioned affiliation to collective wage agreements which mean that there is an average wage across the industry which makes it difficult to increase wages but which also could help to implement safety standards across that industry.

In order to quantify the accidents in monetary terms, the NewExt (2004) report provides values for work-days lost and for the value of a statistical life-year (VSL). These values are estimated for the energy sector of the economy and will now be applied to the manufacturing sector in order to estimate potential monetary losses due to accidents within that sector. The costs of absences are based on the salary costs of the absent worker, the replacement costs which include the employment of temporary staff or additional overtime for current employees and the lost service or production time. As a result, a day of absence will be valued 88€. Additionally, the indirect costs of the absence due to lower costumer satisfaction and poorer quality of products and services which may lead to a loss of future business should also be included. Following the methodology given in the NewExt report (2004) these amount to 160€/day. In total, a day of absence would then be valued 248€. The report also suggests to focus on a central estimate between the maximum of 248€/day and the minimum of 88€/day, i.e. 168€ per day of absence. The VSL was also discussed in the report of NewExt (2004) and a value of 1,000,000 €/VSL was decided to be appropriate. Using these values, the economic loss for the workers within the metal industry can be quantified as summarised in Table 27. The estimations show that the economic loss for the workers in the metal industry would sum up to more than €133 million across the EU-15, reaching the highest national value in Italy (€66.1 million), followed by Spain (€45.1 million) and Germany (€43.7 million). These numbers serve as an estimation of the economic loss for the firms due to accidents within the metal production, processing and manufacturing industry across the EU-15. As the analysis is missing 12 members to cover the complete EU-27, the estimated amount of economic loss due to accidents in this industry has to be assumed as being above €150 million for all European countries.

In addition to the monetary values, the NewExt report of 2004 provides an overview of the possibilities of individuals to internalise the risk they face at their workplace. The two major actions that can be undertaken by individuals are an up-front expenditure to minimize losses and to achieve benefits over life and the purchase of an insurance to be financially protected. The decisions that favour one or the other are based on economic risk and cost-benefit analysis. Although there are many difficulties for the individuals and the firms interpreting the risk perception correctly, the NewExt (2004) report estimates an average coverage of accidents of 75% for material losses across European countries. To additional include personal disutility such as pain or suffering, the compensation payments for this component was set to 50% of the value of the observed material losses. Therefore, the methodology assumes that for the European countries – or the OECD countries in the report – 50% of the full internalisation is covered by the compensation payment. This internalisation is supposed to reflect the shift of costs of using a resource from the producer to the general public. Thus, the report recommends reporting the internalised values next to the externalities.

Table 22: Work-days lost in metal industry compared to total number within manufacturing sector, EU-15, 2005[11]

Country work days-lost	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SWE	UK	Total
Metal production, processing and manufacturing	4,733	4,272	64,092	2,702	54,390	3,562	26,568	2,388	501	48,350	403	3,384	11,254	2,205	8,341	237,145
manufacturing sector	19,409	18,588	246,723	17,576	197,768	14,626	136,211	10,539	4,319	172,321	1,192	22,251	54,174	10,110	46,986	972,793
Total	**24.39%**	**22.98%**	**25.98%**	**15.37%**	**27.50%**	**24.35%**	**19.51%**	**22.66%**	**11.60%**	**28.06%**	**33.81%**	**15.21%**	**20.77%**	**21.81%**	**17.75%**	**24.38%**

Source: EuroStat

Table 23: Ratio of numbers of fatal accidents in metal industry and manufacturing sector, EU-15, 2005[12]

Country fatal accidents	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	Total
Metal production, processing and manufacturing	11	8	33	1	36	1	13	3	2	58			7	3	5	181
manufacturing sector	22	23	127	8	112	6	101	6	7	185		16	56	10	45	724
Total	**50.00%**	**34.78%**	**25.98%**	**12.50%**	**32.14%**	**16.67%**	**12.87%**	**50.00%**	**28.57%**	**31.35%**			**12.50%**	**30.00%**	**11.11%**	**25.00%**

Source: EuroStat

[11] Only those accidents included with a minimum of four work-days lost

[12] No data on fatal accidents in the metal industry was given for Luxemburg and the Netherlands

Table 24: Comparison of different subsectors within manufacturing industry, work-days lost and fatal accidents

Industry / accident	Food & Tobacco	Textiles & Leather	Wooden Products	Paper, Publishing & Printing	coke ovens & petroleum processing	Chemicals	Rubber & Plactics
work-days lost	160,685	37,507	57,318	55,385	925	29,066	50,906
total work-days lost	3,983,881	3,983,881	3,983,881	3,983,881	3,983,881	3,983,881	3,983,881
Total	**4.03%**	**0.94%**	**1.44%**	**1.39%**	**0.02%**	**0.73%**	**1.28%**

Industry / accident	Glass & Ceramics	Metal	Engineering	Electronics and Computers	Vehicle Construction	other goods & recycling	Total
work-days lost	63,294	**237,144**	102,469	43,326	68,059	66,708	972,792
total work-days lost	3,983,881	3,983,881	3,983,881	3,983,881	3,983,881	3,983,881	3,983,881
Total	**1.59%**	**5.95%**	**2.57%**	**1.09%**	**1.71%**	**1.67%**	**24.42%**

Industry / accident	Food & Tobacco	Textiles & Leather	Wooden Products	Paper, Publishing & Printing	coke ovens & petroleum processing	Chemicals	Rubber & Plactics
fatal accidents	101	22	61	28	1	39	17
total fatal accidents	4,011	4,011	4,011	4,011	4,011	4,011	4,011
Total	**2.52%**	**0.55%**	**1.52%**	**0.70%**	**0.02%**	**0.97%**	**0.42%**

Industry / accident	Glass & Ceramics	Metal	Engineering	Electronics and Computers	Vehicle Construction	other goods & recycling	Total
fatal accidents	94	**181**	75	29	30	48	726
total fatal accidents	4,011	4,011	4,011	4,011	4,011	4,011	4,011
Total	**2.34%**	**4.51%**	**1.87%**	**0.72%**	**0.75%**	**1.20%**	**18.10%**

Source: EuroStat

Table 25: Development of ratio of work-days lost in metal industry and total amount for manufacturing sector, EU-15, 1993 – 2005

Year / work-days lost	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Metal production, processing and manufacturing	376,493	365,537	388,864	357,067	347,050	347,369	348,068	361,417	354,361	274,063	253,735	247,090	237,144
Manufacturing sector	1,555,621	1,515,556	1,451,752	1,357,022	1,339,893	1,354,762	1,342,302	1,328,898	1,291,886	1,152,498	1,070,778	1,008,622	972,793
Total	**24.20%**	**24.12%**	**26.79%**	**26.31%**	**25.90%**	**25.64%**	**25.93%**	**27.20%**	**27.43%**	**23.78%**	**23.70%**	**24.50%**	**24.38%**

Source: EuroStat

Table 26: Development of ratio of numbers of fatal accidents in metal industry and manufacturing sector, EU-15, 1993 – 2005

Year / fatal accidents	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Metal production, processing and manufacturing	344	259	336	325	337	310	264	277	268	224	216	215	181
manufacturing sector	1,513	1,330	1,221	1,128	1,162	1,101	1,009	976	933	869	814	794	726
Total	**22.74%**	**19.47%**	**27.52%**	**28.81%**	**29.00%**	**28.16%**	**26.16%**	**28.38%**	**28.72%**	**25.78%**	**26.54%**	**27.08%**	**24.93%**

Source: EuroStat

Table 27: Total amount of Euros lost for workers in metal industry, 2005

Country / accident	AT	BE	DE	DK	ES	FI	FR	GR
work-days lost	795,144	717,696	10,767,456	453,936	9,137,520	598,416	4,463,424	401,184
fatal accident	11,000,000	8,000,000	33,000,000	1,000,000	36,000,000	1,000,000	13,000,000	3,000,000
Total	**11,795,144**	**8,717,696**	**43,767,456**	**1,453,936**	**45,137,520**	**1,598,416**	**17,463,424**	**3,401,184**

Country / accident	IE	IT	LU	NL	PT	SE	UK	Total
work-days lost	84,168	8,122,800	67,704	568,512	1,890,672	370,440	1,401,288	39,840,360
fatal accident	2,000,000	58,000,000			7,000,000	3,000,000	5,000,000	181,000,000
Total	**2,084,168**	**66,122,800**	**67,704**	**568,512**	**8,890,672**	**3,370,440**	**6,401,288**	**133,334,776**

Source: EuroStat and NewExt (2004)

VI. Conclusion

The analysis conducted in the different sections has brought up a wide range of results. The estimations of external costs for the classical air pollutants, some heavy metals and dioxins have been accomplished in several ways using the existing methodologies of EcoSenseWeb, i.e. the chemical transportation models of the EMEP source-receptor matrices and Polyphemus and also results for Euro per unit of emission from other projects. With these methods, the external costs of the metal industry in Europe and in Germany in particular, could be estimated. Furthermore, results are available for Europe-wide and country-specific calculations. All of these three approaches result in about the same amount of external costs for the metal industry in Germany at about €1.1 and €1.3 billion. On the other hand, an extension of the calculations by a number of additional pollutants that were classified as being relevant in the first part of the analysis was more difficult and a variation in the estimated emissions and external costs for these additional pollutants of a factor about 4 was estimated. This difference in the approach and the result of the estimations does not allow for an aggregation of the external costs of the results. Therefore, it was not possible to calculate an overall total amount of the external costs for the metal industry. Nevertheless, the proceedings for the estimations of the external costs of additional heavy metals could serve as an example for future work on the extension of the current methodology by more substances.

Furthermore, the analysis of some non-environmental externalities has been accomplished. While monetary valued effects on employment and risk safety may not be considered as external costs due to the existing compensation of the workers via wages, the impact on the economic situation of the workers and the economy can be significant. The analysis of the metal industry in Europe has shown that the number of employed people in this sector is relatively high. In addition to that, the number of accidents resulting in single work-days losses and those with fatal consequences is higher than those reported for other economic sectors.

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Appendix I: Tables

Table A1: Total emissions of metal industry in EU-27 member states, 2005, in Gg[13]

Country	CO	NH_3	NMVOC	NO_x	SO_x	PM_{10}	$PM_{2.5}$	PM_{co}[14]	TSP	As	Cd	Cr	Cu
Austria	140.83977	0.52682	0.74906	5.38415	5.77318	1.66087	0.76250	0.89837	2.34830	n.a.	0.00024	n.a.	n.a.
Belgium	408.56749	0.03665	3.27221	17.90125	16.73272	8.80297	6.65848	2.14449	13.40323	0.00185	0.00087	0.01159	0.00548
Bulgaria	96.02199	n.a.	1.35872	9.72501	26.47486	n.a.	n.a.	0.00000	n.a.	n.a.	0.01123	n.a.	n.a.
Czech Rep.	118.13032	0.17862	1.21462	10.09533	12.97976	1.74000	1.23000	0.51000	2.04000	0.00035	0.00157	0.00297	0.00501
Denmark	n.a.	n.a.	n.a.	n.a.	n.a.	0.07974	0.02058	0.05916	0.20500	0.00003	0.00002	0.00010	0.00005
Estonia	0.10000	0.06000	0.01000	0.01000	n.a.	0.05000	0.01000	0.04000	0.06000	n.a.	n.a.	0.00018	0.00002
Finland	8.53807	1.19548	1.05980	4.09449	8.18884	1.75409	1.12767	0.62642	2.60899	0.00072	0.00035	0.00567	0.00633
France	1,677.18370	n.a.	4.18761	23.89357	30.16396	6.37663	4.23861	2.13802	8.33374	0.00230	0.00224	0.01350	0.00543
Germany	1,076.35496	0.15736	7.00766	32.57605	43.49652	28.53344	10.80822	17.72522	44.43791	n.a.	0.00010	n.a.	0.00251
Greece	23.11000	n.a.	0.45000	4.07000	23.38000	n.a.	n.a.	0.00000	n.a.	n.a.	n.a.	n.a.	n.a.
Hungary	47.12350	n.a.	8.16421	6.18080	18.96363	5.02022	2.98268	2.03753	9.11756	0.00032	0.00102	0.00180	0.00263
Ireland	0.22800	n.a.	0.01500	3.20800	4.68600	0.59052	0.51927	0.07125	0.73302	0.00010	0.00018	0.00046	0.00027
Italy	106.88057	n.a.	3.45664	2.87600	4.15689	7.05057	5.55364	1.49693	n.a.	0.00019	0.00120	0.01011	0.00664
Latvia	0.13719	0.00249	0.27444	3.60999	0.09964	0.41995	0.36451	0.05543	0.55853	0.00042	0.00021	0.00565	0.00040
Netherlands	115.34210	0.05192	1.45670	7.45896	7.74805	2.02865	1.29843	0.73021	4.51179	0.00029	0.00070	0.00112	0.00105
Poland	4.13520	n.a.	4.18000	2.23980	10.87000	7.13180	4.51680	2.61500	8.77260	0.01959	0.00339	0.01227	0.20811
Portugal	12.28525	n.a.	0.01322	0.36910	0.45927	19.82697	18.58959	1.23738	34.12653	0.00001	0.00001	0.00003	0.00001
Romania	34.25700	n.a.	0.29600	2.23900	3.79200	11.37030	n.a.	11.37030	85.86700	0.00058	0.00112	0.011758	0.00708
Slovakia	93.79979	0.000196	1.06732	8.89980	13.69647	1.55871	0.82504	0.73367	2.79039	0.01780	0.00039	0.00176	0.03136
Slovenia	n.a.	n.a.	n.a.	n.a.	1.31800	n.a.	n.a.	0.00000	2.29150	0.00000	0.00055	n.a.	n.a.
Spain	501.49867	n.a.	4.88146	31.31937	31.20900	9.57424	5.06134	4.51290	13.64019	0.01122	0.00831	0.00509	0.07950
Sweden	9.83896	0.02364	0.15826	2.26659	5.17516	1.46518	1.17409	0.29109	1.53830	0.00026	0.00009	0.00852	0.00174
UK	344.60505	0.00585	2.77214	21.07650	21.70046	8.81630	5.26031	3.55598	n.a.	0.00138	0.00125	0.00675	0.01205

[13] No data are given for Cyprus, Lithuania, Luxemburg and Malta. Furthermore, 'n.a.' stands for not availability of data. This is mentioned in the 'User Guide to WebDab'

where it says that "data might be inconsistent and/or incomplete"

[14] PMco describes coarse fraction of PM10, i.e. the difference of PM10 and PM2.5.

Total	**4,818.97760**	**2.23903**	**46.04506**	**199.49376**	**291.06439**	**123.85113**	**71.00177**	**52.84937**	**237.38458**	**0.05739**	**0.03502**	**0.09935**	**0.37568**

Table A1: Total emissions of metal industry in EU-27 member states, 2005 – continued

Unit	Gg	Gg	Gg	Gg	Gg	g I-Teq	Mg	Gg	Gg	Gg	Mg	Mg	Mg	Mg
Country	**Hg**	**Ni**	**Pb**	**Se**	**Zn**	**DIOX**	**PCB**	**Benzo (a) pyrene**	**Benzo (b) pyrene**	**Benzo (k) pyrene**	**PAH**	**HCB**	**PCP**	**Indeno**
Austria	0.00031	n.a.	0.00773	n.a.	n.a.	6.14631	n.a.	n.a.	n.a.	n.a.	0.00018	0.00467	n.a.	n.a.
Belgium	0.00068	0.00458	0.06061	0.00081	0.11307	15.29500	n.a.	n.a.	n.a.	n.a.	0.00629	0.04554	0.01270	n.a.
Bulgaria	0.00135	n.a.	0.09305	n.a.	n.a.	0.03011	0.00191	n.a.	n.a.	n.a.	0.01564	0.01920	0.00001	n.a.
Czech Rep.	0.00020	0.00115	0.02936	0.00017	0.13196	0.14270	0.03870	0.00029	0.00003	0.00003	0.00041	0.00138	n.a.	0.00006
Denmark	0.00006	0.00016	0.00101	0.00044	0.00204	0.00021	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Estonia	n.a.	0.00005	n.a.	n.a.	0.00010	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Finland	0.00035	0.00585	0.00357	0.00010	0.02097	0.00469	0.01764	n.a.	n.a.	n.a.	0.09300	0.00695	0.00000	n.a.
France	0.00039	0.01554	0.04716	0.00106	0.11472	0.04528	0.00006	0.00005	0.00000	0.00016	0.21704	0.00000	n.a.	0.00044
Germany	0.00000	0.00646	0.00144	n.a.	0.00933	0.04547	0.01658	0.00113	n.a.	n.a.	3.26448	n.a.	n.a.	n.a.
Greece	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Hungary	0.00093	0.00149	0.02722	0.00010	0.04792	0.01756	n.a.	0.00185	0.00133	0.00133	0.00466	0.00383	0.00125	0.16500
Ireland	0.00001	0.01107	0.00024	0.00015	0.00057	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Italy	0.00269	0.00413	0.07104	0.00092	0.61253	0.07859	0.00011	n.a.	n.a.	n.a.	43.79858	n.a.	n.a.	n.a.
Latvia	0.00000	0.00009	0.00941	n.a.	0.01385	0.00020	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Netherlands	0.00021	0.00086	0.02365	0.00000	0.03251	0.00843	n.a.	n.a.	n.a.	n.a.	0.00438	n.a.	n.a.	n.a.
Poland	0.00090	0.00543	0.26550	n.a.	0.43340	0.03230	0.03025	0.58940	2.15292	2.15292	5,163.16000	0.00478	n.a.	267.91000
Portugal	0.00001	0.00046	0.00002	0.00000	0.00003	0.00000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Romania	0.00041	0.01756	0.06366	n.a.	0.10642	0.06934	0.00126	0.00003	n.a.	n.a.	0.03100	0.00149	n.a.	n.a.
Slovakia	0.00163	0.00639	0.03692	0.00295	0.03348	0.03093	0.00584	0.00034	0.00020	0.00020	0.00077	0.00051	n.a.	0.03023
Slovenia	0.00009	n.a.	0.01100	n.a.	n.a.	0.00001	0.00282	0.00014	0.00014	0.00014	0.44283	0.00000	n.a.	0.01812
Spain	0.00279	0.03204	0.16804	0.00476	0.52654	0.09458	n.a.	n.a.	n.a.	n.a.	97.81508	0.33931	0.09501	n.a.
Sweden	0.00019	0.00195	0.00426	0.00001	0.01816	0.00637	n.a.	0.00153	0.00337	n.a.	6.12622	n.a.	n.a.	1.22490
UK	0.00106	0.01246	0.06133	0.00227	0.14687	0.04792	0.17261	0.00016	0.00009	0.00006	0.37249	n.a.	0.00003	0.05642
EU-27	**0.01427**	**0.12771**	**0.98620**	**0.01374**	**2.36445**	**22.09600**	**0.28777**	**0.59492**	**2.15808**	**2.15484**	**5,315.35306**	**0.42767**	**0.10900**	**269.40517**

Table A2: Country-specific Euro per ton factors for emissions in 2000 based on Euro values in 2000

Country	NH_3	NMVOC	NO_x	SO_x	$PM_{2.5}$	PM_{co}	As	Cd	Cr	Hg	Ni	Pb	DIOX
Austria	11,711.00	1,015.00	9,533.00	7,719.00	29,556.00	1,202.00	509,522.25	80,884.34	9,146.00	8,000,000.00	1,508.00	271,247.07	37,000,000,000.00
Belgium	21,871.00	1,569.00	6,373.00	8,543.00	46,271.00	2,668.00	589,675.70	92,472.93	23,910.00	8,000,000.00	4,213.00	293,626.46	37,000,000,000.00
Bulgaria	5,647.00	-52.00	5,382.00	4,865.00	11,962.00	460.00	482,649.98	76,585.75	4,072.00	8,000,000.00	618.40	263,063.80	37,000,000,000.00
Czech Rep.	16,783.00	584.00	7,302.00	7,235.00	25,208.00	1,009.00	511,656.72	80,895.85	9,891.00	8,000,000.00	1,526.00	273,683.20	37,000,000,000.00
Denmark	7,130.00	570.00	3,409.00	4,226.00	13,023.00	581.00	500,748.87	79,084.14	7,194.00	8,000,000.00	1,259.00	267,863.79	37,000,000,000.00
Estonia	5,103.00	163.00	1,481.00	3,392.00	6,159.00	165.00	475,062.93	75,385.56	2,434.00	8,000,000.00	357.70	259,552.02	37,000,000,000.00
Finland	3,160.00	175.00	1,121.00	2,298.00	6,098.00	199.00	472,997.08	75,136.58	1,939.00	8,000,000.00	313.10	258,658.04	37,000,000,000.00
France	8,595.00	702.00	7,264.00	7,844.00	27,821.00	1,248.00	532,864.33	83,621.99	12,750.00	8,000,000.00	2,326.00	276,081.87	37,000,000,000.00
Germany	13,070.00	831.00	8,947.00	8,318.00	39,768.00	2,066.00	560,694.06	88,002.50	18,650.00	8,000,000.00	2,989.00	289,311.42	37,000,000,000.00
Greece	4,260.00	154.00	1,875.00	4,696.00	12,931.00	566.00	493,780.21	78,561.43	6,170.00	8,000,000.00	1,139.00	264,441.27	37,000,000,000.00
Hungary	13,672.00	483.00	8,965.00	6,985.00	26,492.00	1,291.00	506,019.32	80,215.07	8,754.00	8,000,000.00	1,418.00	270,884.94	37,000,000,000.00
Ireland	1,804.00	512.00	3,101.00	4,299.00	12,122.00	498.00	486,903.00	77,170.47	5,071.00	8,000,000.00	738.80	263,100.98	37,000,000,000.00
Italy	10,037.00	511.00	6,541.00	7,049.00	28,813.00	1,701.00	547,000.08	85,204.87	14,100.00	8,000,000.00	2,867.00	278,169.37	37,000,000,000.00
Latvia	4,825.00	296.00	2,590.00	3,854.00	8,844.00	342.00	478,050.96	75,900.49	3,162.00	8,000,000.00	465.60	260,591.01	37,000,000,000.00
Netherlands	16,804.00	1,215.00	6,612.00	10,262.00	46,925.00	2,794.00	589,091.53	92,243.13	24,330.00	8,000,000.00	3,902.00	296,444.86	37,000,000,000.00
Poland	9,651.00	452.00	5,344.00	6,451.00	25,201.00	1,185.00	511,058.84	80,770.49	9,838.00	8,000,000.00	1,513.00	273,383.83	37,000,000,000.00
Portugal	2,955.00	310.00	897.00	2,997.00	17,193.00	877.00	501,942.86	79,351.86	7,134.00	8,000,000.00	1,306.00	267,722.85	37,000,000,000.00
Romania	6,579.00	292.00	7,543.00	5,855.00	18,912.00	794.00	500,151.38	79,071.12	7,375.00	8,000,000.00	1,173.00	269,627.70	37,000,000,000.00
Slovakia	15,094.00	389.00	7,856.00	6,696.00	21,640.00	842.00	504,319.02	79,925.21	8,423.00	8,000,000.00	1,303.00	270,306.14	37,000,000,000.00
Slovenia	13,155.00	834.00	7,569.00	6,737.00	23,113.00	686.00	500,010.93	79,444.39	7,242.00	8,000,000.00	1,229.00	269,964.98	37,000,000,000.00
Spain	3,590.00	325.00	2,300.00	4,136.00	13,794.00	787.00	497,049.18	78,845.90	6,642.00	8,000,000.00	1,111.00	267,319.93	37,000,000,000.00
Sweden	6,093.00	288.00	2,198.00	2,719.00	10,749.00	347.00	478,552.78	76,121.51	3,049.00	8,000,000.00	546.50	260,646.01	37,000,000,000.00
UK	12,871.00	652.00	3,826.00	5,807.00	27,857.00	1,873.00	572,594.17	89,949.73	20,850.00	8,000,000.00	3,729.00	294,972.90	37,000,000,000.00

EU-27	**9,482.00**	**584.00**	**5,591.00**	**6,070.00**	**24,412.00**	**1,325.00**	**507,031.95**	**80,109.00**	**8,535.00**	**8,000,000.00**	**1,395.31**	**270,246.44**	**37,000,000,000.00**

Table A3: Country-specific monetary valuation factors for losses of biodiversity, Euro per ton

Country	NH_3	NMVOC	NO_x	SO_x
Austria	6,580.00	-81.00	1,569.00	485.00
Belgium	3,392.00	-61.00	1,090.00	351.00
Bulgaria	1,403.00	-14.00	269.00	31.00
Czech Rep.	5,079.00	-83.00	1,341.00	399.00
Denmark	1,311.00	-47.00	844.00	336.00
Estonia	3,188.00	-29.00	676.00	167.00
Finland	1,764.00	-31.00	893.00	401.00
France	2,982.00	-54.00	991.00	413.00
Germany	5,999.00	-203.00	1,503.00	580.00
Greece	638.00	-10.00	143.00	19.00
Hungary	3,046.00	-47.00	1,019.00	259.00
Ireland	363.00	-19.00	410.00	152.00
Italy	5,569.00	-74.00	1,129.00	186.00
Latvia	2,980.00	-34.00	638.00	133.00
Netherlands	3,385.00	-61.00	1,030.00	316.00
Poland	3,703.00	-51.00	992.00	213.00
Portugal	991.00	-10.00	184.00	36.00
Romania	2,262.00	-21.00	419.00	58.00
Slovakia	5,227.00	-56.00	1,077.00	332.00
Slovenia	7,663.00	-86.00	1,660.00	512.00
Spain	1,544.00	-25.00	460.00	95.00
Sweden	1,372.00	-39.00	1,031.00	567.00
UK	595.00	-30.00	589.00	211.00
EU-27	**3,266.00**	**-67.00**	**903.00**	**177.00**

Table A4: Country-specific monetary valuation factors for damages to crops via nitrate deposition and ozone, Euro per ton

Country	NH_3	NMVOC	NO_x	SO_x
Austria	-103.00	126.00	570.00	-68.00
Belgium	-141.00	458.00	-116.00	-32.00
Bulgaria	-132.00	37.00	343.00	-2.00
Czech Rep.	-126.00	136.00	399.00	-43.00
Denmark	-89.00	199.00	126.00	-43.00
Estonia	-7.00	30.00	84.00	-11.00
Finland	-2.00	30.00	47.00	-11.00
France	-315.00	224.00	824.00	-65.00
Germany	-63.00	280.00	462.00	-71.00
Greece	-189.00	30.00	217.00	-5.00
Hungary	-167.00	86.00	561.00	-16.00
Ireland	-166.00	123.00	223.00	-58.00
Italy	-266.00	195.00	505.00	-57.00
Latvia	-8.00	40.00	119.00	-11.00
Netherlands	-166.00	384.00	-222.00	-34.00
Poland	-96.00	114.00	238.00	-10.00
Portugal	-215.00	54.00	96.00	-23.00
Romania	-114.00	45.00	297.00	-5.00
Slovakia	-129.00	93.00	458.00	-20.00
Slovenia	-191.00	156.00	582.00	-67.00
Spain	-269.00	83.00	299.00	-37.00
Sweden	-20.00	66.00	141.00	-29.00

UK	-242.00	311.00	-33.00	-46.00
EU-27	**-183.00**	**189.00**	**328.00**	**-27.00**

Table A5: External costs divided by country, EcoSenseWeb

Country	Euros
Germany	744.74
Netherlands	75.67
France	62.12
Poland	52.64
Belgium	41.29
United Kingdom	29.14
Czech Republic	27.15
Italy	26.51
Austria	15.77
Ukraine	13.76
Russia	12.20
Hungary	9.46
Switzerland	9.10
Denmark	9.05
Romania	8.70
Sweden	5.52
Slovakia	5.35
Turkey	5.25
Serbia and Montenegro (Yugoslavia)	4.16
Croatia	3.70
Egypt	3.35
Belarus	3.35
Spain	3.34
Slovenia	2.87
Algeria	2.75
Bulgaria	2.00
Luxembourg	1.88
Bosnia and Hercegovina	1.81
Greece	1.69
Lithuania	1.67
Republic of Moldova	1.45
Tunisia	1.27
Norway	1.14
Finland	0.94
Latvia	0.88
Albania	0.71
Ireland	0.70
Libya	0.69
Syria	0.57
Israel	0.51
The FYR of Macedonia	0.46
Portugal	0.45
Estonia	0.36
Jordan	0.21
Iran	0.20
Kazakhstan	0.20
Lebanon	0.15
Azerbaijan	0.14
Georgia	0.14
Iraq	0.13
Morocco	0.05
Armenia	0.05
Malta	0.05
Cyprus	0.04
Liechtenstein	0.02
Tokelau	0.01
San Marino	0.01

Iceland	0.01
Andorra	0.00
Faroe Islands	0.00
Monaco	0.00
Turkmenistan	0.00
Svalbard & Jan Mayen Islands	0.00
Saudi Arabia	0.00
total	1,197.53

Table A6: External costs divided by country, Polyphemus

Country	Euros
Germany	824.15
Netherlands	68.87
France	58.89
Poland	34.76
Belgium	31.26
United Kingdom	20.27
Czech Republic	15.65
Italy	13.43
Austria	7.73
Switzerland	7.14
Denmark	5.14
Hungary	5.07
Romania	4.69
Ukraine	3.78
Spain	3.68
Sweden	3.08
Slovakia	3.06
Luxembourg	2.66
Serbia and Montenegro (Yugoslavia)	2.25
Belarus	2.10
Croatia	1.62
Russia	1.48
Algeria	1.26
Slovenia	1.18
Lithuania	1.06
Turkey	0.80
Bosnia and Hercegovina	0.77
Bulgaria	0.75
Republic of Moldova	0.65
Greece	0.64
Tunisia	0.64
Norway	0.52
Latvia	0.43
Albania	0.40
Finland	0.34
Ireland	0.33
Portugal	0.32
The FYR of Macedonia	0.23
Estonia	0.12
Morocco	0.07
Kazakhstan	0.03
Malta	0.02
Liechtenstein	0.01

Andorra	0.00
San Marino	0.00
Faroe Islands	0.00
Monaco	0.00
Tokelau	0.00
Iceland	0.00
Armenia	0.00
Azerbaijan	0.00
Cyprus	0.00
Egypt	0.00
Georgia	0.00
Iran	0.00
Iraq	0.00
Israel	0.00
Jordan	0.00
Lebanon	0.00
Libya	0.00
Saudi Arabia	0.00
Svalbard & Jan Mayen Islands	0.00
Syria	0.00
Turkmenistan	0.00
total	**1,131.38**

Appendix II: Contributors to the report

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CHAPTER 3: CASE STUDY FOR THE CHEMICAL INDUSTRY

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Case Study for the chemical industry in Europe

I. Introduction

This study contributes to the picture set by industry work package of WS II.5 of the Exiopol project. The scenario of this case study on the external costs of the chemical industry will focus on the impacts of the emissions of the chemical industry in each of the EU-27 member states and on the total amount of external costs for the EU-27 as a whole. In the following sections the data sources and the estimated results will be discussed in greater detail. Second part of the study we will focus on particular application of ExternE method in feritilizer industry comparing particular powerplants in the Czech Republic and India

II. Data sources used for the analysis

II.1 EMEP WebDab

For sector analysis we need to know environmental burden produced by the sector. Chemical industry is one of the most problematic sectors because there is vast amount of various polluting substances. There is limitation what particular pollutants we are able to asses and valuate within ExternE method (in terms of physical and/or monetary impacts). As a primary data source we have used EMEP database (WebDab). Emission data in WebDab are officially submitted by the Parties to the Convention on Long Range Transboundary Air Pollution to the EMEP programme via the UNECE secretariat are available from the site. There is warning note that data might be inconsistent or/and incomplete. EMEP user guide suggest to use for modelling purposes and intercomparison "Gap-filled emissions" rather than emissions reported by the parties. Gap filled emission data is based on officially reported emissions to the extent possible, but some of the officially reported data have been corrected and/or gap-filled. More details are provided in annual CEIP&EEA technical reports called Inventory review. Problem why we couldn't use gap filled data is that data are not in nomenclature that allows us identification of chemical sector.

Therefore we have to choose data reported by the parties of CLRTAP. Nomenclature for reporting (NFR) had to be chosen. As the sectors of the EMEP NFR correspond to the United Nations Framework Convention on Climate Change (UNFCCC) common reporting format (CRF) the emission category 'NFR02 (level2)' was chosen. The emission data were analysed for the subsectors of sector N02 2 B Chemical industry and N02 1 A 2c Chemicals:

- N02 2 B Chemical industry
  - N02 2 B 1 – Ammonia production
  - N02 2 B 2 – Nitric Acid production
  - N02 2 B 3 – Adipic Acid production
  - N02 2 B 4 – Carbide production
  - N02 2 B 5 – Other Chemical industry
- N02 1 A 2 c – Chemicals

Sectors in NFR 02 nomenclature refers to two different types of activities occurring in chemical industry. Sector N02 2 B refers to emission from chemical processes and emissions associated directly with reaction to produce chemicals. Sector N02 1 A 2c refers to the production of energy in chemical factories. We account them both in this case study but we treat them separately. We aggregate them at the end as some member states finds difficult to report for this sector separated figures and sometimes they include emission of pollutant from whole sector in one category leaving the other one completely empty.

II.2 Greenhouse gases

Data about greenhouse gasses (GHG) produced by chemical industry is taken from UNFCCC (United Nations Convention on Climate Change) online database. The GHG data displayed on the UNFCCC website are data from official submissions of greenhouse gasses (GHG) emissions/removals data by countries that are Parties to the Climate Change Convention. The original version of the data as submitted by Parties is available on the UNFCCC website in "National Inventory Reports" as annual inventory submissions consisting of the national inventory report (NIR) and common reporting format (CRF) of all Parties included in Annex I to the Convention. As well, the secretariat was requested to publish on its site the exact URL addresses of Parties' web sites where these submissions are located. The NIRs contain detailed descriptive and numerical information and the CRFs contain summary, sectoral and trend tables for all greenhouse gas (GHG) emissions and removals, and sectoral background data tables for reporting implied emission factors and activity data.

Nomenclature is same as in previous mentioned database of EMEP and we again use data about greenhouse gasses from categories N02 2B Chemical industry and N02 1A 2 c Chemicals.

II.3 Monetary valuation data

For this particular case study we are using same approach used in metal industry case study, therefore we quoting here text from above.

In order to estimate the external costs resulting from the emission of the above-mentioned substances, monetary valuation factors have to be applied. For NH3, NMVOC, NOx, SOx, PM and dioxins the factors were taken from the results of research within the NEEDS project, an integrated project of the 6th Framework Programme of the European Commission. These factors have been calculated and generalized by a number of runs of the EcoSenseWeb applications. Detailed Information on the estimated Euro per ton values for damages to human health can be found in Desaigues et al. (2007), for losses of biodiversity in Ott et al. (2006) and for damages to crops in ExternE (1999) and ExternE (2005). For the heavy metals – As, Cd, Cr, Ni and Pb – the applied monetary factors are the results of projects of NEEDS and ESPREME, both within the 6th Framework Programme of the European Commission. The results were estimated with WATSON, an integrated water and soil environmental fate, exposure and impact assessment model of noxious substances, which provides Euro per ton values for damages following the ingestion.15 Additionally OMEGA, an integrated assessment of heavy metal releases in Europe, covers the damages resulting from inhalation of substances. For mercury (Hg) the estimations of Spadaro and Rabl (2007) were applied. Finally, monetary valuation factors for Dioxins were extracted from MethodEx (2006).

Impacts due to climate change may be monetized by considering two different conceptual approaches. First, the costs of carbon might be based on abatement costs of reaching certain (arbitrary set) goal. This approach would be correct if one was sure the agreed policy target was also socially optimal. Estimate of abatement costs to reach Kyoto target by the EU15 countries were just used to value damage of carbon emissions

[15] WATSON: http://watson.ier.uni-stuttgart.de/

last years in the ExternE project series. Methodologically more correct – at least following welfare economics ground – approach is, however, to estimate marginal damage costs of carbon, commonly referred to as the Social Costs of Carbon. Although, as noted by Anthoff (2007), the marginal damage figures are not the only measure used to quantify impacts from climate change[16], their estimates have been appearing more often in the literature.

Magnitude of social costs of carbon estimates do, however, significantly vary. Scope and structure of the assessment model present the first reason of variations; value of the estimate would then depend on number of impacts being covered, time horizon of impacts considered, or climate sensitivity assumed in given model (see Watkiss 2007). Next, there are also two key parameters of modelling that certainly will influence magnitude of the estimates: it is discounting and equity weighting. As a meta-analysis of IAM studies by Richard Tol (2005) shows weighting impacts due to equity and giving higher weight to future outcomes, i.e. by applying lower discount rates might indeed result in more than one order larger value of the MSC.

To provide comprehensive picture on MSC, several runs by FUND model were performed within the NEEDS project. Anthoff (2007) reports a range of MSC estimated based on using several pure rates of time preference (such as 0%, 1%, and 3%) plus declining rates over time, without equity weighting *(No_EqW)*or equity weighted by world average *(Aver_EqW)* or EU income average *(EU_EqW)*, including reporting a statistical inference for probabilistic MSC estimates. Values of MSC for given various assumptions of two key model parameters are displayed in Figure *(all in 2000 Euro prices)*.

Table 1: MSC of CO2 estimates based on FUND model v. 3.0.

'deterministic'	0%	1%	3%	1% trimmean	0%	1%	3%
No_EqW	16.4 €	2.1 €	-1.4 €	No_EqW	31.5 €	7.0 €	-0.5 €
Aver_EqW	41.4 €	7.7 €	-1.4 €	Aver_EqW	75.8 €	20.3 €	1.7 €
EU_EqW	197.3 €	36.7 €	-6.8 €	EU_EqW	360.9 €	96.8 €	8.1 €

[16] Some studies also presented total damage costs (e.g. Nordhaus and Boyer 2000; Tol 2002), or balanced growth equivalent (Stern 2006), or a Pareto optimal marginal damage costs, i.e. that are equal to marginal abatement costs (Nordhaus 2005).

average	0%	1%	3%	median	0%	1%	3%
No_EqW	39.8 €	8.9 €	-0.1 €	No_EqW	8.6 €	0.3 €	-1.8 €
Aver_EqW	91.5 €	24.3 €	2.4 €	Aver_EqW	27.2 €	5.4 €	-1.5 €
EU_EqW	435.6 €	115.9 €	11.6 €	EU_EqW	129.5 €	25.9 €	-6.9 €

Note: based on NEEDS project cit. in Anthoff 2005; all values are in 2000 Euros.

MSC estimates if world-wide outcomes are weighted by the EU average are about one order higher than without weighting, for instance, almost 97 € for 1% PRTP and 1% trim mean. Median MSC values are smaller than 1%, 5% and 10% trimmed mean values, while mean values of MSC are the lowest ones. The highest discount rate, the smaller MSC of carbon is. Applying declining discount rate in deterministic model runs, MSC per ton of CO_2 would be 3.8 €. Best guess MSC of CO_2 estimate based on deterministic runs, 1% PRTP and without equity weighting yields a value of 2.1 € per tonne CO_2.

It is just a nature of damage estimation of climate change that the one (say true) value of MSC of carbon can't exist. Any decision about the parameters will have to be just arbitrary based on normative notion followed by the decision maker. Due to the fact, modelling exercise requires having one unique number or distribution of the variable, NEEDS coordination research team has widely discussed what a central value of parameters for discounting and weighting the MSC of carbon estimate shall be based on. As a result, a probabilistic estimate based on 1% PRTP, without equity weighting and taking 1% trimmed mean has been considered as the central MSC of carbon value; this yields 6.96 € per tonne of CO_2 released in decade 2000-2010. *Option 1* just also uses the value of **7 €** per tonne of CO_2 in our damage aggregation. Next two options follow NEEDS discussions on valuing damage due to climate change; these values – being thought by NEEDS consortium – might better reflect actual policy targets as well as value of abatement costs estimates. Therefore, our *Option 2* assumes **15.7 €** and *Option 3* takes **21.1 €** per tonne of CO_2. Lastly, for *Option* 4, we arbitrary chosen the MSC value of **40 €** per tonne of CO_2 to illustrate its impact (one can conjecture this might be future value of CO_2 emission allowances thought).

II.4 Interpretation data

Absolute terms might be misleading and therefore we also used some additional data to interpret the results. We used comparison per capita – to normalize country magnitude and we used comparison per € of gross value added by sector to normalize size of the sector. Data for both comparisons were taken from Eurostat. Data for population from general population statistics, data for gross value added (GVA) from national accounts branches by NACE and in our case we aggregated category “Manufacture of chemicals, chemical products and man-made fibres” with category “Manufacture of rubber and plastic products”.

Table 2: Emissions of chemical processes, EU27, 2005, Gg[17]

Country	NH_3	NMVOC	NO_x	SO_x	$PM_{2.5}$	PM_{co}	As	Cd	Cr	Hg	Ni	Pb	DIOX	CO_2	CH_4	N_2O
Austria	0.1	1.3	0.6	0.8	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	557	16	274
Belgium	0.7	15.2	4.9	3.6	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2241	2	3410
Bulgaria	7.9	4.7	17.1	15.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	623	4	992
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Czech Republic	0.2	0.1	0.3	0.9	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	609	11	1093
Denmark	0.1	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3	0	0
Estonia	0.1	0.7	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	144	0	0
Finland	0.1	2.6	0.9	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	125	7	1569
France	3.0	34.4	7.4	5.6	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2385	0	6244
Germany	8.5	5.4	8.3	25.7	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14897	0	14702
Greece	0.0	2.0	1.2	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Hungary	0.8	10.6	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	822	15	1941
Ireland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Italy	0.2	3.8	3.4	8.2	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1317	7	7760
Latvia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Lithuania	0.3	0.0	0.4	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1154	2	2187
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Netherlands	1.4	7.9	0.0	0.0	0.9	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3746	275	6364
Poland	0.0	13.2	10.9	2.3	3.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3806	265	4686
Portugal	4.0	16.0	0.3	17.4	3.7	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1936	11	612
Romania	23.8	4.5	7.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2442	22	3174
Slovakia	0.0	0.9	0.3	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	1254
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52	6	0
Spain	14.6	16.5	4.5	6.2	0.7	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	727	52	1563
Sweden	0.1	3.4	1.3	0.6	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53	1	449
United Kingdom	4.0	40.2	1.0	7.1	0.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3253	42	2796
EU-27	70.0	183.7	74.9	105.8	10.6	13.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40892	738	61703

[17] Greenhouse gasses are in Gg of CO2 ekv.

Source: EMEP, UNFCCC

Table 3: Emissions of energy process in chemical sector, EU27, 2005, Gg[18]

Country	NH_3	NMVOC	NO_x	SO_x	$PM_{2.5}$	PM_{co}	As	Cd	Cr	Hg	Ni	Pb	DIOX	CO_2	CH_4	N_2O
Austria	0.0	0.2	1.4	0.7	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1369	2	6
Belgium	0.0	0.4	7.7	3.7	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7849	2	66
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2259	1	4
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Czech Republic	0.1	0.6	10.2	16.5	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7996	5	92
Denmark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	525	4	4
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6	0	0
Finland	0.0	0.0	1.7	1.9	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	1	36
France	0.0	0.9	25.8	39.9	2.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16053	13	175
Germany	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Greece	0.0	0.1	1.1	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Hungary	0.1	0.9	2.7	17.7	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4609	2	57
Ireland	0.0	0.0	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	423	0	10
Italy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12230	7	47
Latvia	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25	0	0
Lithuania	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	116	0	1
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Netherlands	0.0	0.7	14.6	3.9	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11764	19	6
Poland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5003	2	21
Portugal	0.0	0.4	3.7	4.3	0.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1842	2	12
Romania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Slovakia	0.2	0.0	3.5	9.1	0.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1877	2	4
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	167	1	1
Spain	0.0	5.4	43.2	5.2	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9445	30	60
Sweden	0.0	0.0	2.2	2.6	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1606	1	18
United Kingdom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0

[18] Greenhouse gasses are in Gg of CO2 ekv.

EU-27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	87882	97	689

Source: EMEP, UNFCCC

Table 4: Emissions of chemical industry total, EU27, 2005, Gg[19]

Country	NH_3	NMVOC	NO_x	SO_x	$PM_{2.5}$	PM_{co}	As	Cd	Cr	Hg	Ni	Pb	DIOX	CO_2	CH_4	N_2O
Austria	0.1	1.5	2.0	1.4	0.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 926	18	281
Belgium	0.7	15.6	12.6	7.3	0.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10 090	4	3 476
Bulgaria	7.9	4.7	17.1	15.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2 882	5	996
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Czech Republic	0.3	0.7	10.5	17.4	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8 606	16	1 185
Denmark	0.1	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	528	4	4
Estonia	0.1	0.7	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	150	0	0
Finland	0.1	2.7	2.6	8.5	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	125	7	1 604
France	3.0	35.4	33.3	45.5	2.3	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18 438	13	6 419
Germany	8.5	5.4	8.3	25.7	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14 897	0	14 702
Greece	0.0	2.1	2.2	11.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Hungary	0.8	11.5	6.8	17.7	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5 432	16	1 998
Ireland	0.0	0.0	0.8	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	423	0	10
Italy	0.2	3.8	3.4	8.2	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13 546	14	7 807
Latvia	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25	0	0
Lithuania	0.3	0.0	0.5	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 270	2	2 187
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Netherlands	1.5	8.6	14.6	3.9	1.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15 509	294	6 370
Poland	0.0	13.2	10.9	2.3	3.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8 809	268	4 707
Portugal	4.0	16.4	4.1	21.7	4.3	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3 778	14	624
Romania	23.8	4.5	7.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2 442	22	3 174
Slovakia	0.2	0.9	3.7	9.1	0.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 877	2	1 259
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	219	7	1
Spain	14.6	21.9	47.7	11.4	1.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10 172	82	1 623
Sweden	0.1	3.5	3.5	3.1	0.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 658	1	466

[19] Greenhouse gasses are in Gg of CO2 ekv.

United Kingdom	4.0	40.2	1.0	7.1	0.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3 253	42	2 796
EU-27	70.0	183.7	74.9	105.8	10.6	13.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	128 774	835	62 392

Source: EMEP, UNFCCC

Table 5: Interpretation variables, EU27, 2005 (mil. €, people)

	Manufacture of chemicals, chemical products and man-made fibers	Manufacture of rubber and plastic products	Population
	Mil. € (current prices)		People
Austria	2873.1	1716.9	8 206 524
Belgium	9076.3	1908.9	10 445 852
Bulgaria	228.9	99.4	7 761 049
Cyprus	63.3	34.1	749 175
Czech Republic	1269.3	1481.2	10 220 577
Denmark	3322.4	1297.1	5 411 405
Estonia	NA	NA	1 347 510
Finland	1980	1047	5 236 611
France	21134	10980	62 637 596
Germany	48010	21960	82 500 849
Greece	1092.2	546.3	11 082 751
Hungary	1540.9	732	10 097 549
Ireland	11678.8	559.5	4 109 173
Italy	16695.3	9651.7	58 462 375
Latvia	64.3	45.7	2 306 434
Lithuania	207.9	221.9	3 425 324
Malta	56.7	40.7	402 668
Netherlands	10013	1834	16 305 526
Poland	3062.4	2457.4	38 173 835
Portugal	1043.5	662.9	10 529 255
Romania	686.1	549.1	21 658 528
Slovakia	365.8	367.9	5 384 822
Slovenia	795.2	381.5	1 997 590
Spain	11567	5479	43 038 035
Sweden	6413.6	1376.3	9 011 392

United Kingdom	24754.3	12015.2	60 059 900
EU-27	176626.5	77488	491 023 535

Source: Eurostat

III. External costs of the chemical industry in EU-27 member states

External costs quantified according to above mentioned data give us interesting image of chemical industry. Looking on chemical processes pollutant number one in terms of damage caused is NH_3 (with NO_X and SO_2) while in energy processes in chemical industry first place holds usual suspects – sulphur dioxide and nitrogen oxides. Please note that this split between energy and none energy part of the chemical industry is heavily influenced by reporting discipline of the member states. Looking on data in table 2-4 process one can see that this discipline has its limits.

Processes in chemical industry within EU produced more than 2 bln. € of external costs. Ninety percents of this cost is due to classical air pollutants and particulate matter. Heavy metals and organic pollutants caused 1.5 mil. €.

In energy processes accounted damage was 1.5 bln € and again it was caused mainly by classical pollutants (more than 90%).

Greenhouse gasses were not quantified in above figures. Doing so, they effectively double external costs from this sector. Chemical processes produced damage ranging between 0.6 bln € to 2.1 bln. €. Energy in chemical industry caused damage ranging between 0.5 bln € to 1.8 bln €. Damage from processes is caused mainly (60%) by N2O while damage from energy is caused mainly by CO_2 (90%).

Euro per capita normalizes up to some degree size of the country. For example France has highest damage from chemical sector compared with rest of the EU countries but normalized values per capita are far from being highest. Values are ranging between 0.3 € per capita for Latvia to 41.6 €per capita for Belgium. Table 7 shows figures per capita and table 8 uses figures per € of gross value added by this sector.

Values "per € of gross value added" normalize external costs to monetary output of the sector. This figure is little tricky because NACE categorization used for GVA is not completely compatible with NFR and UNFCCC nomenclature, however for this comparison we ague that discrepancies are bearable. External costs per € of GVA ranges between 0.1 €c/€ of GVA for Ireland to 82€c/€ of GVA for Bulgaria.

Table 6: External cost from chemical industry (processes and energetics), EU27, 2005 (mil. €)

Country	NH_3	NMVOC	NO_x	SO_x	$PM_{2.5}$	PM_{co}	As	Cd	Cr	Hg	Ni	Pb	DIOX	GHG sc1	GHG sc2	GHG sc3
Austria	1.1	1.6	18.8	11.0	13.9	0.8	0.0	0.0	0.0	0.1	0.0	0.1	0.0	13.3	35.6	46.7
Belgium	15.1	24.5	80.4	62.3	30.0	2.4	0.0	0.0	0.0	2.3	0.0	0.0	0.0	81.4	217.1	285.0
Bulgaria	44.5	-0.2	91.8	73.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.3	62.1	81.6
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	4.9	0.4	76.9	125.8	8.3	0.5	0.1	0.0	0.0	2.5	0.0	0.1	0.0	58.8	156.9	205.9
Denmark	0.6	0.0	0.1	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	8.6	11.2
Estonia	0.7	0.1	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	2.4	3.1
Finland	0.4	0.5	2.9	19.5	0.8	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	10.4	27.8	36.5
France	26.2	24.8	241.6	356.9	64.6	4.3	0.1	0.0	0.0	9.6	0.0	0.1	0.0	149.2	397.9	522.3
Germany	110.5	4.5	74.7	214.1	12.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	177.6	473.6	621.6
Greece	0.0	0.3	4.1	52.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hungary	11.4	5.5	61.2	123.4	8.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.7	119.1	156.4
Ireland	0.0	0.0	2.6	2.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	6.9	9.1
Italy	1.9	2.0	22.3	57.6	9.6	1.2	0.0	0.0	0.0	3.9	0.0	0.0	0.0	128.2	341.9	448.7
Latvia	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.5
Lithuania	2.3	0.0	2.1	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	55.4	72.7
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	24.4	10.5	96.8	40.1	46.4	3.7	0.0	0.1	0.0	0.4	0.0	0.7	0.0	133.0	354.8	465.7
Poland	0.0	6.0	58.0	14.6	76.6	4.8	0.0	0.0	0.0	2.9	0.0	0.0	0.0	82.7	220.5	289.5
Portugal	11.9	5.1	3.7	65.1	73.6	3.9	0.1	0.0	0.0	0.9	0.0	0.1	0.0	26.5	70.7	92.7
Romania	156.4	1.3	58.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.8	90.2	118.4
Slovakia	3.5	0.3	29.2	61.2	10.3	0.6	0.0	0.0	0.0	3.8	0.0	0.0	0.0	18.8	50.2	65.9
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	3.6	4.8
Spain	52.4	7.1	109.7	47.2	14.8	1.1	0.0	0.0	0.0	5.2	0.0	0.0	0.0	71.3	190.0	249.4
Sweden	0.9	1.0	7.6	8.5	9.1	0.3	0.0	0.0	0.0	1.0	0.0	0.0	0.0	12.8	34.0	44.6
United Kingdom	51.7	26.2	3.9	41.4	15.1	1.2	0.0	0.0	0.2	9.1	0.0	4.0	0.0	36.5	97.5	127.9
EU-27	667.6	113.0	1082.4	1332.7	395.3	28.1	0.3	0.1	0.1	42.3	0.1	4.8	0.1	1152.0	3072.0	4032.0

Table 7: External cost from chemical processes, EU27, 2005 (mil. €)

Country	NH_3	NMVOC	NO_x	SO_x	$PM_{2.5}$	PM_{co}	As	Cd	Cr	Hg	Ni	Pb	DIOX	GHG sc1	GHG sc2	GHG sc3
Austria	0.8	1.3	5.5	5.9	4.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	13.6	17.8
Belgium	15.0	23.9	31.5	31.0	7.7	1.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	33.9	90.5	118.7
Bulgaria	44.5	-0.2	91.8	73.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	25.9	34.0
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	4.0	0.1	2.2	6.8	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.3	27.4	36.0
Denmark	0.6	0.0	0.1	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Estonia	0.7	0.1	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	2.3	3.0
Finland	0.4	0.5	1.0	15.0	0.1	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	10.2	27.2	35.7
France	26.2	24.2	53.9	43.6	8.1	0.6	0.0	0.0	0.0	6.5	0.0	0.0	0.0	51.8	138.1	181.2
Germany	110.5	4.5	74.7	214.1	12.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	177.6	473.6	621.6
Greece	0.0	0.3	2.2	16.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hungary	10.7	5.1	37.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	44.4	58.3
Ireland	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Italy	1.9	2.0	22.3	57.6	9.6	1.2	0.0	0.0	0.0	3.9	0.0	0.0	0.0	54.5	145.3	190.8
Latvia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	2.3	0.0	1.8	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.1	53.5	70.2
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	24.3	9.6	0.0	0.0	41.4	3.3	0.0	0.1	0.0	0.4	0.0	0.7	0.0	62.3	166.2	218.1
Poland	0.0	6.0	58.0	14.6	76.6	4.8	0.0	0.0	0.0	2.9	0.0	0.0	0.0	52.5	140.1	183.9
Portugal	11.9	5.0	0.3	52.3	64.3	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	40.9	53.7
Romania	156.4	1.3	58.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.8	90.2	118.4
Slovakia	0.4	0.3	2.1	0.0	1.4	0.1	0.0	0.0	0.0	3.8	0.0	0.0	0.0	7.5	20.1	26.3
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9	1.2
Spain	52.4	5.4	10.4	25.7	9.8	0.8	0.0	0.0	0.0	4.9	0.0	0.0	0.0	14.0	37.5	49.2
Sweden	0.6	1.0	2.9	1.5	2.6	0.1	0.0	0.0	0.0	1.0	0.0	0.0	0.0	3.0	8.0	10.5
United Kingdom	51.7	26.2	3.9	41.4	15.1	1.2	0.0	0.0	0.2	9.1	0.0	4.0	0.0	36.5	97.5	127.9
EU-27	663.9	107.3	418.9	642.5	257.8	18.2	0.0	0.1	0.1	35.1	0.0	4.3	0.0	620.0	1653.3	2170.0

Table 8: External cost from energy processes in chemical industry, EU27, 2005 (mil. €)

Country	NH_3	NMVOC	NO_x	SO_x	$PM_{2.5}$	PM_{co}	As	Cd	Cr	Hg	Ni	Pb	DIOX	GHG sc1	GHG sc2	GHG sc3
Austria	0.3	0.2	13.3	5.1	9.7	0.5	0.0	0.0	0.0	0.1	0.0	0.1	0.0	8.3	22.0	28.9
Belgium	0.1	0.6	48.9	31.3	22.3	1.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0	47.5	126.7	166.2
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.6	36.2	47.6
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	0.9	0.4	74.8	119.0	7.1	0.4	0.1	0.0	0.0	2.5	0.0	0.1	0.0	48.6	129.5	170.0
Denmark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	8.5	11.2
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Finland	0.0	0.0	1.9	4.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.8
France	0.0	0.6	187.7	313.3	56.5	3.7	0.1	0.0	0.0	3.1	0.0	0.1	0.0	97.4	259.9	341.1
Germany	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Greece	0.0	0.0	2.0	36.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hungary	0.7	0.4	23.8	123.4	8.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.0	74.7	98.0
Ireland	0.0	0.0	2.6	2.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	6.9	9.1
Italy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	73.7	196.5	258.0
Latvia	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.5
Lithuania	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.9	2.5
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	0.1	0.9	96.8	40.1	5.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	70.7	188.6	247.6
Poland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.2	80.4	105.6
Portugal	0.0	0.1	3.3	12.9	9.3	0.5	0.1	0.0	0.0	0.9	0.0	0.1	0.0	11.1	29.7	39.0
Romania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slovakia	3.1	0.0	27.1	61.2	8.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.3	30.1	39.5
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.7	3.5
Spain	0.0	1.8	99.3	21.4	4.9	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	57.2	152.6	200.2
Sweden	0.3	0.0	4.7	7.0	6.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	26.0	34.1
United Kingdom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU-27	3.7	5.7	663.5	690.2	137.5	9.8	0.3	0.0	0.0	7.1	0.1	0.5	0.1	532.0	1418.7	1862.0

Table 9: Normalized external cost from chemical industry, EU 27, 2005 (€ per €of GVA; € per capita)

Country	Per GVA	Per capita
Ireland	0.001	3.1
Denmark	0.002	2.0
Slovenia	0.003	1.8
Latvia	0.005	0.3
United Kingdom	0.007	4.2
Sweden	0.008	6.9
Germany	0.013	10.8
Italy	0.017	7.5
Finland	0.017	10.0
Austria	0.018	10.1
Spain	0.025	9.9
EU-27	0.027	13.7
Greece	0.035	5.1
France	0.035	18.0
Belgium	0.040	41.6
Netherlands	0.049	35.4
Poland	0.069	10.0
Czech Republic	0.137	36.8
Portugal	0.138	22.3
Hungary	0.145	32.7
Lithuania	0.158	19.9
Slovakia	0.217	29.6
Romania	0.249	14.2
Bulgaria	0.828	35.0
Estonia	NA	2.7

IV. Conclusion

The analysis covered different aspect of the chemical industry in the Europe. Speciality of the chemical industry is that above other sectors that cause airborne emissions due to incineration of fossil fuels there is considerable part of pollution due to chemical processes themselves. Half of the sector external cost is caused by greenhouse gasses, carbon dioxide are associated with energetic of the sector, chemical processes emit nitrous oxide and methane.

If we look solely on chemical processes in chemical industry within EU, they produced more than 2 bln. € of external costs. Ninety percents of this cost is due to classical air pollutants and particulate matter. Heavy metals and organic pollutants caused 1.5 mil. €.

Looking on greenhouse gasses chemical processes produced damage ranging between 0.6 bln € to 2.1 bln. € (depending on valuation scheme selected). Energy in chemical industry caused damage ranging between 0.5 bln € to 1.8 bln €. Damage from processes is caused mainly (60%) by N2O while damage from energy is caused mainly by CO_2 (90%).

Comparison of the chemical industry between the countries depends on indicator selected, and on denominator used as explanatory value. Values are ranging between 0.3 € of external costs per capita for Latvia to 41.6 €per capita for Belgium. Values “per € of gross value added” normalize external costs to monetary output of the sector. External costs per € of GVA ranges between 0.1 €c/€ of GVA for Ireland to 82€c/€ of GVA for Bulgaria.

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Appendix I: Contributors to the report

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