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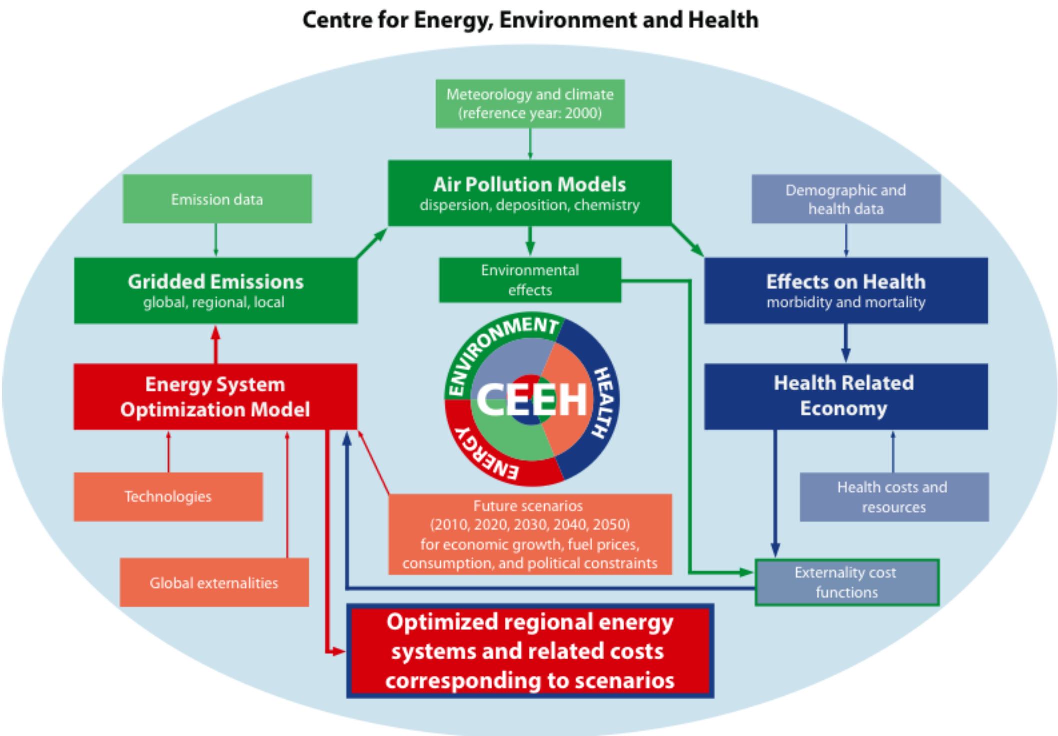
Assessment of Health-Cost Externalities of Air Pollution at the National Level using the EVA Model System



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Danish Summary

Baggrund
Luftforurening har signifikante negative effekter på menneskers helbred og velbefindende og dette har væsentlige samfundsøkonomiske konsekvenser. Vi har udviklet et integreret modelsystem, EVA (Economic Valuation of Air pollution), baseret på den såkaldte ”impact-pathway” metode, med det formål at kunne opgøre de helbredsrelaterede omkostninger fra luftforureningen fordelt på de forskellige kilder og emissionssektorer. Den essentielle ide bag EVA-systemet er at bruge state-of-the-art videnskabelige metoder i alle leddene af ”impact-pathway” kæden for at kunne understøtte politiske beslutninger med henblik på regulering af emissioner, baseret på den bedst tilgængelige viden.

”Impact-pathway” kæden dækker alle leddene fra udslip af kemiske stoffer fra specifikke kilder, over spredning og kemisk omdannelse i atmosfæren, eksponering af befolkningen, beregning af helbredseffekter, til den økonomiske værdisætning af disse helbredseffekter. Den økonomiske værdisætning af effekter kaldes også for indirekte omkostninger eller eksternaliteter. Fx er der direkte omkostninger forbundet med produktionen af elektricitet i form af opførelse af kraftværker og forbrug af kul. De helbredsrelaterede omkostninger fra luftforureningen fra et kulkraftværk er ikke en direkte omkostning relateret til produktion og forbrug, og de betegnes derfor som indirekte omkostninger. De kemiske stoffer, som er medtaget EVA-systemet mht. helbredseffekter er: de primært emitterede partikler, $PM_{2,5}$, de sekundært dannede partikler: $SO4^{2-}$, $NO3^{-}$ og $NH4^{+}$, samt gasserne SO_2, CO og O_3. Det er kun helbredseffekter der for nuværende er medtaget i EVA-systemet. Miljøeffekter og effekter på klimaet vil blive medtaget på et senere tidspunkt.

Formål
Vi præsenterer i denne rapport for første gang estimater for de helbredsrelaterede indirekte omkostninger på nationalt niveau for hver af de overordnede emissionssektorer i Danmark, baseret på EVA systemet. Hovedformålet er at identificere de menneskeskabte aktiviteter og kilder i og omkring Danmark, som giver de største bidrag til helbredseffekterne. Vi har derfor foretaget en generel screening af de overordnede emissionssektorer i Danmark, som bidrager til luftforureningen og beregnet de tilhørende helbredseffekter, samt de totale helbredsrelaterede eksterne omkostninger for år 2000 (både hver sektor for sig og alle sektorerne samlet). År 2000 er valgt som basisår for beregningerne i CEEH, da der i forvejen findes andre sammenlignelige studier for dette år. Emissionssektorerne er repræsenteret ved de 10 overordnede SNAP emissionssektorer (SNAP er en international nomenklatur for kildetyper til luftforurening – Selected Nomenclature for Air Pollution).

Vi har desuden beregnet de eksterne omkostninger fra den internationale skibstrafik særskilt, da denne sektor bidrager væsentligt til luftforurening i Danmark. Vi har beregnet resultater for bidraget fra den samlede skibstrafik på den nordlige halvkugle. Speciel opmærksomhed er givet til den internationale skibstrafik i Østersøen og Nordsøen, dels på grund af beliggenheden af disse farvande omkring Danmark, dels fordi der i disse områder er indført tiltag for at regulere svovlemissioner fra skibe (det såkaldte SECA-område – Sulphur Emission Control Area).

Derudover har vi vurderet helbredseffekter og tilhørende eksternaliteter fra alle emissioner fra den nordlige halvkugle (inkl. de naturlige emissioner) for at estimere de totale helbredsrelaterede eksterne omkostninger fra de totale luftforureningsniveauer både i Danmark og i Europa. Disse resultater er sammenlignet med tilsvarende resultater opnået i Clean Air For Europe (CAFE) projektet. Både for den internationale skibstrafik og for de totale luftforureningsniveauer er der beregnet resultater for årene 2000, 2007, 2011 og 2020. Emissionsopgørelserne for 2000, 2007 og 2011 er baseret på data fra EMEP (European Monitoring and Evaluation Programme). Emissionerne for år 2011 er baseret på opgørelsen for år 2007, med den forskel at svovlemissionerne fra den internationale skibstrafik i Nordsøen og Østersøen i dette år bliver yderligere reguleret. For 2020 er beregningerne baseret på implementering af NEC-II (National Emission Ceilings) direktivet for Europa.

Vi konkluderer at luftforurening udgør et seriøst problem mht. helbredseffekter og at de relaterede eksterne omkostninger er betragtelige. De eksterne omkostninger kan benyttes til en direkte sammenligning af bidragene fra de forskellige emissionssektorer mht. effekter på helbred og kan derved bruges som direkte beslutningsstøtte for regulering af emissioner. I rapporten er de relative bidrag fra de forskellige overordnede emissionssektorer beregnet for år 2000. De større og umiddelbart synlige kilder til luftforurening (fx kraftværker og vejtrafik) udgør ikke nødvendigvis de mest signifikante problemer relateret til helbredseffekter. Andre og mindre åbenbare kilder kan give signifikante effekter på natur og mennesker. Derfor har vi i rapporten screenet alle de overordnede emissionssektorer og vurderet deres indbyrdes bidrag. Vi giver derved et bud på hvilke overordnede sektorer der er væsentlige mht. helbredseffekter fra luftforurening, og hvilke der er mindre væsentlige.

Resultater og konklusioner i hovedtræk

De overordnede resultater og konklusioner i rapporten mht. helbredsrelaterede eksterne omkostninger i Danmark og Europa for år 2000 som følge af **emissioner fra danske landbaserede kilder** er:

- De helbredsrelaterede eksterne omkostninger i Europa fra danske kilder udgør 4,9 mia. Euro/år (37 mia. DKK/år). De eksterne omkostninger indenfor Danmark fra danske kilder udgør 0,8 mia. Euro/år (6 mia. DKK/år).
- Den relative fordeling af de overordnede emissionssektorer i Danmark, som bidrager til helbredsrelaterede eksterne omkostninger fra luftforurening er givet i tabellen herunder. Fordelingen afspejler sektorernes kildestyrke, kildernes geografisk fordeling i forhold til befolkningen og påvirkning af luftforureningsstoffernes levetider som afhænger af ikke-lineære kemiske og fysiske processer i atmosfæren. Første kolonne giver de helbredsrelaterede eksterne omkostninger i hele Europa fra danske emissionssektorer, mens den anden kolonne giver fordelingen hvis man kun medtager effekter inden for Danmark fra de danske kilder.

Emissionssektor	Bidrag i % til de totale helbredsrelaterede eksterne omkostninger fra danske emissioner	
	Bidrag til hele Europa	Bidrag indenfor Danmark
Store centrale kraftværker	10,3 %	5,7 %
Boligopvarmning, inkl. brændeovne	9,3 %	16,3 %
Decentrale kraftværker i forbindelse med industriproduktion	5,3 %	4,3 %
Produktionsprocesser, såsom cement, papir, metal	1,9 %	3,1 %
Ekstraktion og distribution af fossile brændstoffer	1,7 %	2,3 %
Brug af opløsningsmidler fx i maling	2,6 %	2,5 %
Vejtrafik	17,6 %	19,3 %
Andre mobile kilder (traktorer, plæneklippere, mv.)	7,9 %	7,2 %
Affaldshåndtering og forbrænding	0,6 %	0,1 %
Landbrug	42,8 %	39,4 %
Sum	100,0 %	100,0 %

Helbredseffekterne skyldes udslip af de kemiske stoffer kulmonooxid (CO), svovldioxid (SO_2), kvælstofoxider (NO_x), flygtige organiske forbindelser (VOC) og primære partikler ($PM_{2,5}$) fra fx forbrændingsprocesser. Disse stoffer har enten direkte helbredseffekter (fx CO, SO_2 og $PM_{2,5}$) eller bliver kemisk omdannet til andre stoffer i atmosfæren såsom ozon (O_3) eller sulfat- og nitratpartikler. Bidraget fra landbruget skyldes emissioner af ammoniak (NH_3) som omdannes til partikler i atmosfæren (ammoniumsulfat og ammoniumnitrat).

De overordnede resultater og konklusioner mht. helbredsrelaterede effekter fra den **internationale skibstrafik** er:

- Emissionerne fra den internationale skibstrafik (hele den nordlige halvkugle) er ansvarlig for helbredsrelaterede eksterne omkostninger i Europa på 58 mia. Euro/år (435 mia. DKK/år), hvilket svarer til 7 % af de totale helbredsrelaterede eksterne omkostninger i år 2000. I år 2020 er omkostningerne steget til 64 mia. Euro/år (480 mia. DKK/år), svarende til 12 % af de totale helbredsrelaterede eksterne omkostninger.
- Antallet af for tidlige dødsfald i Europa pga. den internationale skibstrafik er ca. 49500 tilfælde i år 2000 og ca. 53200 tilfælde i år 2020.
- Bidraget til de helbredsrelaterede eksterne omkostninger i Danmark fra den internationale skibstrafik udgør 18 % af de totale helbredsrelaterede omkostninger i Danmark for år 2000 og 19 % for år 2020, selvom de totale helbredsrelaterede eksterne omkostninger i Danmark fra den internationale skibstrafik falder fra 800 mio. Euro/år (6 mia. DKK/år) i år 2000 til 480 mio. Euro/år (3,6 mia. DKK/år) i 2020.
- Bidraget til de totale helbredsrelaterede eksterne omkostninger i Danmark fra den internationale skibstrafik i Østersøen og Nordsøen udgør 14 % i både år 2000 og i år 2020. Den procentvise andel af de eksterne omkostninger fra skibene ændrer sig ikke på trods af indførelsen af regulering på svovlemissionerne fra skibene, da de overordnede luftforureningsniveauer falder tilsvarende.

De overordnede resultater og konklusioner mht. helbredsrelaterede effekter fra de **totale luftforureningsniveauer** er:

- De totale helbredsrelaterede eksterne omkostninger i Danmark fra de totale luftforureningsniveauer udgør 4,5 mia. Euro/år (34 mia. DKK/år) for år 2000, svarende til knap 2 % af det danske BNP. Dette tal falder til 3,8 mia. Euro/år (29 mia. DKK/år) for år 2007 og til 2,5 mia. Euro/år (19 mia. DKK/år) i år 2020 (2020 baseret på NEC-II emissionsscenariet).
- Antallet af for tidlige dødsfald i Danmark pga. luftforurening er estimeret til ca. 4000 tilfælde for år 2000, faldende til ca. 3400 tilfælde i år 2007 og ca. 2200 tilfælde i år 2020.
- Den totale helbredsrelaterede eksterne omkostning for hele Europa pga. luftforurening er estimeret til 803 mia. Euro/år (6000 mia. DKK/år) for år 2000, svarende til ~5 % af det samlede BNP indenfor EU (det tilsvarende tal i CAFE-beregningerne er 790 mia. Euro/år). De totale eksterne omkostninger i år 2007 er estimeret til 682 mia. Euro/år (5100 mia. DKK/år) faldende til 537 Euro/år (4000 mia. DKK/år) i år 2020.
- Vi estimerer det totale antal af for tidlige dødsfald i hele Europa pga. luftforurening til 680000 tilfælde i år 2000, faldende til 450000 tilfælde i år 2020.

Perspektivering i forhold til CEEH

Arbejdet som præsenteres i denne rapport indgår som et vigtigt grundelement i Center for Energi, Miljø og Helbred (www.ceeh.dk), og arbejdet er delvist finansieret gennem dette center. Den grundlæggende ide i CEEH er at opstille omkostningseffektive scenarier for fremtidens danske energisystemer. Arbejdet i CEEH adskiller sig fra andre lignende aktiviteter ved, at vi i CEEH ikke kun medtager de direkte omkostninger i forbindelse med energisystemerne, men også de indirekte omkostninger (eksternaliteter). Da disse indirekte omkostninger er ganske betydelige – som det vil fremgå af denne rapport – har det stor betydning for hvilke fremtidige energi-systemer, der rent økonomisk er mest effektive. Som et eksempel bliver omkostningseffektiviteten for vindenergi væsentlig forøget relativt til fx fossile brændsler og bio-brændsler, når man medtager de indirekte omkostninger. Disse resultater vil blive præsenteret i andre CEEH rapporter.

Summary

Air pollution has significant negative impacts on human health and well-being, which entail substantial economic consequences. We have developed an integrated model system, EVA (Economic Valuation of Air pollution), based on the impact-pathway chain, to assess the health-related economic externalities of air pollution resulting from specific emission sources or sectors. The EVA system was initially developed to assess externalities from power production, but in this study it is extended to evaluate external costs at the national level from all major emission sectors. The essential idea behind the EVA system is that state-of-the-art scientific methods are used in all the individual parts of the impact-pathway chain and to make the best scientific basis for sound political decisions with respect to emission control.

The main objective of this work is to find the anthropogenic activities and emission sources in and around Denmark that give the largest contribution to human health impacts. In order to meet this objective we have made an overall screening of all significant emission sectors in Denmark that contribute to impacts on human health. In this report, we estimate the impacts and total health-related external costs from the main emission sectors in Denmark, represented by the 10 major SNAP (Selected Nomenclature for Sources of Air Pollution; see Appendix C for details) categories as well as all emission sectors simultaneously. Besides these major categories, we assess the external costs from international ship traffic, since this sector is an important contributor to air pollution in Denmark. Special attention has been on the international ship traffic from the Baltic Sea and the North Sea, since these waters are close to Denmark and special regulatory actions on sulphur emissions have been introduced in these areas. Furthermore, we assess the impacts and externalities of all emissions from the Northern Hemisphere simultaneously (including natural emissions) to estimate the total health-related external costs from the total air pollution levels in Europe, and these results are compared to similar results obtained in the Clean Air For Europe (CAFE) project. Both for international ship traffic and for the total air pollution levels, results are presented for present and future conditions, represented by the years 2000, 2007, 2011 and 2020.

We conclude that air pollution still constitutes a serious problem to human health and that the related external costs are considerable. The related external costs found in this work can be used directly to compare the contributions from the different emission sectors, potentially as a basis for decision making on regulation and emission reduction. The major immediate and visible emission sources (e.g. power plants and road traffic) do not always constitute the most significant problems related to human health. Other less obvious sources can cause significant impacts on nature and human health.

The major results and conclusions concerning external costs within Denmark can be summarised as follows:

- The main emission sectors in Denmark contributing to health-related external costs in Denmark are: agriculture (39%), road traffic (19%), domestic heating (wood stoves; 16%), other mobile sources (7%), and power plants (6%).
- Taking into account the health-related external costs in Europe, the sectors are: agriculture (43%), road traffic (18%), major power plants (10%), domestic heating (wood stows; 9%) and other mobile sources (8%).
- Emissions in Denmark cause health-related external costs in Europe of 4.9 billion (bn) Euros/year. Out of this, the effects in Denmark from Danish sources correspond to 0.8 bn Euros/year.
- The total external cost in Denmark from all air pollution sources in Europe is 4.5 bn Euros/year for the year 2000, corresponding to ~2% of the Danish GDP. This figure is decreasing to 3.8 bn Euros/year for the year 2007 and projected to 2.5 bn Euros/year for the year 2020 based on the NEC-II emission scenario.

- The number of premature deaths in Denmark due to air pollution is ~4000 for the year 2000, decreasing to ~3400 in the year 2007 and ~2200 in the year 2020.

The major results and conclusions concerning effects from international ship traffic are:

- Emissions from international ship traffic are responsible for external costs related to impacts on human health of 58 bn Euros/year corresponding to 7% of the total health costs in Europe in 2000 increasing to 64 Euros/year in the year 2020 corresponding to 12% of the total health costs.
- The number of premature deaths in Europe due to international ship traffic is ~49500 and ~53200 for the year 2000 and 2020, respectively.
- The contribution to health-related external costs from international ship traffic to Denmark is 18% of the total external cost in Denmark in the year 2000 and 19% in the year 2020, even though the total external cost from international ship traffic is decreasing from ~800 million (mio) Euros/year to ~480 mio Euros/year.
- The contribution to the external cost of health effects in Denmark from international ship traffic in the Baltic Sea and North Sea is 14% in both years 2000 and 2020.

The major results and conclusions concerning effects from the total air pollution levels are:

- The total health-related external cost for the whole of Europe is 803 bn Euro/year for the year 2000. The total external cost in 2007 is 682 bn Euro/year. For the year 2020 the total external cost is decreasing to 537 bn Euro/year.
- We estimate the total number of premature deaths in the whole of Europe in the year 2000 due to air pollution to ~680000/year, decreasing to ~450000 in the year 2020.

The work presented in this report is an important element of the Centre for Energy, Environment and Health (www.ceeh.dk), and the work has been financed partly via CEEH. The basic idea in CEEH is to identify cost effective scenarios for future energy systems in Denmark. The approach in CEEH is different from other similar activities, which generally only considers the direct costs associated with the energy systems. In CEEH we also include the indirect costs or externalities. Since these indirect costs are quite large – as can be seen from the present report – they influence the choice of economically effective energy systems significantly. As an example the cost efficiency of wind energy relative to e.g. fossil fuels and bio-fuels is increased when indirect cost are considered. These results will be published in other CEEH reports.

1. Introduction

Atmospheric pollution has serious impacts on human health. In particular, atmospheric particulate matter (PM) is responsible for increased mortality and morbidity, primarily via cardiovascular and respiratory diseases (Schlesinger et al., 2006). In addition to such diseases, air pollution levels have been shown to be associated with health outcomes such as diabetes (Pearson et al., 2010), premature births (Ponce et al., 2005), life expectancy (Pope et al., 2009) and infant mortality (Woodruff et al., 2008). Such associations have been demonstrated in both short term (e.g. Maynard et al., 2007) and long-term epidemiological studies (e.g. Pelucchi et al., 2009). The effects of PM are most pronounced among those with increased susceptibility such as infants, the elderly, and people with high BMI (Puett et al., 2009) or with chronic diseases such as diabetes (O'Neill et al., 2005) or asthma (Dales et al., 2009). Several studies have shown that the effects of fine PM depend upon the source of the PM. The effects of different sources appear to differ between regions; for example, Zanobetti et al. (2009) showed that PM originating from industrial combustion is associated with higher rates of hospital admission than PM from other sources whereas Karr et al. (2009) also found contributions from local traffic and from wood smoke (Karr et al., 2009).

Globally, urban outdoor air pollution is responsible for an estimated 1.4% of premature deaths, or 0.5% of disability-adjusted-life-years lost (Ezzati et al., 2002). In particular, studies indicate that PM causes approximately 3% of deaths attributable to cardiopulmonary disease among adults, and approximately 5% of lung and trachea cancers (Cohen et al., 2004).

To reduce the negative effects of air pollution on human health or natural eco-systems, it is useful to model air pollution emission sources in order to determine an optimal regulation strategy (e.g. using a cost/benefit approach). This can be done to assess the costs/benefits of a hypothetical change in emissions, which may be useful for planning policy and regulatory measures. Amann et al. (2005) and Watkiss et al. (2005) provide recent examples of this in the European context, where they modelled the effects of implementing the EU's directives on atmospheric ozone and PM concentrations. They estimated that the annual costs of ozone and PM in the EU25 countries amounted to between 276 bn Euros/year and 790 bn Euros/year in the year 2000, and that this would be reduced by 87 bn Euros/year and 181 bn Euros/year, respectively, if the directives are followed.

Such optimisations typically rely upon standardised source-receptor relationships, which are normally based on concentrations calculated with a chemical transport model (CTM). One example is the RAINS/GAINS system (Alcamo et al., 1990; Klassen et al., 2004), as used by Amann et al. (2005) and Watkiss et al. (2005). However, such calculations rely on the assumption of a linear source-receptor relationship between emission changes and subsequent changes in air pollution levels. A slightly more sophisticated approach has also been applied in RAINS, where the linearity assumption has been substituted for a piecewise linear relationship for PM, and for ozone the relationship may be parameterised using polynomials (Heyes et al., 1996). However, such assumptions are still approximations to the real response to emission reductions and are constructed for saving computing time. The alternative approach, which we apply in this work, is to calculate the impacts from every emission scenario using state-of-the-art scientific methods without assuming linearity of the highly non-linear atmospheric chemistry.

This report examines the effects of air pollution in Denmark, where roughly 3000-4000 people die prematurely every year due to present levels of atmospheric pollution (Palmgren et al., 2005). On the transnational level, air pollution is a major focus area for the EU and WHO, which both provide directives/guidelines for limit values of PM or ozone concentrations to minimise impacts on human health (EU 2008; WHO 2006a).

In this work, we explore the implications of using a three-dimensional, Eulerian chemistry-transport model (CTM) to evaluate the external costs of air pollution. This was done with the EVA model (Economic Valuation of Air pollution; see section 2.1), using estimates of exposure from the Danish Eulerian Hemispheric Model (DEHM; see section 2.2). Other components of EVA are exposure-response functions and economic valuations of individual impacts. The exposure-response functions used in EVA, adapted from Watkiss et al. (2005), are based on assessments from experts in public health in the EU and in consultation with the WHO. The estimates for health costs are converted to Danish prices and preferences, based on the methodology of Watkiss et al. (2005).

The use of a comprehensive CTM to calculate the effects under specific emission scenarios has one key advantage: it accounts for the non-linear chemical transformations and feedback mechanisms influencing air pollutants. Non-linearity in the source-receptor relationship is particularly evident for certain atmospheric components, such as NO_x, VOC, ozone, PM, and NH_3 but also for SO_2 as will be shown in this report.

Normally, when estimating the impacts from specific emission sources, two model runs (simulations using a CTM) are carried out: one including all emissions, and one including all emissions minus the specific emissions of interest. Estimated yearly mean concentrations from the latter model run are subtracted from those of the first model run, and the resulting difference provides an estimate of the contribution of the specific emissions sources of interest to the total air pollution levels (the so-called δ-function). However, if the difference in concentrations due to the specific source is relatively small, there is a risk that this difference will be of the same order of magnitude or smaller as the numerical noise from the CTM or smaller. To reduce the influence of this numerical noise when estimating δ-functions, we have developed a “tagging” method. This method estimates source-receptor relationships and accounts for non-linear processes such as atmospheric chemistry, while maintaining a high signal-to-noise ratio. This method is more accurate than simply subtracting two concentration fields.

The work presented in this report was carried out within Centre for Energy, Environment and Health (CEEH), a research centre funded by the Danish Council for Strategic Research. CEEH is a collaboration between scientists from different research fields, with a mission to develop a system to optimise and support planning of future energy systems in Denmark, where both direct and indirect costs related to environment, climate, and health are considered.

Since the external costs, as can be seen in this report, are quite large we have found in CEEH that including these costs in an energy optimization model significantly improves the cost effectiveness of e.g. wind-energy relative to fossil fuels and bio-fuels. Therefore the present report documenting and validating in more detail the external costs is a very important part of the development work in CEEH. The external cost estimates in the present report include a number of sectors, which are not part of the CEEH energy system optimization. However, in order to validate the EVA system, it is important to include all relevant emission sectors, since the chemistry associated with air pollution is highly non-linear. It is noted that in CEEH we also develop a so-called health impact assessment (HIA) model, which can be used as a method, similar to EVA, to estimate externality costs. The HIA model based estimates are designed to include also the possible influences of future changes in demography.

Using the EVA system, we estimate the total health-related external costs from the main emission sectors in Denmark, represented by the 10 major emission sections (or SNAP categories; defined in appendix C) as well as the total air pollution levels. Furthermore, we assess the impacts and external costs of emissions from international ship traffic around Denmark, since there is a high volume of ship traffic in the region. Both for international ship traffic and for the total air pollution levels, results are presented for former, present and future conditions, represented by the years 2000, 2007, 2011 and 2020. Results are given both for Denmark and Europe for all scenarios.

In section 2, a description of the EVA model system is given. In section 3, the hypotheses and questions that constitute the background for this study, and the simulations set up to answer these questions, are defined and the results from the individual scenarios using the EVA model system are presented. The detailed results from all the individual scenarios are presented in appendix A (figures) and appendix B (tables). Section 4 includes the general results and discussions of the results and section 5 contains the general conclusions of this work.

2. The EVA Model System

In this section a description of the EVA model system (Frohn et al., 2005; 2007; Andersen et al., 2006; 2007; 2008; Brandt et al., 2010) is given. The section first presents an overview of the model system, and then a description of the individual modules in the system.

2.1. Overview of the EVA model

The concept of the EVA system is based on the impact pathway chain (e.g. Friedrich and Bickel, 2001), as illustrated in figure 1. The EVA system consists of a regional-scale CTM, address-level or gridded population data, exposure-response functions and economic valuations of the impacts from air pollution. The system was originally developed to value site-specific health costs related to air pollution, such as from specific power plants (Andersen et al., 2006), but is in this work extended to assess health cost externalities at the national level.

The essential idea behind the EVA system is that state-of-the-art methods are used in all the individual parts of the impact-pathway chain. Other comparable systems commonly use linear source-receptor relationships, which do not accurately describe non-linear processes such as atmospheric chemistry and deposition. The EVA system has the advantage that it describes such processes using a comprehensive, state-of-the-art chemical transport model when calculating how specific changes to emissions affect air pollution levels. The geographic domain used by DEHM covers the Northern Hemisphere, and therefore describes the intercontinental contributions, and includes higher resolution nesting over Europe (see section 2.2 and figure 2). All scenarios are run individually and not estimated using linear extra-/interpolation from standard reductions as e.g. used in the RAINS/GAINS system (Alcamo et al., 1990; Klassen et al., 2004).

To estimate the effect of a specific emission source or emission sector, emission inventories for the specific sources are implemented in DEHM, as well as numerous other anthropogenic and natural emission sources. However, quantifying the contribution from specific emission sources to the atmospheric concentration levels is a challenge, especially if the emissions of interest are relatively small. Numerical noise in atmospheric models can be of a similar order of magnitude as the signal from the emissions of interest. To calculate the δ-concentrations (i.e. the marginal difference in regional ambient concentration levels due to a specific emission source), we have developed a new "tagging" method (see figure 3; section 2.3), to examine how specific emission sources influence air pollution levels, without assuming linear behaviour of atmospheric chemistry, and reducing the influence from the numerical noise. This method is more precise than taking the difference between two concentration fields.

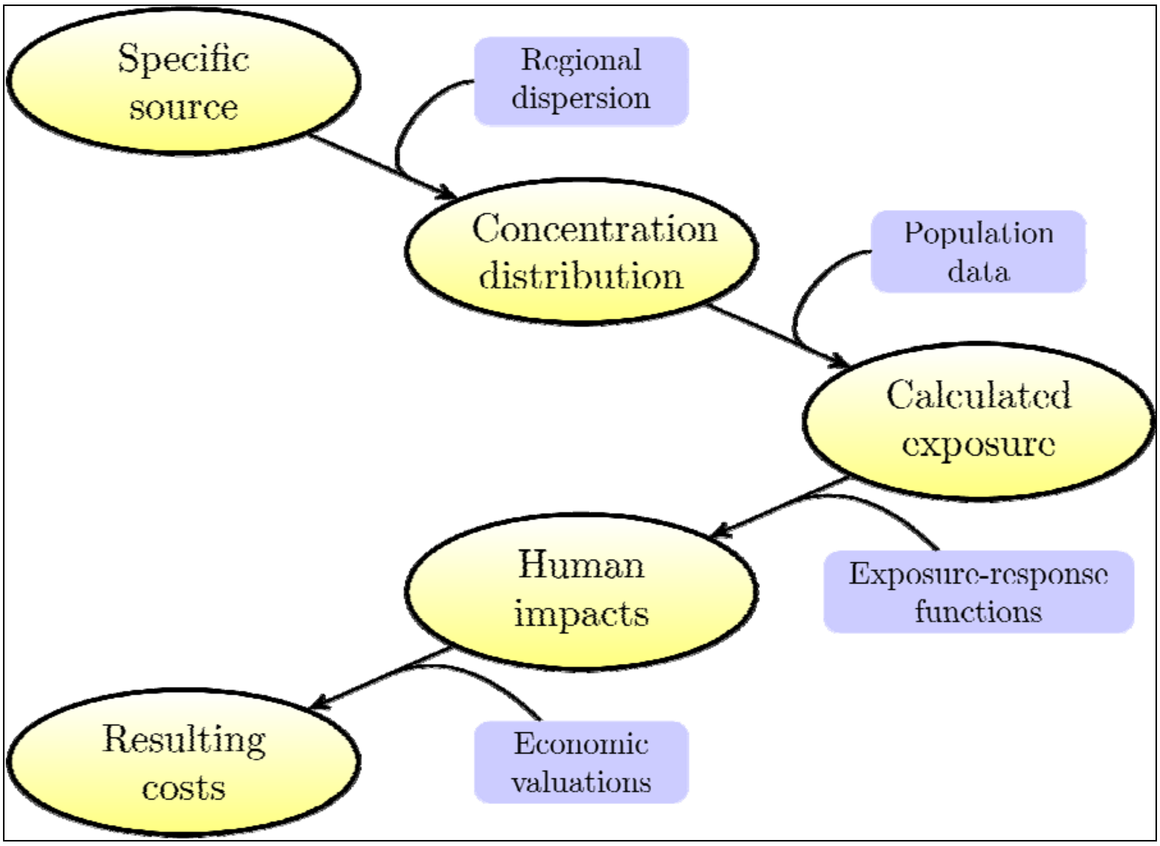

Figure 1: A schematic diagram of the impact-pathway methodology. The effects of site-specific emissions result (via atmospheric transport and chemistry) in a concentration distribution, which together with detailed population data can be used to estimate the population-level exposure. Using exposure-response functions and economic valuations, the exposure can be transformed into impacts on human health and related external costs.

Estimates of delta-concentrations are combined with address-level population data for Denmark and gridded population data for the rest of Europe, to calculate the exposure. Population-level health outcomes are estimated by combining population-level exposure with exposure-response functions found in the literature. External costs for the entire population are estimated using cost functions customised for Danish conditions in the EVA model system.

2.2. The Danish Eulerian Hemispheric Model

The Danish Eulerian Hemispheric Model (DEHM) is a three-dimensional, offline, large-scale, Eulerian, atmospheric chemistry transport (CTM) (Christensen, 1997; Christensen et al., 2004; Frohn 2004; Frohn et al., 2001; 2002; 2003; Brandt et al., 2001; 2003; 2007; 2009; Geels et al., 2002; 2004; 2007; Hansen et al., 2004; 2008a; 2008b; Hansen et al., 2011; Hedegaard et al., 2008; 2011) developed to study long-range transport of air pollution in the Northern Hemisphere and Europe. The model domain covers most of the Northern Hemisphere, discretized in a 96 × 96 horizontal grid, using a polar stereographic projection (figure 2). The projection is true at 60º north, where the horizontal grid resolutions for the coarse, medium and fine grids are 150 km × 150 km, 50 km × 50 km, and 16.67 km × 16.67 km, respectively, using two-way nesting (Frohn et al., 2002). The vertical grid is defined using the σ-coordinate system (Phillips, 1957), with 20 vertical layers. The model describes concentration fields of 58 chemical compounds and 9 classes of particulate matter ($PM_{2.5}$, PM_{10}, TSP, sea-salt < 2.5 µm, sea-salt > 2.5 µm, smoke, fresh black carbon, aged black carbon, organic carbon). A total of 122 chemical reactions are included.

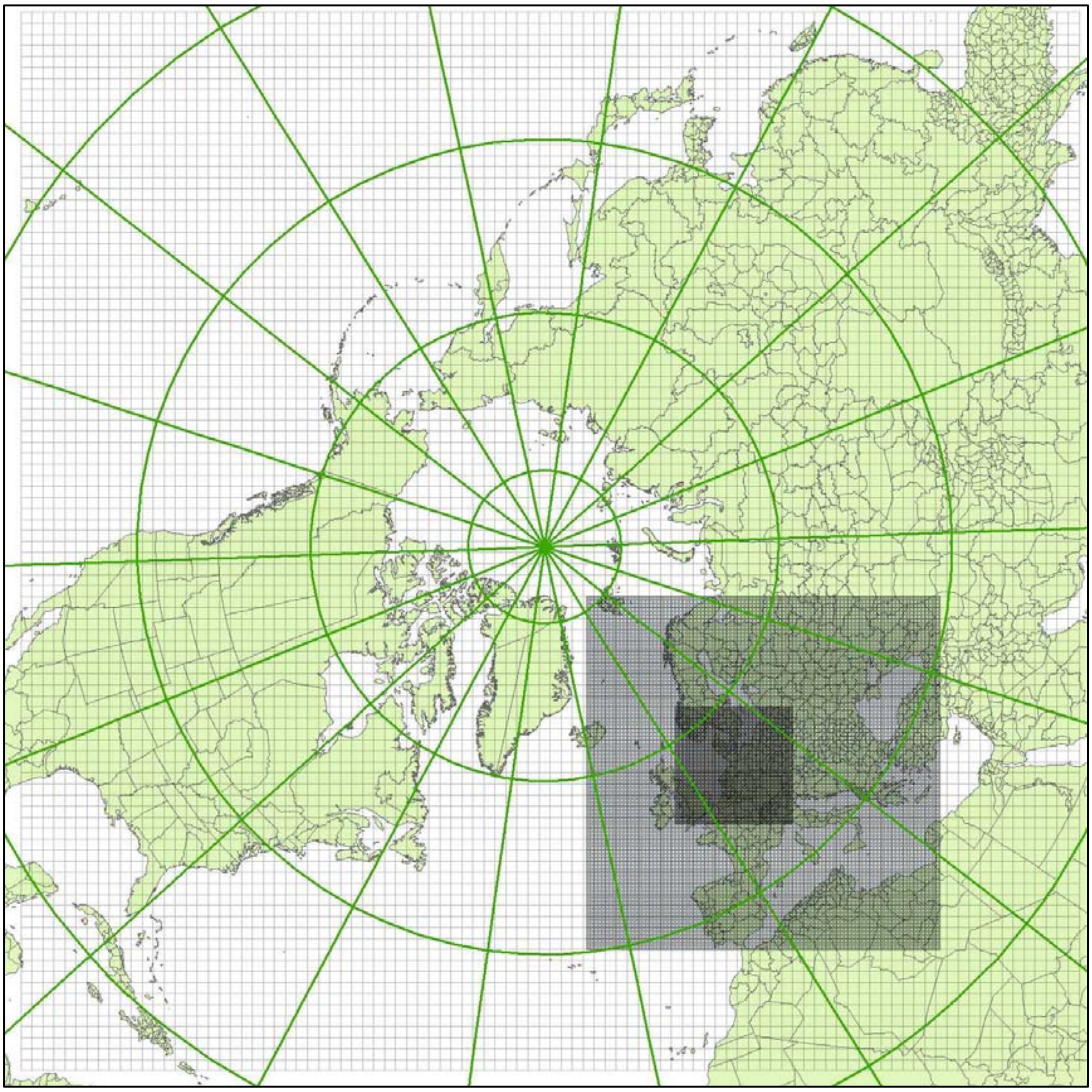

Figure 2: The DEHM model domain (polar stereographic projection) with two nests. The mother domain covers the Northern Hemisphere with a resolution of 150 km × 150 km. The two nested domains included have resolution of 50 km × 50 km and 16.67 km × 16.67 km, respectively.

The model has undergone an extensive model validation where model results have been validated against measurements from the whole of Europe over a 20 year period (Hansen et al., in preparation). In DEHM, the continuity equation is solved:

$$\frac{\partial c}{\partial t} = -\left(u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + \dot{\sigma}\frac{\partial c}{\partial \sigma} \right) + K_x \frac{\partial^2 c}{\partial x^2} + K_y \frac{\partial^2 c}{\partial y^2} + \frac{\partial}{\partial \sigma}\left(\rho K_\sigma \frac{\partial c}{\partial \sigma} \right) + P(c,t) - L(c,t)$$

where c is the concentration, t is time, u, v, and $\dot{\sigma}$ are the wind speed components in the x, y and σ directions, respectively. K_x, K_y, and K_σ are dispersion coefficients, while P and L are production and loss terms, respectively. The above equation is approximated by splitting it into sub-equations, which are solved iteratively. The sub-models represent: a) advection, b) horizontal diffusion, x-direction, c) horizontal diffusion, y-direction, d) vertical diffusion, and e) sources and sinks (including chemistry). While some accuracy is lost due to the splitting, the sub-models can each be solved using the most appropriate numerical methods. Frohn et al. (2002) provides further details of the splitting procedure, including how each sub-model is solved. The Forester and Bartnicki filters are applied to resolve Gibbs oscillations and negative concentration estimates, respectively (Forester, 1977; Bartnicki, 1989), however, the Bartnicki filter is only used for the background field and not for the tagged field described in the next section.

Meteorological variables (wind speed, pressure, temperature, humidity) are obtained from the MM5v3 meteorological model (Grell et al., 1994). Integration of the sub-models involves a non-constant time-step, ensuring that the Courant-Friedrich-Lewy condition is satisfied. The time step is based on the grid spacing and the fastest wind-speed in the model domain, thus the time step in each sub-nest is typically approximately one-third of that for the parent nest.

Wet deposition, included in the loss term, is expressed as the product of scavenging coefficients and the concentration (Christensen, 1995). In contrast, dry deposition is solved separately for gases and particles, and deposition rates depend on the land-cover (Frohn, 2004).

Boundary conditions (BCs) for the outermost domain depend on the direction of the wind, such that free BCs are used for sections where wind flows out of the domain. Constant BCs are used for sections of the boundary where wind is blowing into the domain; in this case, the boundary value is set to the annual average background concentration.

Emissions are based on several inventories, including EDGAR (Olivier & Berdowski, 2001), GEIA (Graedel et al., 1993), retrospective wildfires (Schultz et al., 2008), ship emissions both around Denmark (Olesen et al., 2009) and globally (Corbett and Fischbeck, 1997), and emissions from the EMEP database (Mareckova et al., 2008).

2.3. The tagging method

In order to calculate the contributions from a specific emission source or sector to the overall air pollution levels (the δ-concentrations), one can in principle run an Eulerian CTM twice – once with all emissions and once with all emissions minus the specific source. The difference between the two resulting annual mean concentration fields gives an estimate of the δ-concentration – we will call this the *subtraction method* for estimating δ-concentrations.

Modern Eulerian CTMs rely on higher-order numerical methods for solving the atmospheric advection in order to avoid numerical diffusion. Although higher-order algorithms are relatively accurate, they nevertheless introduce a certain amount of spurious oscillations or noise – this is called the Gibbs phenomenon. These unwanted oscillations can cause major problems for estimating δ-concentrations via the subtraction method. We have found through a number of experiments that the δ-concentrations may be of similar or smaller order of magnitude compared to the numerical oscillations.

To avoid this problem, we developed a more accurate method for comparing concentrations from two sets of emission fields. We call this method “tagging”, denoting that we keep track of contributions to the concentration field from a particular emission source or sector. An overview of this method is given in figure 3. The idea is that we model the δ-concentrations explicitly, rather than calculating them post-hoc (i.e. by subtraction). Tagging makes use of the fact that the numerical noise is typically proportional to the concentrations being modelled. Even if the δ-concentrations are much smaller than the “background” concentrations (i.e. for some baseline scenario), they will generally be orders of magnitude larger than the oscillations using the tagging method. Consequently, estimates of the δ-concentrations are much more accurate.

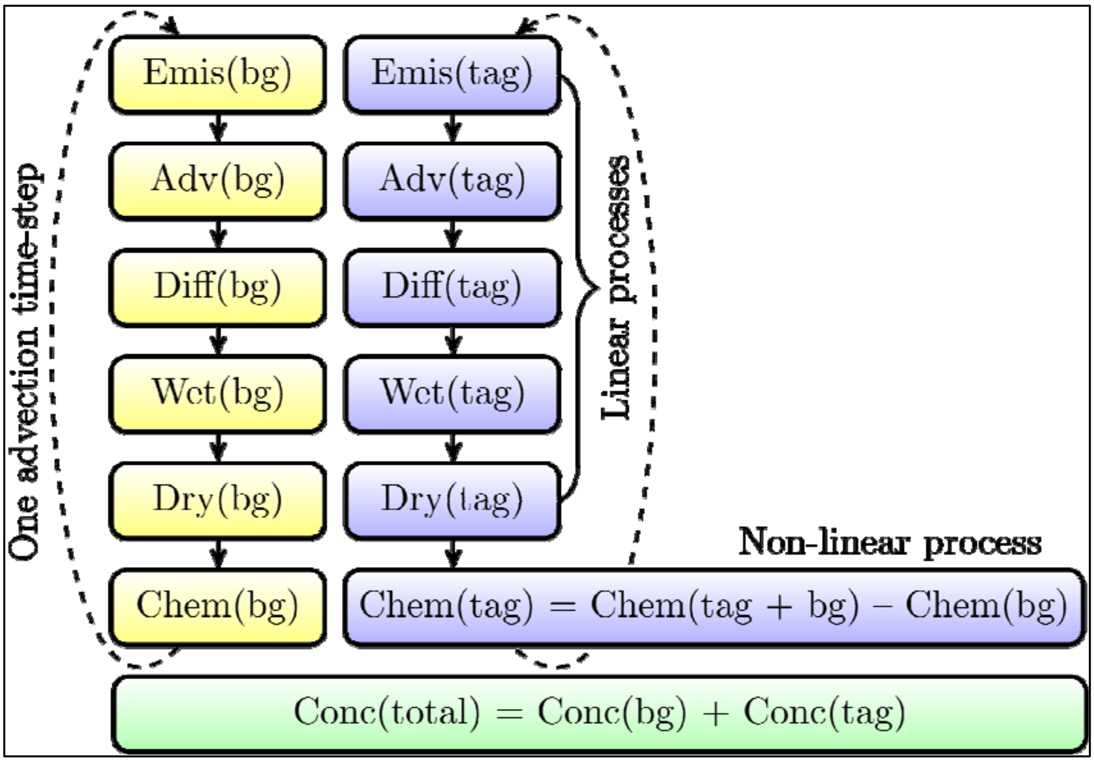

Figure 3: An overview of the tagging method. The concentration field for a specific emission source (tag) is modelled in parallel with the background field (bg) in the CTM. The need for tagging is due to the non-linear process of atmospheric chemistry (Chem). The linear processes are emissions (Emis), advection (Adv), atmospheric diffusion (Diff), wet deposition (Wet), and dry deposition (Dry). For the non-linear process, the tagged concentration fields are estimated by first adding the background and tag concentration fields, then applying the non-linear operator (e.g. the chemistry). The concentration field obtained by applying the non-linear operator to the background field alone is then subtracted. Thus the contribution from the specific emission source is accounted for appropriately without assuming linearity of the non-linear atmospheric chemistry.

Tagging involves modelling the background concentrations and the δ-concentrations in parallel. Special treatment is required for the non-linear process of atmospheric chemistry, since the δ-concentrations are strongly influenced by the background concentrations in such processes; although this treatment involves taking the difference of two concentration fields, it does not magnify the oscillations, which are primarily generated in the advection step. Thereby the non-linear effects (e.g. from the background chemistry) can be accounted for in the δ-concentrations without losing track of the contributions arising from the specific emission source or sector due to Gibbs phenomenon.

Tagging has two major disadvantages compared to the subtraction method. Firstly, it requires that the two simulations be run simultaneously in the CTM, thereby doubling the required memory. If many simulations are to be compared to a common baseline, then the tagging method will require roughly twice the computational time compared to the subtraction method. Secondly, it is not well-suited for cases where many specific scenarios should be compared to several others, since each pair-wise comparison requires its own (paired) model run; in other words, if n is the number of scenarios to compare, the subtraction method will require n simulations whereas the tagging method will require $n(n - 1)$ simulations. Furthermore, results from the tagging method require far more storage space compared to the subtraction method. These disadvantages must be weighed against the increased accuracy. Since present days computer costs are relatively low, a high number of simulation is not insurmountable.

2.4. Population data

Denmark has a central registry, detailing the address, gender and age of every person in Denmark (the Central Person Register, CPR). A subset of this database was extracted for the year 2000, chosen as the base year for the EVA system, see figure 4. Address data was interpolated to the DEHM grid to obtain gridded population data. For each grid cell, the number of persons of each age and gender was aggregated, as a first step in estimating population-weighted exposure. On the European scale, a similar data set was obtained from the EUROSTAT 2000 database (http://epp.eurostat.ec.europa.eu/), covering every country within the European Union. The EVA system is not applied outside of Europe in this work and therefore population data in the rest of the world is not applied.

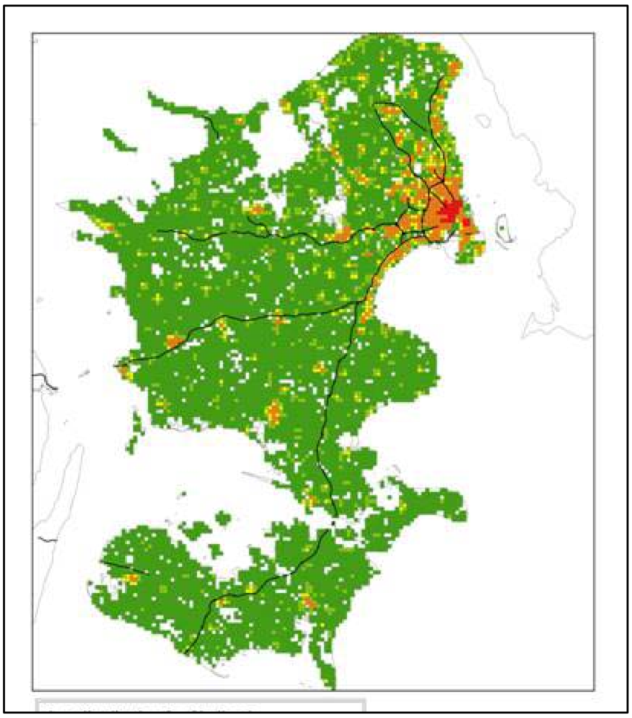

Figure 4: Population distribution presented in a 1 km × 1 km resolution covering Eastern Denmark based on the Danish Central Person Register (CPR).

2.5. Exposure-response functions and monetary values

To calculate the impacts of emissions from a specific source or sector, δ-concentrations and address-level population data are combined to estimate human exposure, and then the response is calculated using an exposure-response function, which has the form:

$$R = \alpha \cdot \delta c \cdot P$$

where R is the response (e.g. in cases, days, or episodes), δc is the δ-concentration (i.e. the additional concentration resulting from emissions of a particular emission source), P is the affected share of the population, and α is an empirically-determined constant for the particular health outcome, typically obtained from published cohort studies. In this study we model the exposure-response relationship as a linear function. Pope et al. (2000) showed that this is a reasonable approximation, based on a cohort study of 500,000 individuals and this is also supported by the joint World Health Organization/UNECE Task Force on Health (EU, 2004; Watkiss et la., 2005). The corresponding monetary values are country-specific, depending on the economic conditions of the individual nations. The exposure-response relations and valuations used in the EVA system (Table 1) are applicable for Danish and European conditions. For details and references for these coefficients and valuations, see Andersen et al. (2006).

All relevant chemical compounds (i.e. those for which solid evidence of exposure-response functions are found in literature) are included in the study. For compounds in aerosol phase, the impacts are assumed to be proportional to their contribution to the particle mass, as opposed to the number of particles. Presently, the compounds related to human health impacts included in the EVA system are: O_3, CO, SO_2, SO_4^{2-}, NO_3^-, and the primary emitted part of $PM_{2.5}$. This calculation is based on the assumption that health impacts can be caused by changes in the air pollution concentrations of these compounds. This assumption is also used in the Clean Air for Europe (CAFE) calculation in Watkiss et al. (2005) and Amann et al. (2005), supporting European Commission strategies.

Mortality

Following conclusions from the scientific review of the Clean Air For Europe appraisal (Hurley et. al., 2005:30; Krupnick, Ostro and Bull, 2005), we base the exposure-response function for chronic mortality in response to $PM_{2.5}$ on the finding of Pope et. al. (2002). It is the most extensive study available and its results are supported by a re-analysis, which examined methodological issues in great detail (Krewski et. al., 2000).

Chronic mortality refers to long-term mortality risks associated with exposure. Life-tables for Denmark, year 2000, provide the basis for quantifying impacts of a 1-year increase in exposure and we assume a 10-year time-lag between the exposure pulse and subsequent changes in mortality risks for the relevant age-groups above 30. The number of lost life years for a cohort with normal age distribution, when applying Pope's exposure-response for all-cause mortality (Relative Risk, RR=1,06), and the latency period indicated, sums to 1138 per 100.000 individuals for a 10 µg $PM_{2.5}$/m3 increase.

While the ER for chronic mortality is derived from cohort studies, we know from numerous time-series studies that air pollution exposure also may cause acute effects. Because acute deaths are valued differently from chronic death (see valuation section below) it is important to quantify these separately. Several studies have established a linkage between sudden infant death and exposure to SO_2. It has also been established that ozone concentrations above the level of 35 ppb involve a mortality increase, presumably for weaker and elderly individuals. We apply the ER's selected in CAFÉ for post-neonatal death (age group 1-12 months) and acute ozone death (Hurley et. al., 2005). Finally there are studies which have shown that SO_2 cause acute deaths and we apply the ER identified in the APHEA study (partly for sensitivity, but they contribute hardly anything to overall external costs in our results).

Morbidity

Chronic exposures to $PM_{2.5}$ cause some trajectories of mortality that involve periods with morbidity. This is the case with lung cancer, for instance, and we apply the specific ER (RR=1,08) for lung cancer indicated in Pope (2002) as a basis for figuring out the morbidity costs associated with lung cancers.

Bronchitis is a chronic disease and its prevalence has been shown to increase with chronic exposure to $PM_{2.5}$. We apply an ER (RR=1,007) for new cases of bronchitis on basis of the AHSMOG study (based on non-smoking seventh-day Adventists) the same epidemiological study as in CAFE (Abbey, 1995; Hurley et. al., 2005). The background rate is the ExternE crude incidence rate, which is in line with a Norwegian study, rather than the pan-European estimates used in CAFE (ExternE, 1999; Eagan et. al., 2002).

Restricted activity days comprise two types of responses to exposure; so-called minor restricted activity days as well as work-loss days. This distinction is to enable accounting for the different costs associated with days of reduced well being and actual sick days. It is assumed that 40% of RAD's are work-loss days. The background rate and incidence is derived from ExternE (1999). Hospital admissions are deducted to avoid any double counting.

Hospital admissions and health effects for asthmatics (bronchodilator use, cough and lower respiratory symptoms) are also based on ExternE (1999).

For the effects of heavy metals (lead and mercury) we here refer to results obtained with the Risk-Poll model by Rabl and Spadaro (2004) for loss of IQ for exposure during first year of life or in foetus stage. These findings are based on a meta-study for lead (Schwartz et. al., 1994) and a pilot study on mercury (Budtz-Jørgensen et. al. 2004). The relationship between air lead and blood lead is significant for final results and has been consolidated with a bio-kinetic model of body accumulation (Pizzol et. al., 2010).

Valuation

OECD guidelines for environmental cost-benefit analysis (OECD, 2006) address the complex debate on valuation of mortality. It is not human life per se which is valued, but the willingness to pay for preventing risks of fatalities. Whereas in transport economics it has become customary to employ a Value of Statistical Life (VSL), environmental economics has sophisticated valuation by developing the metric of a Value Of Life Year lost (VOLY). In part this is due to the difference between transport victims that are more mid-age, whereas victims of environmental exposures tend to be more elderly (as a result of latency time lag and chronic exposures). Hence fewer life years are assumed lost per individual as a result of environmental exposures.

OECD guidelines recommend applying a VSL approach to valuation for acute mortality and a VOLY approach for chronic mortality. Acute mortality occurs as an instant result of exposure, whereas chronic mortality results from increased levels of exposure over a long period of time. However, while a degree of consensus has emerged over estimates of VSL, in part because of the rich literature published over the past decades, the estimates used for a VOLY are based on relatively few studies. An expert panel was gathered by the European Commission and agreed on a consensus estimate of 1.4 million Euro for an EU-wide VSL, an update essentially on the original Jones-Lee study (1988). Alberini et. al. (2006) have derived a VOLY estimate from a three country study which was used as a basis for the CAFE assessment. With an Alberini VOLY of 52,000 euro it takes about 27 VOLY's for a full VSL of 1.4 million Euros.

In Denmark the average age for a traffic victim is 45-48, with the implication that in average the number of years lost are 27-30. Hence there is reasonable consistency with the VSL-VOLY factor of 27, if one assumes that preferences for risk aversion are linear with remaining life expectancy. It could be a bold assumption, as certain studies indicate that preferences for risk aversion may change with age more according to a reverse U-curve, but due to very few respondents doubts hang over these results. A panel advising US EPA noted that VOLY in fact may discriminate against elderly and that risk aversion needs to be treated according to a common format for all age groups.

For our purposes we may nevertheless note that the approach recommended in OECD guidelines is conservative and does not result in upper-bound estimates of willingness to pay for risk aversion.

Table 1: Health effects, exposure-response functions and economic valuation (applicable for Danish/European conditions) currently included in the EVA model system. (PM = Particulate Matter, including primary $PM_{2.5,}$ NO_3^- and SO_4^{2-}. YOLL is Years of Lost Lifes. SOMO35 (Sum of Ozone Means Over 35 ppb) is the sum of means over 35 ppb for the daily maximum 8-hour values of ozone).

Health effects (compounds)	Exposure-response coefficient (α)	Valuation, Euros (2006-prices)
Morbidity		
Chronic Bronchitis (PM)	8.2E-5 cases/μgm^{-3} (adults)	52,962 per case
Restricted activity days (PM)	=8.4E-4 days/ μgm^{-3} (adults) -3.46E-5 days/ μgm^{-3} (adults) -2.47E-4 days/ μgm^{-3} (adults>65) -8.42E-5 days/ μgm^{-3} (adults)	131 per day
Congestive heart failure (PM)	3.09E-5 cases/ μgm^{-3}	16,409 per case
Congestive heart failure (CO)	5.64E-7 cases/ μgm^{-3}	
Lung cancer (PM)	1.26E-5 cases/ μgm^{-3}	21,152 per case
Hospital admissions		
Respiratory (PM)	3.46E-6 cases/ μgm^{-3}	7,931 per case
Respiratory (SO_2)	2.04E-6 cases/ μgm^{-3}	
Cerebrovascular (PM)	8.42E-6 cases/ μgm^{-3}	10,047 per case
Asthma children (7.6 % < 16 years)		
Bronchodilator use (PM)	1.29E-1 cases/ μgm^{-3}	23 per case
Cough (PM)	4.46E-1 days/ μgm^{-3}	59 per day
Lower respiratory symptoms (PM)	1.72E-1 days/ μgm^{-3}	16 per day
Asthma adults (5.9 % > 15 years)		
Bronchodilator use (PM)	2.72E-1 cases/ μgm^{-3}	23 per case
Cough (PM)	2.8E-1 days/ μgm^{-3}	59 per day
Lower respiratory symptoms (PM)	1.01E-1 days/ μgm^{-3}	16 per day
Loss of IQ		
Lead (Pb) (<1 year)*	1.3 points/ μgm^{-3}	24,967 per point
Mercury (Hg) (fosters)*	0.33 points/ μgm^{-3}	24,967 per point
Mortality		
Acute mortality (SO_2)	7.85E-6 cases/ μgm^{-3}	2,111,888 per case
Acute mortality (O_3)	3.27E-6*SOMO35 cases/ μgm^{-3}	
Chronic mortality (PM)	1.138E-3 YOLL/ μgm^{-3} (>30 years)	77,199 per YOLL
Infant mortality (PM)	6.68E-6 cases/ μgm^{-3} (> 9 months)	3,167,832 per case

* Exposure-response function for Pb and Hg are included in the EVA system. However, they are not included in these studies.

The position of the European Commission has been to use the same unit values for VSL and VOLY across the European Union, although incomes and presumably willingness-to-pay for risk reductions vary considerably. The reviewers of the CAFE cost-benefit analysis made note of these inconsistencies and recommended to weigh risk aversions with purchasing power coefficients of different member states. In our predominantly national CEEH application with EVA we have done so and have used the PPP (purchasing power parities) for Denmark. Hence values of VOLY and VSL in 2006-prices are 77,000 and 2,111,000 respectively. Infant mortality is valued higher, while there is no cancer premium for adults.

For morbidity effects and in the absence of original Danish contingent valuation studies, we have opted for a cost-of-illness approach. For hospital admissions, for instance, unit costs are available in the DRG database of the National Board of Health. Still, 'cough' and 'lower respiratory symptoms' are based on WTP-benefit transfer. Estimates for lung cancer are based on Gundgaard et. al. (2002). For work-loss days 20% productivity loss has been added. Chronic bronchitis and IQ-loss are the result of more complex calculations explained in Pizzol et. al. (2010) and Jensen (2006). Valuation of IQ-loss is linked with changed expectations for lifetime earnings.

The exposure-response coefficients and the related valuation for morbidity and mortality used in the EVA system are summarised in table 1.

2.6. Discussion on health effects from particles

Documentation of negative health effects from particles come from experiments on animals, humans, in laboratories, from short term (time-series) and long term epidemiological studies and the evidence is massive. Hundreds of studies have observed associations with short-term peaks in particle concentrations and adverse health effects (typically based on same-day exposure or exposure from previous 1-3 days but occasionally longer and up to 40 days post exposure). The list of health effects observed in such studies is long, ranging from symptoms such as cough over hospitalization rates or other measures of morbidity to premature mortality. The key morbidity effects quantified in the literature are respiratory hospital admissions and cardiovascular hospital admissions. A number of prospective cohort studies have demonstrated associations between long-term average exposure to particles and health effects including mortality. The latter type of studies have significantly strengthened the likelihood of a direct link between air pollution and severe health outcomes (Dockery et al., 1993; Laden et al., 2006; Krewski et al., 2000; Pope et al., 1995; 2002; Krewski et al., 2009; Jerrett et al., 2005; Abbey et al., 1999; Enstrom et al., 2009; Filleul et al., 2005).

In this work primary and secondary particles are treated equal regarding their attribution to health effects. As described previously, airborne particles have many different sources and may be composed quite differently depending on their sources, the distance to these, climate, and geography. In Denmark, secondary particles dominated by sulphate, nitrate and ammonium constitute a large fraction of the particle mass. Before the pollutants reach humans and can be respired the particles have had time to mix and react and neither primary nor secondary particles are breathed in their pure forms.

Several studies have investigated which particle components are associated most strongly with the health effects. Some investigators argue that it is justified to attribute greater risks for primary particles than for secondary (Andersson et al., 2009; Jerrett et al. 2005). This is based on the higher risks seen in studies based on intra-city exposure gradients compared to inter-city exposure. Andersson et al. (2009) argue that epidemiological studies finding associations of nitrogen oxides as proxies for primary vehicle exhaust exposure also indicate that a higher relative risk than 1.06 should be applied for primary particulates.

Negative health effects of SO2 have been documented and despite the great decrease in SO2 emissions in the industrialized parts of the world, effects of SO2 are still observed, by e.g. Pope et al. (2002). That SO2 plays a role is also supported by the 2.1 % decline in all-cause annual change in mortality in Hong Kong after reduction of the sulphur content of fuels in 1990 (Hedley et al., 2002). As the sulphate and PM10 concentrations were not lowered in the 5-year follow-up period, the effects were ascribed to SO2. The importance of SO2 is also supported by the short-term effects of

SO2 observable across Europe in the late 1990ties (Katsouyanni et al., 1997). Other studies, however, do not support the importance of SO2 in causing health effects (Schwartz et al., 2000; Buringh et al., 2000).

From long-term cohort studies there is good evidence of associations between health effects and the sulfate fraction of particles (Pope et al., 2002). In contrast, the nitrate fraction has not been associated as strongly with health effects in such studies or correlations with other compounds have not been excluded as contributing to the effects of nitrate (Ostro et al., 2010). Several smaller epidemiological studies and experimental studies have separated exposures into its chemical compounds and often found that metals show the strongest associations (Franklin et al., 2007). Although such source apportionment studies in recent years commonly have associated health effects with transition metals, some have also found effects associated with sulphates (Zanobetti et al., 2009; Franklin et al., 2008) or nitrates (Ostro et al., 2007; Andersen et al., 2007). A serious problem of interpreting such source specific associations is that most compounds are closely correlated.

When studied experimentally, pure ammonium nitrate and ammonium sulphate do not appear to cause adverse health effects even at concentrations well above those commonly encountered within cities (Schlesinger and Cassee, 2003; Schlesinger, 2007). In view of this and the fact that particle composition varies greatly between locations, it may appear surprising that the health effects associated with particulate air pollution have been observed quite consistently across regions. Possible explanations for this could be that the particle mix that people in all regions of the World are exposed to: 1) contains both primary and secondary particles which adhere and onto which more toxic gases, vapours, and solids are adsorbed (e.g. metals, PAHs and POPs) thus minimizing the difference in toxicity between the particles; 2) is correlated with toxic gases like CO and NOx (which themselves have toxic properties and which may interact with particles when affecting health) in the vicinity of roads or combustion sources. Current evidence suggests that reductions in the respirable fractions of particulate matter concentrations in the air lead to immediate and sustained improved health in the populations exposed. At present it is not possible to predict whether a complete omission of the sources of secondary nitrates and sulphates would reduce health effects correspondingly or whether the remaining primary particles would become more toxic as metals, PAHs, POPs and gases concentrate more on them, thus increasing the health effects associated with them, leading to less than predicted improvement in health.

Unfortunately, the current data are too limited to draw firm conclusions on the toxicity of ambient sulphate and nitrate and in particular to distinguish between different sources of these. A major reason to assume health effects from sulphate- and nitrate-rich particles has been the fact that studies point to emissions from traffic and heavy emitters such as power plants as most strongly related with observed effects and that in many studies the majority of these particles are commonly ascribed to power plants and vehicle emission. Accordingly nitrates are generally found to be higher in urbanized areas (such as the Industrial Midwest, Northeast, and southern California in the USA) (US EPA, 2005). As both sulphates and nitrates form in the atmosphere at distance both in time and space from where their precursor gases were emitted, and form by the same processes no matter their source, there is no reason to consider ammonium-nitrate or ammonium-sulphate stemming from rural emissions less toxic than when formed from inner-city nitric oxide emissions. This is supported by Harrison and Yin (2000).

The problem of how to estimate health effects of secondary particles have been addressed differently in previous air pollution externality models. ExternE (1997 and 2005) made the distinction between the effects of nitrates and sulphates because nitrates need other particles to condense on, whereas sulphates self-nucleate and are therefore smaller on average. Sulphates were treated like

$PM_{2.5}$ and nitrates like PM10. In the NEEDS report (NEEDS, 2007) sulphate and nitrate particles were quantified insofar as they contributed to the total particulate matter concentration. As a sensitivity analysis they proposed to treat primary particles at 1.3 times the toxicity of the $PM_{2.5}$ mixture and secondary particles at 0.7 times the toxicity of $PM_{2.5}$. In DEFRA (2006) the same hazard rate for long-term mortality was used for all particle components. The same approach was chosen in The Clean Air For Europe (CAFE) Programme (Holland et al., 2005) but sensitivity analyses were conducted by assigning different toxicities to primary particles, sulphates and nitrates. The choice in CEEH to assign equal health effect to all components of particles is thus in line with other recent major reports. However, similar to the NEEDS report, we have also carried out a sensitivity analysis, where the secondary inorganic aerosols (nitrate, ammonium and sulphate) are treated at 0.7 times the toxicity of $PM_{2.5}$ and the primary emitted part of $PM_{2.5}$ is treated as 1.3 the toxicity of $PM_{2.5}$.

3. Definition of scenarios and detailed results

In this section, a number of scenarios are defined in order to answer specific questions (section 3.1). In section 3.2, the results from the individual scenario runs are discussed. In section 4, the overall results will be presented at an aggregated level.

3.1. Definition of overall questions and scenarios

All results that follow are given as human health impacts and external costs, both for the whole of Europe and for Denmark specifically – the latter being part of the former. When making decisions about regulation of specific emission sectors, it is important to consider all impacts from the emission sources of interest from all affected countries. However, national interests can also be important, and therefore the human health impacts and external costs are also given for Denmark alone.

In recent years, many of the emission sources/sectors have received considerable attention and action has been taken to regulate emissions where practical and feasible. One could claim that the most visible sectors have been the primary targets of regulation; for example, catalysts and filters have been installed in power plants and vehicles to reduce the amount of pollution emitted (e.g. sulphur, PM, and NO_x). Furthermore, actions have been taken to remove harmful compounds (such as lead, benzene, and sulphur) from gasoline and diesel fuels. All of these actions have had a positive, measurable, and significant impact on air pollution levels.

However, there are many other sources of air pollution than the most obvious, visible sources that are relatively close to humans. When quantifying emissions, more than ten major emission sectors are defined, and two of these are major power plants and road traffic. Furthermore, emission sources do not have to be close to humans in order to have a significant impact on health. Air pollution can be transported in the atmosphere by the wind over thousands of kilometres, and many of the harmful compounds (e.g. the secondary inorganic particles) are produced by chemical reactions along the way, hours or days after their primary compounds are emitted. For that reason, it is not necessarily the most obvious, visible, and closest emission sources that cause the greatest impacts on human health or the environment. Emission sources far away can also have significant and equally important impacts as nearby sources.

Therefore the main aim of this work is to examine all the major emission sectors in Denmark and to quantify their relative importance in terms of their impacts on human health and related external costs, both on the European scale and for Denmark. The external cost is the parameter or the basic unit, which can be used to directly intercompare the sectors. The framework of this study can be used as the basis for future regulatory action in emission reduction strategies.

The main question we try to answer with this work is therefore: Which primary activities and emission sources in and around Denmark are the greatest contributors to health-related externalities? More specifically, the main question can be divided into the following five questions:

- Q1: What are the relative contributions from the ten major emission sectors in Denmark with respect to impacts on human health and related external costs? (i.e. what are the major sources of the health impacts?)
- Q2: What are the total impacts on human health and related external costs due to all the emissions in Denmark?
- Q3: What are the present and future impacts on human health and related external costs in Europe and Denmark from all international ship traffic?
- Q4: What are the present and future impacts on human health and related external costs in Europe and Denmark from international ship traffic in the Baltic Sea and the North Sea?
- Q5: What are the total health impacts and associated externalities from the total present and future air pollution levels?

To answer these questions, a number of different scenarios have been defined in order to estimate health-related externalities from different kinds of emission sources (see table 2). Each scenario is defined by the following three attributes:

1) The **region** where the emission sources are located; In this work the regions are Denmark (DK), the whole hemispheric model domain (all), or the Baltic Sea together with the North Sea (BaS-NoS).
2) The emission sector, where the emission sectors are defined via the major **SNAP** categories. The ten major anthropogenic SNAP categories are defined in table 2 (DK/1-DK/10) as well as SNAP category 15, which we have defined as international ship traffic in our system (is normally contained in SNAP category 8 – other mobile sources. In the following the SNAP category 8 is other mobile sources except the international ship traffic).
3) The **emission year**. The base emission year has been chosen to be year 2000. This has been the base year in many other studies (e.g. the CAFE studies) and therefore it is easier to compare the results in this work to other studies. Besides the year 2000, some scenarios have been calculated for the years 2007, 2011 and 2020 as well. These years were chosen because they are relevant for regulatory actions for emission reduction, and it is interesting to examine the impacts of already planned regulations. In all three years, a maximum sulphur content has been defined for the heavy bunker fuel used by the international ships in the SECA areas (Sulphur Emission Control Areas), which includes both the Baltic Sea and the North Sea. Furthermore, for the year 2020 different targets for emission reduction have been set by the European Commission, such as the so-called thematic strategy for air pollution and the NEC (National Emission Ceilings) strategy. For the year 2020 the emission scenario consists of a specific set of assumptions. It is expected that a new international directive on national emission ceilings to be reached in 2020 is proposed in the near future. The directive is not proposed yet so in this study a scenario for land based emissions is applied that is a combination of the EU thematic strategy for clean air in Europe and scenarios for the 27 EU countries made by the International Institute for Applied Systems Analysis (Amann et al., 2008) as part of the preparatory work of a new NEC directive (NEC-II)

Table 2. Definition of the specific scenarios (or “tags” in the model). Each scenario is defined by a region and a SNAP category (first column), an emission year (second column), a short description of the emissions of interest in the scenario (column 3), and the corresponding model results as shown in the figures in appendix A (column 4).

Region/ SNAP	Emission year	Emission scenario (or the ”tag”)	Appendix A Figure
DK/1	2000	Combustion in energy and transformation industries, Denmark	**A1**
DK/2	2000	Non-industrial combustion plants (in Denmark this equals the domestic heating)	**A2**
DK/3	2000	Combustion in manufacturing industry, Denmark	**A3**
DK/4	2000	Production processes, Denmark	**A4**
DK/5	2000	Extraction and distribution of fossil fuels and geothermal energy, Denmark	**A5**
DK/6	2000	Solvents and other product use, Denmark	**A6**
DK/7	2000	Road transport, Denmark	**A6**
DK/8	2000	Other mobile sources and machinery, Denmark (excluding international ship traffic)	**A8**
DK/9	2000	Waste treatment and disposal, Denmark	**A9**
DK/10	2000	Agriculture, Denmark	**A10**
DK/1-10	2000	Sum of the above 10 SNAP categories, Denmark	**-**
DK/all	2000	All anthropogenic emissions from Denmark (SNAP 1- SNAP 10)	**A11-A13**
All/15	2000	Int. ship traffic for the year 2000, (S=2,7%)*, whole model domain (EMEP=2000)	**A14**
All/15	2007	Int. ship traffic for the year 2007, NS/BS: S=1.5%*, whole domain (EMEP=2006)	**A15**
All/15	2011	Int. ship traffic for the year 2011, NS/BS: S=1.0%*, whole domain (EMEP=2006)	**-**
All/15	2020	Int. ship traffic for the year 2020, NS/BS: S=0.1%*, whole model domain, (NEC-II)	**A16**
BaS-NoS/15	2000	Int. ship traffic for the year 2000, (S=2,7%)*, whole model domain (EMEP=2000)	**A17**
BaS-NoS/15	2007	Int. ship traffic for the year 2007, NS/BS: S=1.5%*, whole domain (EMEP=2006)	**A18**
BaS-NoS/15	2011	Int. ship traffic for the year 2011, NS/BS: S=1.0%*, whole domain (EMEP=2006)	**-**
BaS-NoS/15	2020	Int. ship traffic for the year 2020, NS/BS: S=0.1%*, whole model domain, (NEC-II)	**A19**
All/all	2000	All emissions (anthropogenic; GEIA/EDGAR; EMEP 2000 + natural; international ship traffic as All/15 for the year 2000)	**A20-A22**
All/all	2007	All emissions (anthropogenic; GEIA/EDGAR; EMEP 2006 + natural international ship traffic as All/15 for the year 2007)	**A23**
All/all	2011	All emissions (anthropogenic: GEIA/EDGAR, EMEP 2006 + natural international ship traffic as All/15 for the year 2011)	**-**
All/all	2020	All emissions (anthropogenic: GEIA/EDGAR; NEC-II + natural international ship traffic as All/15 for the year 2020)	**A24**

*The North Sea (NoS) and Baltic Sea (BaS) are part of the Sulphur Emission Control Areas (SECA).

The specific scenarios are defined in table 2. In this table, references to the corresponding figures showing the DEHM model results in appendix A are given. The first ten scenarios (DK/1 to DK/10) are defined for the ten major Danish emission sectors in order to answer question 1. The scenario including all anthropogenic emissions in Denmark (DK/All) is defined in order to answer question 2. The scenario named DK/1-10 is a sum of the results obtained in scenarios DK/1 to DK/10. If the impacts from emission reductions on the air pollution levels were linear, the results from scenarios

DK/1-10 and DK/all would be the same. However, the source-receptor relationships are non-linear due to the effects of atmospheric chemistry, and therefore the scenarios DK/1-10 and DK/all are not expected to be equal. However, the impact from the non-linear atmospheric chemistry depends very much on the chemical regime in the region of interest and on the size of the emission reductions. Therefore it is impossible to estimate the difference between the sum of the 10 scenarios or the 10 scenarios simultaneously a priori.

The scenarios All/15 for the years 2000, 2007, 2011 and 2020 are defined in order to answer question 3. In these simulations, the EMEP emissions covering Europe for the year 2007 have been used for the model calculations 2007 and 2011 and the NEC-II emissions have been used for the year 2020. In the four years (2000, 2007, 2011 and 2020), different ceilings for the sulphur content of the heavy bunker fuel used by the ships are introduced in the SECA area (in this case, the Baltic Sea and the North Sea). For the year 2000, a maximum of 2.7% of sulphur in the fuel is allowed, decreasing to 1.5% in 2007, 1% in 2011 and 0.1% in the year 2015 the latter used for the 2020 scenario in this study.

The scenarios BaS-NoS/15 are defined to answer question 4. The scenarios are similar to the scenarios defined above, except in this case we examine only emissions from international ship traffic in the Baltic Sea and the North Sea, in contrast to the All/15 scenario, where the impacts of emissions from international ship traffic in the whole Northern Hemisphere are investigated.

The All/all scenarios are defined to answer question 5. In this case we aim to estimate the total impact on human health and related externalities from all air pollution, regardless of its origin. To do this, the total air pollution levels due to all emissions (both anthropogenic and biogenic) for the four different years are used as input to the human health impacts module as well as the external cost module in the EVA model system. There are two reasons for estimating the total impacts from present and future air pollution levels:

1) In the public debate, as well as in the political decision making process, it is interesting to have estimates of the total impacts from air pollution in order to quantify the magnitude of the problem. These calculations can be used as a basis for socio-economic research and discussions on the cost and benefits of carrying out emission-reduction strategies.
2) The results can be compared to other similar studies where the total impacts from air pollution have been estimated. The most important results for comparison are the results from the CAFE (Clean Air For Europe) project (Watkiss et al., 2005; Amann et al. 2005). These comparisons constitute the only “validation” of the whole integrated EVA model system. If the results are similar for the total air pollution levels, then we can have greater confidence in the results from the scenarios (note that the linear assumptions of atmospheric chemistry does not apply for the total air pollution levels the CAFE caluculations – only for the scenarios). We can call it a test or verification of the EVA system.

3.2. Results from the individual scenarios using the EVA model system

In this section, the results from the individual scenarios defined in the previous section using the EVA model system will be described. In appendices A and B the detailed results from the simulations are given.

DEHM model results for the individual scenarios

Appendix A includes the results from the DEHM model as plots of annual mean air pollution concentrations over the three geographical domains included in the model. The figures show either the δ-functions from the individual model runs or the total air pollution levels calculated by the model for the six chemical compounds included in the impact chain (SO_2, SO_4^{2-}, CO, primary $PM_{2.5}$, NO_3^- and O_3). An overview of the figures and their relationship to the scenarios is also given in table 2.

Figures A1-A10 show the contribution to the mean annual air pollution levels (δ-concentrations) due to the emissions from the whole of Denmark for SNAP categories 1-10 for the year 2000. Results are shown for DEHM domain number 2 covering Europe. The figures correspond to the scenarios DK/1 to DK/10 in table 2.

Figures A11-A13 show the contribution to the mean annual air pollution levels (δ-concentrations) due to the emissions from the whole of Denmark for all SNAP categories 1 to 10 simultaneously, for the year 2000. Results are shown for all the three DEHM domains. The figures correspond to the scenarios DK/all in table 2.

Figures A14-A16 show the contribution to the mean annual air pollution levels (δ-concentrations) due to the emissions from the Northern Hemisphere for SNAP category 15 (international ship traffic) for the years 2000, 2007, and 2020. The figures correspond to the scenarios All/15 in table 2.

Figures A17-A19 show the contribution to the mean annual air pollution levels (δ-concentrations) due to the emissions from the Baltic Sea and the North Sea (BaS-NoS) for SNAP category 15 (international ship traffic) for the years 2000, 2007, and 2020. The figures correspond to the scenarios BaS-NoS/15 in table 2.

Figures A20-A22 show the mean annual air pollution levels due to the emissions from the Northern Hemisphere for the year 2000. Results are shown for DEHM domain number 1 (the Northern Hemisphere), DEHM domain number 2 (Europe), and DEHM domain 3 (northern Europe). The figures correspond to the scenarios All/all for the year 2000 in table 2

Figures A23 and A24 show the mean annual air pollution levels due to the emissions from the Northern Hemisphere for the years 2007 and 2020 for DEHM model domain number 2 (Europe). The similar result for the year 2000 is shown in figure A21. The figures correspond to the scenarios All/all for the years 2007 and 2020 in table 2.

Figures for all future scenarios for the year 2011 are not shown, since they are very similar to the results for the year 2007. The only difference between the 2007 and 2011 model results is the decrease in the sulphur content of the heavy bunker fuel from 1.5% to 1%.

The results for ozone (O_3) in all the figures show that NO_x emissions in Denmark contribute to both a decrease and an increase in the ozone levels in different areas. This is because the typical effect of the NO_x emissions is a decrease in the ozone levels in the source area (in this case, Denmark) and nearby. Further away from the source, the typical effect of the NO_x emissions is an increase in the ozone concentration levels. This is a well-known non-linear effect, where the chemical production or loss of ozone depends on the chemical regime – meaning the concentrations of the ozone precursors.

Human health impacts and health cost externalities for the individual scenarios

Appendix B contains the detailed results from the EVA model system given as tables, including the different impacts as function of the chemical compounds and the related external costs for all the scenarios defined in table 2. An overview of all the health impacts included in the EVA model system and the related economic valuation per cases is given in table 1.

For all health impacts, two tables are presented; in one table, the total impacts per scenario and compounds as well as related external costs for the whole of Europe are shown. The other table contains the same data, but here the impacts and related external cost are given only for Denmark, which has a special focus in this study. The impacts and external costs presented in the tables for Denmark are included in the results valid for Europe. The tables in appendix B are organised according to the impacts in table 1, as follows:

In tables B1 to B12 the impacts and related external costs for morbidity are given:
- Tables B1-B2: Chronic Bronchitis (PM).
- Tables B3-B4: Restricted Activity Days (PM).
- Tables B5-B6: Respiratory Hospital Admissions (PM and SO2).
- Tables B7-B8: Cerebrovascular Hospital Admissions (PM).
- Tables B9-B10: Congestive Heart Failure (PM and CO).
- Tables B11-B12: Lung Cancer (PM).

In tables B13 to B18 the impacts and related external costs for asthma are given:
- Tables B13-B14: Bronchodilator Use (PM).
- Tables B15-B16: Cough (PM).
- Tables B17-B18: Lower Respiratory Symptoms (PM).

In tables B19 to B24 the impacts and related external costs for mortality are given:
- Tables B19-B20: Acute YOLL (SO_2 and O_3).
- Tables B21-B22: Chronic YOLL PM).
- Tables B23-B24: Infant mortality (PM).

In the tables B19 and B20, the results for O_3 are divided into "O_3 more" and "O_3 less". This refers to the fact discussed above that depending on the chemical regime, O_3 is either chemically produced or lost in different areas as a result of specific NO_x emissions. In this sense, the effect of NO_x emissions on ozone concentration levels is both a cost and a benefit in different areas. In this work, both the cost and the benefit are included in the overall results.

In the next section, these results are aggregated as a basis for the overall results and discussions of this work.

4. Overall results and discussions

The main objective of this work is to make a general assessment of the health-related externalities of air pollution, both at the European level and with a special focus on Denmark. This section describes this assessment.

The secondary objective of the results from the EVA model system, related to the work in the Centre for Energy, Environment and Health (CEEH), is to provide the external cost per emitted kg of the different emitted chemical compounds. The external cost of a specific emitted compound is highly dependent on the location of the emissions in relation to the spatial distribution of the population around the source of interest as well as on chemical and physical atmospheric processes. For example, there is obviously a fundamental difference between the human health effects of one kg of NO_x emitted in the North Sea compared to one kg of NO_x emitted in the city of Copenhagen, due to the difference in the population density close to the respective sources and taking into account the meteorological conditions (e.g. the prevailing wind direction). For the same reason, a power plant located east of Copenhagen will give a different price per emitted kg compared to a power plant located west of Copenhagen.

The costs per kg emitted chemical compound found in this work are used as input to the energy system optimisation model, Balmorel (Ravn et al., 2001), which simulates and optimises the electricity and heat production market in Scandinavia and Germany. The Balmorel model is based on linear optimisation of an energy system, focussing on the power production. It includes district heating systems, individual heating, production of transport fuels, as well as the road transport sector. The kg prices provided in this report will represent an average over the whole of Denmark for each emission sector. In the future work within CEEH, these prices will be given with a geographic dependence, where Denmark will be divided into five regions.

4.1. Total emissions for all the scenarios

In order to estimate the external cost per emitted kg of all the relevant chemical compounds, information on the total emissions involved in all the different scenarios defined in table 2 is required. These emissions are given in table 3.

Table 3: Total emissions in ktonnes for all the different scenarios defined in table 2. The emissions are given for the emitted compounds CO, SO_2 (in ktonnes S), NO_x (in ktonnes N), NH_3, and $PM_{2.5}$ (primary emissions of $PM_{2.5}$ including dust, black carbon (BC) and organic carbon (OC)).

Region/SNAP	Emission year	CO	S	N	NH_3	$PM_{2.5}$
DK/1	2000	4.68	6.36	15.47	0.00	0.80
DK/2	2000	64.21	1.91	2.15	0.00	11.52
DK/3	2000	6.56	2.99	5.04	0.41	1.34
DK/4	2000	0.10	0.49	0.13	0.00	0.25
DK/5	2000	0.00	0.00	0.00	0.00	0.05
DK/6	2000	0.00	0.00	0.00	0.00	0.00
DK/7	2000	128.45	0.18	22.07	2.18	4.72
DK/8	2000	42.61	1.46	11.30	0.00	2.35
DK/9	2000	0.11	0.03	0.93	0.00	0.00
DK/10	2000	0.00	0.00	0.00	85.25	1.61
DK/sum 1-10	2000	246.72	13.42	57.09	87.84	22.64
DK/all	2000	246.70	13.40	57.10	87.84	22.60
All/15	2000	126.1	1011.5	884.1	0.0	276.5
All/15	2007	149.2	993.2	1016.3	0.0	264.7
All/15	2011	149.2	935.3	1016.2	0.0	252.6
All/15	2020	92.9	1162.3	1237.2	0.0	262.6
BaS-NoS/15	2000	38.0	297.7	257.5	0	64.8
BaS-NoS/15	2007	43.8	161.1	289.8	0	30.0
BaS-NoS/15	2011	43.8	103.2	289.8	0	20.7
BaS-NoS/15	2020	53.5	15.6	293.4	0	13.9
All/all	2000	24089.9	10298.3	6102.6	5195.8	3272.0
All/all	2007	19448.5	8278.7	5903.5	4655.0	2718.4
All/all	2011	19448.5	8220.8	5903.5	4655.0	2706.2
All/all	2020	21172.9	5770.2	4236.2	4660.6	3232.6

4.2. Health impacts

The detailed EVA model results for human health impacts and related external costs are presented in the tables in appendix B, where the number of cases per scenario and per chemical compound is given for all the different health impacts. The tables in this section summarise the results that are related to the five overall questions defined in section 3.

Table 4 displays the number of cases in Europe and Denmark related to the different impacts due to all Danish anthropogenic emissions (scenario: DK/all) for the year 2000. Furthermore, references to the tables in appendix B are given. The results in this table relate to question Q2, defined in section 3. As can be seen in the table, the number of cases in Denmark for acute YOLL is negative. This is because the NO_x emissions in Denmark actually cause a decrease in the ozone levels within Denmark (see also the lower right figure in panel A13 in appendix A). In the CAFE calculations (Watkiss et al., 2005), a factor of 10.6 is used to convert between the cases of chronic YOLL and the number of premature deaths. Using this factor, the anthropogenic Danish emissions cause approximately 4600 premature deaths in Europe and approximately 800 premature deaths within Denmark.

Tables 5 and 6 present the number of cases in Europe and Denmark, respectively, related to international ship traffic in the Northern Hemisphere (scenario: All/15) for the four different years. The results in these tables relate to question Q3, defined in section 3.

Tables 7 and 8 give the number of cases in Europe and Denmark, respectively, related to international ship traffic in the Baltic Sea and the North Sea (scenario: BaS-NoS/15) for the four different years. The results in these tables relate to question Q4, defined in section 3.

Table 4: Total number of cases of the different impacts related to all Danish anthropogenic emissions (scenario: **DK/all**) for the year 2000.

Health impact	Number of cases in Europe	Number of cases in Denmark	See tables
Chronic Bronchitis	4.35E+03	8.02E+02	B1-B2
Restricted Activity Days	4.44E+06	8.20E+05	B3-B4
Respiratory Hospital Admissions	2.34E+02	4.44E+01	B5-B6
Cerebrovascular Hospital Admissions	5.56E+02	1.01E+02	B7-B8
Congestive Heart Failure	3.24E+02	6.90E+01	B9-B10
Lung Cancer	6.66E+02	1.23E+02	B11-B12
Bronchodilator Use Children	1.28E+05	2.16E+04	B13-B14
Bronchodilator Use Adults	8.51E+05	1.57E+05	B13-B14
Cough Children	4.41E+05	7.46E+04	B15-B16
Cough Adults	8.76E+05	1.62E+05	B15-B16
Lower Respiratory Symptoms Children	1.70E+05	5.28E+04	B17-B18
Lower Respiratory Symptoms Adults	3.16E+05	5.83E+04	B17-B18
Acute YOLL	8.52E+01	-8.49E+00	B19-B20
Chronic YOLL	4.90E+04	8.52E+03	B21.B22
Infant mortality	4.99E+00	1.02E+00	B23-B24

Table 5: Total number of cases in **Europe** of the different impacts related to international ship traffic in the Northern Hemisphere (scenario: **All/15**) for the four different years.

Health impact	**Number of cases in Europe**			
Year	**2000**	**2007**	**2011**	**2020**
Chronic Bronchitis	4.60E+04	4.49E+04	4.28E+04	4.96E+04
Restricted Activity Days	4.70E+07	4.59E+07	4.37E+07	5.07E+07
Respiratory Hospital Admissions	2.67E+03	2.55E+03	2.41E+03	2.77E+03
Cerebrovascular Hospital Admissions	5.90E+03	5.76E+03	5.49E+03	6.36E+03
Congestive Heart Failure	2.99E+03	2.92E+03	2.78E+03	3.22E+03
Lung Cancer	7.05E+03	6.88E+03	6.55E+03	7.59E+03
Bronchodilator Use Children	1.37E+06	1.34E+06	1.28E+06	1.48E+06
Bronchodilator Use Adults	9.01E+06	8.79E+06	8.37E+06	9.71E+06
Cough Children	4.75E+06	4.63E+06	4.41E+06	5.12E+06
Cough Adults	9.27E+06	9.05E+06	8.62E+06	9.99E+06
Lower Respiratory Symptoms Children	1.83E+06	1.79E+06	1.70E+06	1.97E+06
Lower Respiratory Symptoms Adults	3.34E+06	3.26E+06	3.11E+06	3.60E+06
Acute YOLL	3.63E+03	3.50E+03	3.40E+03	4.47E+03
Chronic YOLL	5.25E+05	5.12E+05	4.88E+05	5.66E+05
Infant mortality	5.16E+01	5.04E+01	4.80E+01	5.56E+01

Table 6: Total number of cases in **Denmark** of the different impacts related to international ship traffic in the Northern Hemisphere (scenario: **All/15**) for the four different years.

Health impact	**Number of cases in Denmark**			
Year	**2000**	**2007**	**2011**	**2020**
Chronic Bronchitis	6.97E+02	5.45E+02	4.92E+02	4.23E+02
Restricted Activity Days	7.13E+05	5.57E+05	5.03E+05	4.32E+05
Respiratory Hospital Admissions	4.21E+01	3.15E+01	2.76E+01	2.22E+01
Cerebrovascular Hospital Admissions	8.78E+01	6.86E+01	6.20E+01	5.33E+01
Congestive Heart Failure	4.74E+01	3.70E+01	3.34E+01	2.86E+01
Lung Cancer	1.07E+02	8.35E+01	7.54E+01	6.48E+01
Bronchodilator Use Children	1.89E+04	1.48E+04	1.34E+04	1.15E+04
Bronchodilator Use Adults	1.36E+05	1.07E+05	9.64E+04	8.28E+04
Cough Children	6.52E+04	5.11E+04	4.62E+04	3.97E+04
Cough Adults	1.40E+05	1.10E+05	9.92E+04	8.52E+04
Lower Respiratory Symptoms Children	4.12E+04	3.70E+04	3.60E+04	3.49E+04
Lower Respiratory Symptoms Adults	5.07E+04	3.96E+04	3.58E+04	3.07E+04
Acute YOLL	3.56E+01	2.50E+01	2.05E+01	1.97E+01
Chronic YOLL	7.45E+03	5.83E+03	5.26E+03	4.52E+03
Infant mortality	8.75E-01	6.85E-01	6.19E-01	5.31E-01

Table 7: Total number of cases in **Europe** of the different impacts related to international ship traffic in the Baltic Sea and the North Sea (scenario: **BaS-NoS/15**) for the four different years.

Health impact	**Number of cases in Europe**			
Year	**2000**	**2007**	**2011**	**2020**
Chronic Bronchitis	1.89E+04	1.51E+04	1.31E+04	1.23E+04
Restricted Activity Days	1.94E+07	1.55E+07	1.34E+07	1.26E+07
Respiratory Hospital Admissions	1.16E+03	8.82E+02	7.46E+02	6.60E+02
Cerebrovascular Hospital Admissions	2.43E+03	1.94E+03	1.68E+03	1.58E+03
Congestive Heart Failure	1.25E+03	1.00E+03	8.67E+02	8.14E+02
Lung Cancer	2.90E+03	2.32E+03	2.00E+03	1.88E+03
Bronchodilator Use Children	5.65E+05	4.51E+05	3.90E+05	3.67E+05
Bronchodilator Use Adults	3.71E+06	2.96E+06	2.56E+06	2.41E+06
Cough Children	1.95E+06	1.56E+06	1.35E+06	1.27E+06
Cough Adults	3.82E+06	3.05E+06	2.64E+06	2.48E+06
Lower Respiratory Symptoms Children	7.53E+05	6.01E+05	5.20E+05	4.89E+05
Lower Respiratory Symptoms Adults	1.38E+06	1.10E+06	9.51E+05	8.94E+05
Acute YOLL	5.55E+02	2.40E+02	1.43E+02	2.51E+02
Chronic YOLL	2.16E+05	1.72E+05	1.49E+05	1.40E+05
Infant mortality	2.13E+01	1.70E+01	1.47E+01	1.38E+01

Table 8: Total number of cases in **Denmark** of the different impacts related to international ship traffic in the Baltic Sea and the North Sea (scenario: **BaS-NoS/15**) for the four different years.

Health impact	**Number of cases in Denmark**			
Year	**2000**	**2007**	**2011**	**2020**
Chronic Bronchitis	5.56E+02	4.33E+02	3.85E+02	3.35E+02
Restricted Activity Days	5.69E+05	4.42E+05	3.93E+05	3.43E+05
Respiratory Hospital Admissions	3.49E+01	2.57E+01	2.20E+01	1.77E+01
Cerebrovascular Hospital Admissions	7.01E+01	5.45E+01	4.85E+01	4.22E+01
Congestive Heart Failure	3.82E+01	2.97E+01	2.65E+01	2.31E+01
Lung Cancer	8.52E+01	6.62E+01	5.89E+01	5.13E+01
Bronchodilator Use Children	1.51E+04	1.17E+04	1.05E+04	9.10E+03
Bronchodilator Use Adults	1.09E+05	8.46E+04	7.53E+04	6.56E+04
Cough Children	5.21E+04	4.06E+04	3.61E+04	3.15E+04
Cough Adults	1.12E+05	8.71E+04	7.75E+04	6.75E+04
Lower Respiratory Symptoms Children	3.34E+04	3.07E+04	2.98E+04	3.01E+04
Lower Respiratory Symptoms Adults	4.04E+04	3.14E+04	2.80E+04	2.43E+04
Acute YOLL	2.14E+01	9.91E+00	5.41E+00	3.05E+00
Chronic YOLL	5.95E+03	4.62E+03	4.11E+03	3.58E+03
Infant mortality	6.99E-01	5.44E-01	4.84E-01	4.21E-01

Table 9: Total number of cases in **Europe** of the different impacts related to all the emissions in the Northern Hemisphere – i.e. the total air pollution levels (scenario: **All/all**) for the four different years.

Health impact	**Number of cases in Europe**			
Year	**2000**	**2007**	**2011**	**2020**
Chronic Bronchitis	6.33E+05	5.35E+05	5.32E+05	4.18E+05
Restricted Activity Days	6.47E+08	5.47E+08	5.44E+08	4.27E+08
Respiratory Hospital Admissions	3.78E+04	3.14E+04	3.12E+04	2.38E+04
Cerebrovascular Hospital Admissions	8.12E+04	6.86E+04	6.82E+04	5.36E+04
Congestive Heart Failure	5.02E+04	4.27E+04	4.25E+04	3.52E+04
Lung Cancer	9.69E+04	8.19E+04	8.14E+04	6.40E+04
Bronchodilator Use Children	1.89E+07	1.60E+07	1.59E+07	1.25E+07
Bronchodilator Use Adults	1.24E+08	1.05E+08	1.04E+08	8.18E+07
Cough Children	6.53E+07	5.52E+07	5.49E+07	4.31E+07
Cough Adults	1.28E+08	1.08E+08	1.07E+08	8.42E+07
Lower Respiratory Symptoms Children	2.52E+07	2.13E+07	2.12E+07	1.66E+07
Lower Respiratory Symptoms Adults	4.60E+07	3.88E+07	3.86E+07	3.04E+07
Acute YOLL	4.98E+04	4.39E+04	4.37E+04	3.62E+04
Chronic YOLL	7.22E+06	6.10E+06	6.07E+06	4.77E+06
Infant mortality	7.10E+02	5.99E+02	5.96E+02	4.68E+02

Table 10: Total number of cases in **Denmark** of the different impacts related to all the emissions in the Northern Hemisphere – i.e. the total air pollution levels (scenario: **All/all**) for the four different years.

Health impact	**Number of cases in Denmark**			
Year	**2000**	**2007**	**2011**	**2020**
Chronic Bronchitis	4.00E+03	3.34E+03	3.30E+03	2.17E+03
Restricted Activity Days	4.09E+06	3.42E+06	3.38E+06	2.22E+06
Respiratory Hospital Admissions	2.22E+02	1.82E+02	1.79E+02	1.16E+02
Cerebrovascular Hospital Admissions	5.03E+02	4.20E+02	4.16E+02	2.73E+02
Congestive Heart Failure	3.43E+02	2.88E+02	2.85E+02	2.06E+02
Lung Cancer	6.12E+02	5.12E+02	5.06E+02	3.32E+02
Bronchodilator Use Children	1.08E+05	8.98E+04	8.88E+04	5.84E+04
Bronchodilator Use Adults	7.83E+05	6.54E+05	6.47E+05	4.25E+05
Cough Children	3.71E+05	3.10E+05	3.07E+05	2.02E+05
Cough Adults	8.06E+05	6.73E+05	6.66E+05	4.37E+05
Lower Respiratory Symptoms Children	2.51E+05	2.14E+05	2.15E+05	1.41E+05
Lower Respiratory Symptoms Adults	2.91E+05	2.43E+05	2.40E+05	1.58E+05
Acute YOLL	1.71E+02	1.47E+02	1.42E+02	1.26E+02
Chronic YOLL	4.27E+04	3.56E+04	3.53E+04	2.32E+04
Infant mortality	5.02E+00	4.20E+00	4.15E+00	2.73E+00

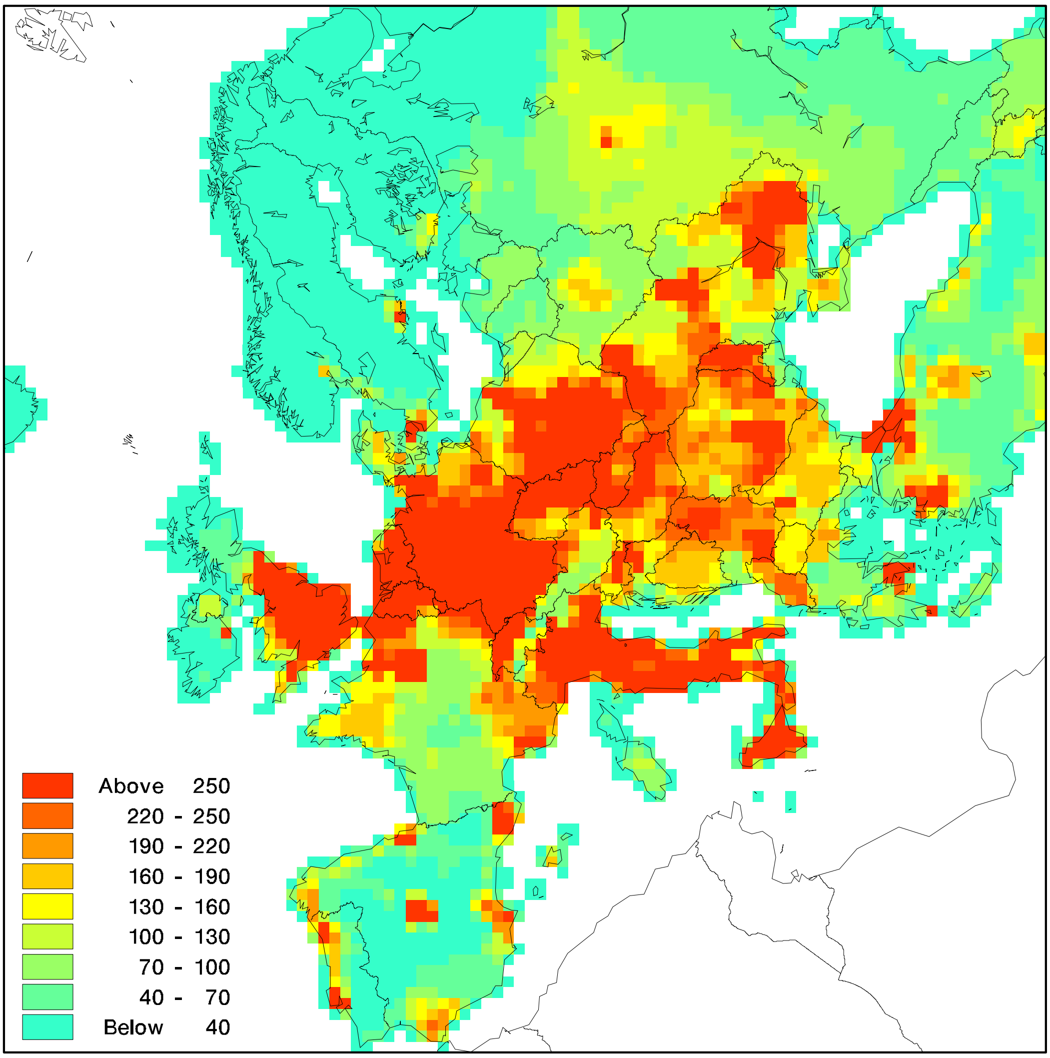

Figure 5: Number of premature deaths per grid cell in Europe (DEHM model domain 2) as calculated with the integrated EVA model system for the year 2000 for the total air pollution levels (scenario All/all). The area of the grid cells are 50 km x 50 km = 2500 km^2 so the colors refer to the number of premature deaths per 2500 km^2. The total number of premature deaths in the whole model domain is 680000, calculated from the number of chronic YOLL (see table 9) divided by a factor of 10.6 (as used in the CAFE; Watkiss et al., 2005). High numbers of premature deaths as shown in the map, require both high levels of annual particle concentrations and high population density.

Finally, tables 9 and 10 show the number of cases in Europe and Denmark, respectively, related to all emissions in the Northern Hemisphere (scenario: All/all) for the four different years. The results in these tables relate to question Q5 defined in section 3: what are the total impacts from the present and future air pollution levels? An example of the results geographical distributed is given in figure 5, showing the cases of premature deaths in Europe (model domain 2) calculated from the chronic YOLL for the year 2000 using the factor described above.

The results in the tables show that the impacts on human health due to air pollution from the different sectors are predicted to decrease over the years from 2000 to 2020, with the exception of international ship traffic, where an increase is seen for the year 2020. This is due to a general increase in international ship traffic according to the projected ship emissions provided by Corbett and Fischbeck (1997).

4.3. The total health-related cost externalities

In this section, the external costs are given for the different scenarios. Furthermore, we defined a number of questions in section 3 and in the following we will draw the major conclusions to these questions.

Table 11: The total external costs in Euros for the whole of Europe per chemical compound for all the different scenarios. Total S is the sum of the external cost of SO_2 and SO_4^{2-}. Total N is the sum of the external costs of O_3 and NO_3^-. *The external costs from NH_3 emissions are included in the impacts related to S and N through chemical reactions in the atmosphere.

Region/ SNAP	Emission year	CO	Total S	Total N	NH_3	$PM_{2.5}$
DK/1	2000	4.77E+03	1.48E+08	4.20E+08	-	1.52E+07
DK/2	2000	1.23E+05	8.21E+07	1.25E+08	-	3.24E+08
DK/3	2000	8.53E+03	9.18E+07	1.83E+08	-	2.63E+07
DK/4	2000	1.32E+03	4.31E+07	5.71E+07	-	1.02E+07
DK/5	2000	2.49E+03	3.46E+07	6.21E+07	-	1.31E+06
DK/6	2000	8.81E+03	5.60E+07	9.45E+07	-	3.92E+04
DK/7	2000	3.59E+05	3.29E+07	7.58E+08	-	2.08E+08
DK/8	2000	8.90E+04	3.14E+07	3.36E+08	-	7.95E+07
DK/9	2000	-1.26E+01	2.80E+05	3.19E+07	-	1.61E+05
DK/10	2000	1.18E+03	1.00E+09	1.39E+09	-	3.22E+07
DK/sum 1-10	2000	5.98E+05	1.52E+09	3.46E+09	-	6.97E+08
DK/all	2000	5.93E+05	1.30E+09	2.92E+09	-	7.04E+08
All/15	2000	-7.75E+05	2.70E+10	2.52E+10	-	6.11E+09
All/15	2007	-7.07E+05	2.34E+10	2.85E+10	-	5.00E+09
All/15	2011	-6.88E+05	2.10E+10	2.87E+10	-	4.60E+09
All/15	2020	-8.49E+05	2.43E+10	3.54E+10	-	4.46E+09
BaS-NoS/15	2000	3.76E+04	1.16E+10	8.17E+09	-	2.27E+09
BaS-NoS/15	2007	5.14E+04	5.97E+09	1.01E+10	-	1.05E+09
BaS-NoS/15	2011	5.05E+04	3.55E+09	1.04E+10	-	7.25E+08
BaS-NoS/15	2020	2.16E+04	3.60E+08	1.32E+10	-	4.90E+08
All/all	2000	1.39E+08	3.20E+11	3.31E+11	-	1.51E+11
All/all	2007	1.23E+08	2.47E+11	3.07E+11	-	1.28E+11
All/all	2011	1.22E+08	2.43E+11	3.07E+11	-	1.28E+11
All/all	2020	1.25E+08	1.60E+11	2.35E+11	-	1.42E+11

Section 4.2 as well as Appendix B includes the human health impacts, as well as the related external costs, for all the different human health impacts and scenarios. In table B25, these external costs are accumulated over all the different impacts to give the total external costs per chemical compounds for the whole of Europe. Corresponding figures for Denmark alone are given in table B26. The total external costs in Euros for the whole of Europe, per chemical compound for all the different scenarios are given in table 11.

Exposure-response functions are included for both SO_2 and SO_4^{2-}. However, the emission of sulphur is taking place only as SO_2, which in the atmosphere is chemically transformed into SO_4^{2-}. Therefore the total external costs related to the emission of SO_2 should include the human health impacts from both SO_2 and SO_4^{2-} and therefore the sum is provided in the table as "Total S" and this cost should be seen in relation to the emission of "S" given in table 3. Similarly, the external costs related to O_3 and NO_3^- is summed into "Total N". This cost should be seen in relation to the emission of NO_x (or N in table 3), which is a precursor to both O_3 and NO_3^-. As mentioned previously, emissions of NO_x can lead to both a decrease and an increase of O_3 in different areas, and both the cost and the benefit are included in the external costs for O_3 in table B25. The primary emitted part of $PM_{2.5}$ consists of dust, black carbon, and organic carbon; these are handled as inert tracers in the DEHM model, and can therefore be handled as a direct effect due to emissions of the same chemical compound.

In table 12, the total health-related externalities for Europe and Denmark are shown for all scenarios. These include the 10 major individual emission SNAP categories for Denmark (DK/1-DK/10) and their sum (DK/sum 1-10), for all emissions in Denmark (DK/all), international ship traffic (All/15), international ship traffic in the Baltic Sea and the North Sea (BaS-NoS/15), and all emission in the whole of Europe (All/all). All costs are in 2006 prices. The SNAP categories are (as given in table 2):

1) Combustion in energy and transformation industries,
2) Non-industrial combustion plants (in Denmark, this means the emissions from wood stoves),
3) Combustion in manufacturing industry,
4) Production processes,
5) Extraction and distribution of fossil fuels and geothermal energy,
6) Solvents and other product use,
7) Road transport,
8) Other mobile sources and machinery,
9) Waste treatment and disposal,
10) Agriculture, and
15) International ship traffic.

All results covering the five questions in section 3 are given in table 12 as external cost for the whole of Europe and similarly for Denmark by itself – the latter being part of the first. For international ship traffic and for all emissions from the whole of Europe, simulations for four different years (2000, 2007, 2011, and 2020) were run in order to examine the evolution of these costs over time. For the years 2000, 2007 emissions from the EMEP database were used. For the year 2020, the total emissions for each country are based on the National Emission Ceilings version 2 (NEC-II) but using the 2007 spatial emission distribution, since the NEC-II emissions are only country-based. The 2011 emissions are based on the 2007 emissions but with changes according to the agreements within the Sulphur Emission Control Areas (SECA) for international ship traffic. In these areas the sulphur content of the heavy fuel used by the ships was reduced from 2.7% in the year 2000 to 1.5% in the year 2007, 1% in the year 2011, and down to 0.1% from the year 2015. The SECA areas include the North Sea and the Baltic Sea.

Table 12: Total health-related externalities for Europe and Denmark for the 10 major individual emission SNAP categories for Denmark (DK/1-DK/10) and their sum (DK/sum1-10), for all emissions in Denmark (DK/all), for international ship traffic (All/15), for international ship traffic in the Baltic Sea and the North Sea (BaS-NoS/15), and for all emissions in the whole of Europe (All/all). For the latter three categories, the calculations were carried out for four different emission years. All costs are in 2006 prices. All external costs are given both in Euros and in bn DKK.

Region/SNAP	Emission year	Sum Europe Euros	Sum DK Euros	Sum Europe bn DKK	Sum DK bn DKK
DK/1	2000	5.84E+08	5.50E+07	4.38E+00	4.13E-01
DK/2	2000	5.31E+08	1.58E+08	3.98E+00	1.19E+00
DK/3	2000	3.01E+08	4.15E+07	2.26E+00	3.11E-01
DK/4	2000	1.10E+08	3.04E+07	8.25E-01	2.28E-01
DK/5	2000	9.80E+07	2.19E+07	7.35E-01	1.64E-01
DK/6	2000	1.50E+08	2.43E+07	1.13E+00	1.82E-01
DK/7	2000	9.99E+08	1.87E+08	7.49E+00	1.40E+00
DK/8	2000	4.47E+08	6.96E+07	3.35E+00	5.22E-01
DK/9	2000	3.23E+07	1.14E+06	2.42E-01	8.55E-03
DK/10	2000	2.43E+09	3.82E+08	1.82E+01	2.87E+00
DK/sum 1-10	2000	5.68E+09	9.71E+08	4.26E+01	7.28E+00
DK/all	2000	4.92E+09	8.17E+08	3.69E+01	6.13E+00
All/15	2000	5.84E+10	8.05E+08	4.38E+02	6.04E+00
All/15	2007	5.69E+10	6.23E+08	4.27E+02	4.67E+00
All/15	2011	5.43E+10	5.58E+08	4.07E+02	4.19E+00
All/15	2020	6.41E+10	4.84E+08	4.81E+02	3.63E+00
BaS-NoS/15	2000	2.20E+10	6.27E+08	1.65E+02	4.70E+00
BaS-NoS/15	2007	1.72E+10	4.74E+08	1.29E+02	3.56E+00
BaS-NoS/15	2011	1.47E+10	4.14E+08	1.10E+02	3.11E+00
BaS-NoS/15	2020	1.41E+10	3.57E+08	1.06E+02	2.68E+00
All/all	2000	8.03E+11	4.54E+09	6.02E+03	3.41E+01
All/all	2007	6.82E+11	3.80E+09	5.12E+03	2.85E+01
All/all	2011	6.78E+11	3.75E+09	5.09E+03	2.81E+01
All/all	2020	5.37E+11	2.53E+09	4.03E+03	1.90E+01

In table 13, the relative contribution from all the major Danish emission sectors is given as the percentage of the sum of external cost due to emissions from Denmark (DK/1-10). The contribution is calculated both with respect to all external costs in the whole of Europe and within Denmark itself. The relative contributions depend on whether results are estimated for impacts in the whole of Europe or for impacts within Denmark alone. This can partly be explained by the typical emission heights related to the different sectors. High altitude sources (e.g. stacks from power plants) will result in lower human exposure to air pollution close to the stacks. For SNAP category 1 (DK/1), which includes the major power plants, the high stacks spread the air pollution away from the population nearby the stacks, so the human exposure is smaller close to the stacks. Further away from the power plants, the effect from moving the emissions to higher altitudes is diminished. The results in table 13 show that the relative contribution from the major power plants with respect to the external costs in Denmark is about half the external costs in the whole of Europe.

Table 13: Contributions in % from Danish emission sectors to the total external costs related to health impacts in Europe and Denmark.

Region/SNAP	Emission year	Contribution in % to the total cost in Europe from DK emissions	Contribution in % to the total cost in Denmark from DK emissions
DK/1	2000	10.3	5.7
DK/2	2000	9.3	16.3
DK/3	2000	5.3	4.3
DK/4	2000	1.9	3.1
DK/5	2000	1.7	2.3
DK/6	2000	2.6	2.5
DK/7	2000	17.6	19.3
DK/8	2000	7.9	7.2
DK/9	2000	0.6	0.1
DK/10	2000	42.8	39.4
DK/sum 1-10	2000	100.0	100.0

The opposite is seen within SNAP category 2 (DK/2), including the non-industrial combustion plants. In Denmark SNAP category 2 corresponds to domestic emissions, including domestic heating and wood stoves, which typically have a relatively low emission height. In this case, the relative contribution to the external costs within Denmark is nearly twice the relative contribution for the whole of Europe. For road traffic, there is also a significant, though smaller difference in the relative contribution to Europe or Denmark, respectively, the latter being larger.

From table 13, it is also seen that the largest contributor to human health impacts and related external costs is SNAP category 10, which is the agricultural sector, contributing with approximately 40% of the total external costs. The availability of free ammonia contributes to the formation of ammonium sulphate and ammonium nitrate, which in turn as secondary particles have a significant impact on human health (ExternE, 1997). The external cost of ammonia (NH_3) emissions in the agricultural sector is associated with the exposure-response functions of the sulphate (SO_4^{2-}) and nitrate (NO_3^-) particles, due to the chemical transformation of NH_3 into NH_4SO_4, $NH_4(SO_4)_2$, and NH_4NO_3. The mass of ammonium (NH_4^+) must be included in the total particle mass associated with these particles (ExternE, 1999). According to WHO (2006b), it is currently not possible to precisely quantify the contributions of different chemical components of PM, or PM from different sources, to the health effects caused by exposure to PM. Based on the findings of the WHO Systematic Review project and the recommendations of the Task Force on Health, the effects of PM on mortality are assessed using the total PM mass ($PM_{2.5}$ or PM_{10}) as indicator (WHO, 2006b) (see also the discussion in section 2.6). A study for the USA suggest that a 10% reduction in livestock ammonia emissions can lead to over $4 billion annually in particulate-related health benefits (Mccubbin et al., 2002). The amount of ammonia emissions from the agricultural sector is very high and is nearly equal to the sum (in ktonnes) of the emissions from all other sector of SO_2, NO_x, and $PM_{2.5}$ in Denmark for the year 2000 (see table 3) and therefore the health related external cost is dominated by emissions from this sector in Denmark. The emissions of NH_3 have a large contribution to the external costs for several reasons:

1. The mass of NH_4^+ is included in the dose-response functions for SO_4^{2-} and NO_3^-.
2. Nitric acid (HNO_3) is already present in the atmosphere from other sources – including the whole of Europe. When NH_3 is emitted, it reacts with HNO_3 to form NH_4NO_3. HNO_3 deposits relatively fast (zero surface resistance) compared to NH_4NO_3. The lower deposition rate

of NH_4NO_3 leads to increased atmospheric concentration of NO_3^- in particle form in areas with higher NH_3 emissions.

3. The SO_4^{2-} concentration is not increased in itself, but the particle mass from NH_4^+ is included in the mass for the SO_4^{2-} exposure-response function.

From the tables 12 and 13, including the total health cost externalities and the contribution in percentage from the Danish emission sectors, combined with the results for health impacts in tables 4-10, we can now answer the questions defined in section 3:

Answer to question 1:
The question was defined as:

Q1: What are the relative contributions from the ten major emission sectors in Denmark with respect to impacts on human health and related external costs? (i.e. what are the major sources within Denmark to the health impacts?)

The results for the base year 2000 in this work show that the major contributors in Denmark to the total health related external costs are: 1) agriculture (DK/10; 42.8%), 2) road traffic (DK/7; 17.6%), 3) power production (DK/1; 10.3%), 4) non-industrial (domestic) combustion plants (DK/2; 9.3%), 5) other mobile sources (DK/8; 7.9%), 6) combustion in manufacturing industry (DK/3; 5.3%), and 7) solvents and other product use (DK/6; 2.6%) with respect to impacts in the whole of Europe. Three other sectors: production processes (DK/4), extraction and distribution of fossil fuels and geothermal energy (DK/5) and waste treatment and disposal (DK/9) together contribute around 4%.

If we only take into account the health-related external costs within Denmark from all Danish anthropogenic sources, the most dominant sectors are still agriculture (DK/10; 39.4%) and road traffic (DK/7; 19.3%), but the third most important is now non-industrial (domestic) combustion (DK/2; 16.3%). Other mobile sources (DK/8; 7.2%) move up to number four on the list. Power production (DK/1; 5.7%) moves from number three to number five, indicating that this sector causes relatively less human health impacts when only impacts in Denmark are considered. Combustion in the manufacturing industry (DK/3; 4.3%) keeps its place as number six. The production processes (DK/4), extraction and distribution of fossil fuels and geothermal energy (DK/5) and solvents and other product use (DK/6) have a relative contribution between 2.5% and 3.1%. The last sector waste treatment and disposal (DK/9) contributes with approximately 0.1%.

Answer to question 2:
The question was defined as:

Q2: What are the total impacts on human health and related external costs due to all the emissions in Denmark?

The results in table 12 show that the total health-related external cost in Europe from all Danish emissions (DK/all) is estimated to be 4.92 bn Euros/year, while the same emissions account for an external cost of 817 Mio Euros/year in Denmark alone. The human health impacts due to all Danish anthropogenic emissions are summarised in table 4.

For comparison, the total health-related external costs in Denmark due to the total air pollution levels from all sources in the Northern Hemisphere adds up to 4.54 bn Euros/year for the year 2000. These figures indicate that Denmark is a net exporter of health-related external costs.

Comparing the external costs with the sum of the results from all the 10 SNAP categories individually (DK/sum 1-10), a difference can be seen. The similar figures for the sum are 5.68 bn Euros/year and 971 Mio Euros/year giving a difference of approximately 15% (impact in Europe) and 19% (impacts in Denmark). This difference is to be expected and is explained by the non-linear atmospheric chemistry. When non-linear processes are involved, the sum of individual processes will not equal the results from all the processes simultaneously. The size of the difference depends very much on the atmospheric chemical regime in the region of interest. The chemical regime depends again on the general air pollution levels in the region. A much larger difference than the 15% / 19% estimates in the Danish region could be expected in other and higher polluted areas of Europe. Furthermore, the non-linear dependence will also depend on the size of the emission sources examined; for example, similar investigations for Germany would most likely result in different values. An early study of the non-linear effects of emission reductions is given in e.g. Bastrup-Birk et al. (1997) showing very large differences of the non-linear effect within Europe.

Answer to question 3:
The question was defined as:

> Q3: What are the present and future impacts on human health and related external costs in Europe and Denmark from international ship traffic in general?

The international ship traffic (scenarios All/15) constitutes a major problem for impacts on human health. According to Corbett and Fischbeck (1997), pollution from international ship traffic causes roughly 60,000 mortalities each year world wide. In our calculations with the EVA system, only the human health impacts in Europe were taken into account. The impacts on human health are given in tables 5 and 6 for Europe and Denmark, respectively. According to our results, the number of mortalities for Europe alone is 49,500 for the year 2000 increasing to 53,400 in the year 2020 (chronic YOLL divided by the factor 10.6 given in the CAFE report; Watkiss et al., 2005). A similar study for the USA performed by the US-EPA estimates 21,000 premature deaths with a related external cost of $47-$110 bn in the year 2020 (US-EPS, 2009). This indicates that the result by Corbett and Fischbeck (1997) might be strongly underestimated. We estimate that the total external costs in Europe will increase from 58.4 bn Euros/year in the year 2000 to 64.1 bn Euros/year in the year 2020. In the intervening years, smaller decreases are seen. The decrease for the years 2007 and 2011 is due to regulations in the sulphur content in the fuel used by the ships in the SECA area, while the increase in the total external costs for the year 2020 is due to a general increase in the expected ship traffic world wide.

For Denmark the external costs related to all international ship traffic is expected to decrease from 805 Mio Euros/year in the year 2000 to 484 Mio Euros/year in the year 2020. This decrease is a direct result of introducing the SECA area where the sulphur content in the heavy fuel is reduced from 2.7% in the year 2000 to 0.1% from the year 2015.

If we examine the relative external costs from all international ship traffic (All/15), it is estimated to be responsible for 7% of the total health effects in Europe due to air pollution in the year 2000, increasing to 12% in the year 2020. The corresponding numbers for Denmark are 18% in the year 2000 and 19% in the year 2020, even though the total external costs are decreasing from 805 Mio Euros/year to 484 Mio Euros/year.

Answer to question 4:
The question was defined as:

> Q4: What are the present and future impacts on human health and related external costs in Europe and Denmark from international ship traffic in the Baltic Sea and the North Sea?

The Baltic Sea and the North Sea are included in the SECA areas, and it is therefore interesting to investigate the impacts from regulating these areas specifically. Furthermore, the ship traffic in these areas is relatively large compared to other regions of the world, and especially in the Danish straits (Øresund and Storebælt).

According to our results, the total health-related external cost from international ship traffic in this area is 22.0 bn Euros/year for the year 2000, decreasing to 14.1 Euros/year for the year 2020. The impacts on health, related to this sector are given in the tables 7 and 8.

For Denmark, we estimate that the external costs due to international ship traffic in the Baltic Sea and the North Sea is 627 mio Euros/year for the year 2000, decreasing to 357 mio Euros/year for the year 2020 – a decrease of 43%. From this we can conclude that the regulatory efforts of reducing sulphur emissions in the SECA area are expected to significantly reduce external costs. This indicates that a similar regulation of the international ship traffic in the whole world would have a tremendous positive effect on human health.

However, the impacts from ship emissions in the SECA area remain significant. The reason for this is that the NO_x emissions from international ship traffic are not regulated in SECA, and NO_x is a precursor for nitrate particles (NO_3^-). In fact, if we calculate the relative contribution to external costs in Denmark from international ship traffic in the Baltic Sea and the North Sea, in relation to the total external costs from all emission sources (by dividing the results from BaS-NoS/15 with All/all for the respective years), it remains nearly constant at 14% over the years from the year 2000 to the year 2020, due to the similar decrease in the total air pollution levels from other sources, so the relative contribution remains unchanged.

Answer to question 5:
The question was defined as:

> Q5: What are the total health impacts and associated externalities from the total present and future air pollution levels?

The total health related external cost due to the total air pollution levels from all emission sources in the Northern Hemisphere is calculated to be 803 bn Euros/year for the year 2000, decreasing to 537 bn Euros/year in the year 2020 (scenarios All/all). The decrease in these numbers is due to the general emission reductions in Europe if NEC-II is implemented, and also to the regulation of international ship traffic by introducing SECA areas. For Denmark, the estimated external costs is 4.54 bn Euros/year for the year 2000, decreasing to 2.53 bn Euros/year in the year 2020. The total impacts on human health from the present and future air pollution levels are given in the tables 9 and 10.

Our estimates of the external costs of total air pollution levels in Europe are similar to results presented in the last baseline report from CAFE 2005 (Watkiss et al., 2005), see also section 5.6. They used the EMEP unified model (Simpson et al., 2003) to simulate transnational air pollution over Europe. The RAINS model (Alcamo et al., 1987) was then applied to estimate human health and environmental impacts, costs and potential air-quality targets. They estimated that the annual health impacts from air pollution due to PM and O_3 alone cost between 275 and 790 bn Euros. The higher value is similar to our estimate using the EVA model system. However, we should emphasize that the results from the EVA model system cover the whole of Europe and not only the EU25 countries as in the CAFE results and that the EVA results are most likely to lie in the middle range of the CAFE results.

4.4. Externality costs per kg emission

In table 14, the external costs for each chemical compound (table 12) have been divided by the emissions for the specific runs (table 3), giving the external cost per kg of the emission separated into compounds and sectors. The cost per kg is in the Centre for Energy, Environment and Health (CEEH) used as input to the energy optimisation model, Balmorel.

The kg prices shown in table 14 vary with the special characteristics associated with each sector/scenario, the chemical compound, and the year of emission. The special characteristics associated with emission sources are the geographical distribution of the sources in relation to the geographical distribution of the population affected by the emissions. Furthermore, the emission height as well as the influence from non-linear atmospheric chemistry is very important.

Table 14: Cost per kg emission (in unit Euros/kg –C, -S, -N, or –$PM_{2.5}$) for the 10 major individual SNAP categories for Denmark (DK/1-DK/10), for all emissions in Denmark (DK/all), for international ship traffic (All/15), for international ship traffic in the Baltic Sea and the North Sea (BaS-NoS/15), and for all emission in the Northern Hemisphere (All/all). For the latter three categories, the calculations were carried out for four different emission years.

Region/SNAP code	Emission year	CO [C]	SO_2 [S]	NOx [N]	NH_3 [N]	$PM_{2.5}$
DK/1	2000	0.001	23.3	27.1		19.0
DK/2	2000	0.002	43.0	58.1		28.1
DK/3	2000	0.001	30.7	36.3		19.6
DK/4	2000	0.013	88.0	439.2		40.8
DK/5	2000	-	-	-		26.2
DK/6	2000	-	-	-		-
DK/7	2000	0.003	182.8	34.3		44.1
DK/8	2000	0.002	21.5	29.7		33.8
DK/9	2000	0.000	9.3	34.3		-
DK/10	2000	-	-	-	28.0*	20.0
DK/All	2000	0.002	97.0	51.1		31.2
All/15	2000	-0.006	26.7	28.5		22.1
All/15	2007	-0.005	23.6	28.0		18.9
All/15	2011	-0.005	22.5	28.2		18.2
All/15	2020	-0.009	20.9	28.6		17.0
BaS-NoS/15	2000	0.001	39.0	31.7		35.0
BaS-NoS/15	2007	0.001	37.1	34.9		35.0
BaS-NoS/15	2011	0.001	34.4	35.9		35.0
BaS-NoS/15	2020	0.000	23.1	45.0		35.3
All/All	2000	0.006	31.1	54.2		46.1
All/All	2007	0.006	29.8	52.0		47.1
All/All	2011	0.006	29.6	52.0		47.3
All/All	2020	0.006	27.7	55.5		43.9

*The cost per kg related to NH_3 emissions is related to the dose-response of S and N in the agricultural sector, due to the chemical transformation of NH_3 (gas) into NH_4SO_4, $NH_4(SO_4)_2$, and NH_4NO_3 (particles). If the cost per kg emission is needed for kg SO_2 and kg NO_x instead of kg S and kg N, the conversion factor between S and SO_2 is (32+2*16)/32 = 2. The conversion factor between N and NO_x is (14+2*16)/14 =3.2857.

The costs per kg emission of CO are relatively low and only associated with the impact of congestive heart failure (see tables in appendix B for details).

The costs per kg emission of SO_2 are highly dependent on the type of emission source – especial with respect to the height of the source and the geographical distribution in relation to the population. Impacts are associated both with the emitted compounds SO_2 (gas) and the secondary formed compounds SO_4^{2-} (particle), which are chemically formed in the atmosphere over a period of hours to days. One sector, the road traffic, stands out compared to the others with a cost of 182.8 Euros per kg emitted S. The emissions from road traffic occur relatively close to the population – both as surface emissions and close to urbanised areas with high population density. The high cost per kg is interesting, since the sulphur content in diesel fuels used in cars in Denmark has already been regulated since 1999. It should be noted that even though the cost per kg is high, the regulation of the sulphur content in diesel fuels has resulted in a low total emission of sulphur from road traffic. One can conclude that the high cost per kg of sulphur is an indication that health effects of this sector are very important and that regulation of the sector appears to have been cost-effective.

Another explanation also applies for the relatively high kg price for S for road traffic. In the simulations, all emitted compounds are reduced simultaneously from the emission sectors of interest. This means that when we examine e.g. the road traffic, the emissions of e.g. NO_x and SO_2 are reduced at the same time in the model. The NO_x emissions strongly influence the photochemistry in the area, especially the production of O_3 which again chemically produces OH and H_2O_2. These compounds have an impact on the reaction rates e.g. from SO_2 to SO_4^{2-} and will therefore influence the chemical production of sulphate aerosols originating from other emission sources in the area. In the Scandinavian region, there are a lot of SO_2 emissions from the international ship traffic. The NO_x emissions from traffic increases the reaction rates from SO_2 to SO_4^{2-} and therefore these emissions alone result in higher concentrations of SO_4^{2-} aerosols and subsequently higher human health related external costs and higher cost per kg emission.

Another interesting aspect is that the cost per kg of sulphur from international ship traffic in the Baltic Sea and the North Sea is comparable to other sectors, such as major power plants. Most of the international ship traffic is obviously not located in highly populated areas, even though many of the ships are passing close to the coast, such as in Øresund or Storebælt. There are two important aspects of the ship emissions compared to other emission sectors, such as power plants:

1) The height of the ship emissions is much lower than the height of the stacks from the power plants. Moreover the ship emissions take place in the marine boundary layer, which is more shallow than the mixing layer over land surfaces. This means that the emissions of compounds such as sulphur are mixed in a lower volume of air, which results in higher concentrations near the surface, so when the emitted air pollution from ships is transported over land, where people are located, the contribution from ships will result in a more direct exposure. This is in contrast to emissions from power-plant smoke-stacks, which are released at a height of several hundred meters, located inland and relatively closer to the population – in this case much of the air pollution will pass over the populated areas before reaching the surface.

2) Most of the external costs related to the emission of sulphur are associated with the secondary sulphate particles. It takes hours to days for SO_2 to be chemically transformed into SO_4^{2-}, and therefore sources located far away from the highly populated areas (e.g. international ship traffic) can have a larger impact than sources near or inside the populated areas (e.g. power plants).

One sector stands out with respect to relatively high external cost per kg of all the different emitted compounds, and that is sector 4 (DK/4), which represents the production processes. This indicates that the emissions from this sector have not been sufficiently regulated. Furthermore, smoke stacks in this sector are typically lower than those of major power plants and located in densely populated areas (in or near the major cities).

4.5. Comparison with results from Clean Air for Europe

In this section we compare results from the EVA model system with overall results from the last baseline report from Clean Air for Europe (CAFE) (Watkiss et al., 2005). The main goal of the CAFE programme, launched in 2001 by the EU Commission, was: "achieving levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment". The analysis by Watkiss et al. (2005) included estimates of air pollution concentrations from the EMEP model (European Monitoring and Evaluation Programme) coupled to the RAINS model. The report included an assessment of the impacts on human health and the environment from the total air pollution levels in the years 2000 and 2020 – these results are therefore a good basis for comparison with results in this work. Clearly, air pollution concentrations predicted for hypothetical scenarios cannot be validated against real measurement data. While it is possible to test the individual parts of the EVA system (e.g. comparing estimated concentrations from DEHM with observations, validating exposure-response functions and economic valuations), it is difficult to validate the system as a whole, except by comparing EVA estimates with results of similar studies.

In the results presented in this report, we have assessed the total impacts on human health and the corresponding external costs from the total air pollution levels, including all anthropogenic and natural sources for the Northern Hemisphere for four different years (2000, 2007, 2011, and 2020). The scenario is denoted All/all in the tables, meaning all regions and all emissions for the whole model domain are included. These results are directly comparable with the results in Watkiss et al. (2005), a report commissioned by the European Commission DG Environment. In the following, a direct comparison is made for some of the key parameters in the study. We will denote the results provided in Watkiss et al. (2005) as "CAFE" and the results in this report as "EVA".

The YOLL (Years Of Life Lost) is a key parameter for the overall mortality. The comparable numbers in CAFE and EVA are as follows: In the CAFE study the result was: "Annual impacts across the EU 25 total an estimated 3.7 million years of life lost each year (based on the year 2000). This can also be expressed as 348,000 estimated premature deaths". EVA estimates 7.2 million chronic YOLL, based on the year 2000 in model domain 2, which includes the whole of Europe (see table B21, where this appears as the sum of chronic YOLL for the compounds $PM_{2.5}$, NO_3^-, and SO_4^{2-}). The estimate from the EVA system is twice the estimate from the CAFE study, however, the CAFE results apply for the EU25 countries and the EVA results are valid for the whole of Europe, including approximately twice as many people, thus possibly accounting for the difference between the two estimates.

For the impacts of hospital admissions, the two studies provide the following results: CAFE: "The morbidity effects of PM range from around an estimated 100000 cases of respiratory or cardiac hospital admissions". EVA: 38000 respiratory hospital admissions (see table B5) + 81000 cerebrovascular hospital admissions (see table B7) giving a total of around 119000 cases for the year 2000 for the European model domain.

For the impacts of restricted activity days: CAFE: "several hundred million restricted activity days each year". EVA: 647 Mio restricted activity days (domain 2).

For the total external costs, the comparable figures from the two studies are: CAFE: Core estimates of annual health impacts due to air pollution in 2000 and in 2020 in EU25 is between 790 bn Euro and 609 bn Euros, respectively (using the "value of a statistical life" mean). EVA: Total external cost in 2000 (whole domain) is 803 bn Euro and 537 bn Euros for the year 2020. The total external costs are very similar for the two studies for the two years. Taking into account that the EVA system covers a greater area than the EU25 countries, the EVA results provide a lower estimate of the total external costs for Europe. This is partly due to the fact that different valuations of the individual impacts were used in the two studies, and to the fact that in our study we have been conservative in the economic valuation of the different impacts.

In the year 2000, the GDP of the EU25 countries was 8947 bn Euros (Watkiss et al., 2005), so the total external costs related to impacts on human health (whole model domain 2) constitute a significant part of the GDP. The total external cost in Denmark according to EVA is 4.54 bn Euros (34 bn DKK) for the year 2000, which corresponds to approximately 2% of the Danish GDP (2009 figure). The total external cost due to the total air pollution levels for Denmark is expected to decrease to 2.53 bn Euros in the year 2020 (see table 3). The corresponding figure for the year 2000 in the CAFE study is 7.3 bn Euros. Compared to our results of 4.53 bn Euros for the same year, we can conclude that our results are conservative. Some of the difference between the CAFE result for Denmark and the EVA result could also originate from the linearization of the source-receptor relationship in CAFE while the EVA results does not assume linearity.

One other interesting parameter is the number of premature deaths in Denmark. Using the EVA system, we calculate 42,700 chronic YOLL for the year 2000 for Denmark. If we convert this to premature deaths (dividing by a factor of 10.6, as suggested by the CAFE report), we get approximately 4,000 premature deaths per year in Denmark, which is very similar to other Danish estimates (e.g. Palmgren et al., 2005). For the years 2007 and 2020, the corresponding figures are 3,400 and 2,200 for Denmark, showing an expected decrease in the year 2020 to nearly half of the number in the year 2000.

In general, we can conclude that the comparable figures presented here between the CAFE study and the EVA results are in the same order of magnitude, especially if we take into account that we compare the EU25 countries (CAFE) with the whole European model domain 2 (EVA), which also includes parts of Russia, Ukraine, etc. We conclude that the results provided by the EVA model system are in satisfactory agreement with results previously presented in the literature.

One could ask why we have developed the EVA model system if the overall results presented above are very similar with the results in the CAFE report. However, comparing the overall results for the general air pollution levels does not mean that the results for the different scenarios are similar. There are at least two reasons for developing an alternative system:

1. The fundamental difference between the EVA model system and the RAINS system is the handling of scenarios. RAINS uses linearized approximations to the source-receptor relationships when handling scenarios. EVA simulates the real scenarios every time taking into account the non-linear effects of atmospheric chemistry and using our newly developed tagging method, reducing the noise/signal ratio in the δ functions.
2. In the EVA system, we have developed economic valuation applicable for Danish and European conditions. We have made the assessment using conservative estimates for the economic valuation of the different health impacts. Furthermore, these economic valuations have been under scrutiny and validation within the Danish Ministry of Finance.

4.6. Sensitivity to different weighting of particle type

As discussed in section 2.6, the choice in CEEH to assign equal health effect to all compounds of particles is in line with other recent major reports. In the NEEDS project, experiments were made to assess the impacts on the overall results by giving different weights to the different types of particles. As a sensitivity analysis, we have treated the secondary inorganic aerosols (nitrate, ammonium and sulphate) as 0.7 times the toxicity of $PM_{2.5}$ and the primary emitted part of $PM_{2.5}$ is treated as 1.3 the toxicity of $PM_{2.5}$. The results are summarized in tables 15-17 below.

The overall health related external cost from all air pollution for the whole of Europe is decreased from 803 bn Euros/year for the year 2000 to 684 bn Euros/year (see table 15), corresponding to a decrease of 17%.

Table 15: Total health-related externalities for Europe and Denmark for the 10 major individual emission SNAP categories for Denmark (DK/1-DK/10) and their sum, for all emissions in Denmark (DK/all), for international ship traffic (All/15), for international ship traffic in the Baltic Sea and the North Sea (BaS-NoS/15), and for all emissions in the whole of Europe (All/all). For the latter three categories, the calculations were carried out for four different emission years. All costs are in 2006 prices. All external costs are given both in Euros and in bn DKK.

Region/SNAP	Emission year	Sum Europe Euros	Sum DK Euros	Sum Europe bn DKK	Sum DK bn DKK
DK/1	2000	4.25E+08	4.07E+07	3.19E+00	3.05E-01
DK/2	2000	5.72E+08	1.85E+08	4.29E+00	1.39E+00
DK/3	2000	2.30E+08	3.23E+07	1.73E+00	2.42E-01
DK/4	2000	8.60E+07	2.48E+07	6.45E-01	1.86E-01
DK/5	2000	7.29E+07	1.58E+07	5.47E-01	1.19E-01
DK/6	2000	1.17E+08	1.75E+07	8.78E-01	1.31E-01
DK/7	2000	8.31E+08	1.95E+08	6.23E+00	1.46E+00
DK/8	2000	3.64E+08	7.09E+07	2.73E+00	5.32E-01
DK/9	2000	2.38E+07	8.48E+05	1.79E-01	6.36E-03
DK/10	2000	1.72E+09	2.75E+08	1.29E+01	2.06E+00
DK/sum 1-10	2000	4.44E+09	8.58E+08	3.33E+01	6.43E+00
DK/all	2000	3.92E+09	7.49E+08	2.94E+01	5.62E+00
All/15	2000	4.68E+10	6.59E+08	3.51E+02	4.94E+00
All/15	2007	4.51E+10	4.89E+08	3.38E+02	3.67E+00
All/15	2011	4.29E+10	4.32E+08	3.22E+02	3.24E+00
All/15	2020	5.04E+10	3.72E+08	3.78E+02	2.79E+00
BaS-NoS/15	2000	1.71E+10	4.94E+08	1.28E+02	3.71E+00
BaS-NoS/15	2007	1.28E+10	3.56E+08	9.60E+01	2.67E+00
BaS-NoS/15	2011	1.08E+10	3.06E+08	8.10E+01	2.30E+00
BaS-NoS/15	2020	1.03E+10	2.60E+08	7.73E+01	1.95E+00
All/all	2000	6.84E+11	3.87E+09	5.13E+03	2.90E+01
All/all	2007	5.82E+11	3.30E+09	4.37E+03	2.48E+01
All/all	2011	5.79E+11	3.26E+09	4.34E+03	2.45E+01
All/all	2020	4.84E+11	2.25E+09	3.63E+03	1.69E+01

The corresponding prices per kg emitted chemical compound are given in table 16.

As seen in Table 17, the relative contribution from the different emission sectors in Denmark will not be changed much, however, the impacts from the agricultural sector in Denmark are decreased from 39% to 32%, yet it is still being the dominant sector.

Table 16: Cost per kg emission (in units Euros/kg –C, -S, -N, or –$PM_{2.5}$) for the 10 major individual SNAP categories for Denmark (DK/1-DK/10), for all emissions in Denmark (DK/all), for international ship traffic (All/15), for international ship traffic in the Baltic Sea and the North Sea (BaS-NoS/15), and for all emission in the Northern Hemisphere (All/all). For the latter three categories, the calculations were carried out for four different emission years. *The cost per kg related to NH_3 emissions is related to the dose-response of S and N in the agricultural sector, due to the chemical transformation of NH_3 (gas) into NH_4SO_4, $NH_4(SO_4)_2$, and NH_4NO_3 (particles). If the cost per kg emission is needed for kg SO_2 and kg NO_x instead of kg S and kg N, the conversion factor between S and SO_2 is (32+2*16)/32 = 2. The conversion factor between N and NO_x is (14+2*16)/14 =3.2857.

Region/SNAP code	Emission year	CO [C]	SO_2 [S]	NOx [N]	NH_3 [N]	$PM_{2.5}$
DK/1	2000	0.001	17.1	19.1	-	24.6
DK/2	2000	0.002	31.3	42.5	-	36.5
DK/3	2000	0.001	22.1	25.6	-	25.6
DK/4	2000	0.013	63.3	320.0	-	53.2
DK/5	2000	-	-	-	-	34.2
DK/6	2000	-	-	-	-	-
DK/7	2000	0.003	134.4	24.3	-	57.4
DK/8	2000	0.002	17.0	20.9	-	43.8
DK/9	2000	0.000	8.2	25.1	-	-
DK/10	2000	-	-	-	19.6	26.0
DK/All	2000	0.002	68.7	36.6	-	40.5
All/15	2000	-0.006	19.3	21.9	-	28.7
All/15	2007	-0.005	17.0	21.4	-	24.6
All/15	2011	-0.005	16.1	21.6	-	23.7
All/15	2020	-0.009	15.0	22.0	-	22.1
BaS-NoS/15	2000	0.001	28.6	22.1	-	45.5
BaS-NoS/15	2007	0.001	27.3	24.3	-	45.7
BaS-NoS/15	2011	0.001	25.4	25.0	-	45.6
BaS-NoS/15	2020	0.000	17.9	32.0	-	45.8
All/All	2000	0.006	22.8	41.5	-	60.2
All/All	2007	0.006	21.7	39.8	-	61.4
All/All	2011	0.006	21.7	39.8	-	61.7
All/All	2020	0.006	20.1	43.2	-	57.2

Table 17: Contributions in % from Danish emission sectors to the total external costs related to health impacts in Europe and Denmark.

Region/SNAP	Emission year	Contribution in % to the total cost in Europe from DK emissions	Contribution in % to the total cost in Denmark from DK emissions
DK/1	2000	9.6	4.7
DK/2	2000	12.9	21.6
DK/3	2000	5.2	3.8
DK/4	2000	1.9	2.9
DK/5	2000	1.6	1.8
DK/6	2000	2.6	2.0
DK/7	2000	18.7	22.7
DK/8	2000	8.2	8.3
DK/9	2000	0.5	0.1
DK/10	2000	38.7	32.1
DK/sum 1-10	2000	100.0	100.0

5. Overall conclusions

In this report we have presented a new integrated model system, EVA, based on the impact pathway approach and customised for Danish and European conditions. The system is capable of calculating the health-related external costs from specific emission sources and sectors. The main idea of developing the system was to apply state-of-the-art science, models, data, and methodologies in every link of the impact pathway chain. Furthermore, we have developed a new tagging method, where the problem with noise-to-signal ratio has been reduced in the calculation of the source contributions (the δ-functions).

The EVA system has been run with different scenarios, assessing the human health impacts and associated external costs from different emission sectors in Denmark and international ship traffic as well as the total concentration levels, the latter two for four different years (2000, 2007, 2011, and 2020). The results have been compared to similar studies from the Clean Air For Europe (CAFE) project, showing similar results, and we have concluded that the EVA system gives satisfactory results. The final result, which will be used in the Centre for Energy, Environment and Health (CEEH), is the cost per kg emission for the different sectors and chemical compounds. These results will be used as input to the Balmorel model for optimising the energy production and consumption in Denmark, including both the direct costs and the external costs.

One of the major conclusions from the results in this work is that the major contributors in Denmark to the total human health-related external costs in the whole of Europe (in order of impact) are agriculture, road traffic, power production, non-industrial (domestic) combustion (including the use of wood stoves), other mobile sources, combustion in manufacturing industry, and solvents and other product use. The assumption here is that the different secondary inorganic aerosols and the primary emitted particles are equally harmful to human health.

If we only take into account the health-related external costs within Denmark from all Danish anthropogenic sources, the non-industrial domestic combustion sources dominated by wood stoves are relatively more important.

The results in this work show that the agricultural sector contributes significantly to health impacts and related external cost. The agricultural sector already contributes significantly to impacts on the environment due to eutrophication of the terrestrial and marine eco-systems. From the results in this study we conclude that not only the impacts on nature should be taken into account when regulating the emissions of ammonia. Also impacts on human health should be considered.

The total health-related external cost in Europe from all Danish emissions is estimated to 4.92 bn Euros/year, while the same emissions account for an external cost of 817 Mio Euros/year in Denmark alone. For comparison, the total health-related external costs in Denmark due to the total air pollution levels from all sources in the Northern Hemisphere add up to 4.54 bn Euros/year for the year 2000. These figures indicate that Denmark is a net exporter of health-related external costs.

International ship traffic constitutes a major problem for impacts on human health. We estimate that the total external costs in Europe will increase from 58.4 bn Euros/year in the year 2000 to 64.1 bn Euros/year in the year 2020, due to a general increase in the ship traffic worldwide. If we examine the relative external costs from all international ship traffic, it is responsible for an estimated 7% of the total health effects in Europe due to air pollution in the year 2000, increasing to 12% in the year 2020.

According to our results the total health-related external costs from international ship traffic in the Baltic Sea and the North Sea is 22.0 bn Euros/year for the year 2000, decreasing to 14.1 bn Euros/year for the year 2020. For Denmark, the impacts from international ship traffic in the Baltic Sea and the North Sea result in external costs of an estimated 627 mio Euros/year for the year 2000, decreasing to an estimated 357 mio Euros/year for the year 2020 – a decrease by 43%. From this we can conclude that the regulatory efforts of reducing sulphur emissions in the SECA area are expected to significantly reduce the health-related external costs of international shipping. However, the problem of impacts from ship emissions in this area remains significant, due to NO_x emissions, which lead to the formation of nitrate particles (NO_3^-). In fact, if we examine the relative external costs in Denmark from international ship traffic in the Baltic Sea and the North Sea, with respect to the total external costs from all emission sources, it remains nearly constant at roughly 14% over the years from the year 2000 to the year 2020, due to the similar decrease in the total air pollution levels. From this we can also conclude that the relative contribution from the international ship traffic is of comparable size with the contributions from road traffic or the use of domestic wood stoves in Denmark.

For Denmark, the external cost related to all international ship traffic is expected to decrease from 805 Mio Euros/year in the year 2000 to 484 Mio Euros/year in the year 2020. This is a direct result of the introduction of the SECA area, where the sulphur content in the heavy fuel is reduced from 2.7% in the year 2000 to 0.1% in the year 2015. The relative impacts on human health in Denmark from international ship traffic are estimated to be 18% in the year 2000 and 19% in the year 2020, even though the total external costs are decreasing, due to a general decrease in air pollution levels. Introducing the same regulatory efforts to all the international ship traffic as in the SECA area would have a significant positive impact on human health in Europe.

The total health-related external costs in Europe due to the total air pollution levels from all emission sources in the Northern Hemisphere are calculated to be 803 bn Euros/year for the year 2000, decreasing to 537 bn Euros/year in the year 2020. The decrease in these calculations is due to the general emission reductions in Europe provided that NEC-II is implemented and given the regulation of international ship traffic by introducing SECA areas. For Denmark the external costs are estimated to be 4.54 bn Euros/year for the year 2000, decreasing to 2.53 bn Euros/year in 2020.

The results in this study show that air pollution constitutes a serious problem to human health and that the related external costs are considerable. The main objective of this work was to find the primary activities and emission sources in and around Denmark that give the largest contribution to human health impacts. The related external costs found in this work can be used to directly compare the contributions from the different emission sectors, potentially as a basis for decision making on regulation and emission reduction. The major immediate and visible emission sources (e.g. power plants and road traffic) do not always constitute the most significant problems related to human health. Other less obvious sources can cause significant impacts on nature and human health. Therefore it is important to make an overall screening of all emission sectors or emission sources in order to create a scientific basis for sound political decisions. In this report, we defined five overall questions that illustrate the capability of the EVA system to give useful answers when making regulation priorities.

The economic valuation in this study only includes some of the known harmful chemical compounds. In these calculations, we did not include compounds as polycyclic-aromatic hydrocarbons (PAHs), persistent organic pollutants (POPs), metals, heavy metals, dioxins, and secondary organic aerosols (SOA). However, these compounds commonly share the same sources as the compounds included in this study and the health effects are likely to be included due to the correlations with the included compounds. Also, the system does not presently include impacts and related external costs on the natural environment or climate. Furthermore, taking into account that we only included health impacts where the exposure-response function are well-documented and accepted by the WHO and EU Commission, and that the economic valuation of the health impacts has been conservative, the overall results in this work can also be considered conservative.

The absolute external costs in this work should be used with precaution. The external costs are, of course, associated with a certain degree of uncertainty, which on the other hand is very difficult to quantify in such a complex model system. The main uncertainties in the integrated model system is associated with the emissions (which have an uncertainty of +/- 30% on annual basis) and the uncertainty related to the health impacts from the individual chemical compounds associated to air pollution. With our present knowledge we are not able to distinguish between the impacts from different particle types. However, there are many research studies linking the total mass of $PM_{2.5}$ with health effects, showing strong and significant correlations. In order to assess the influence from assuming different toxicity from primary and secondary formed particles, we made a sensitivity analysis with the EVA system. This sensitivity analysis did not change the overall conclusions of the work.

The results from the EVA system have been compared to the CAFE results and have proven consistent with results used to support the decision making in the EU Commission. Compared to other similar systems, our goal has been to apply state-of-the-art methodologies, models and data in every link of the impact pathway chain and to develop a new method for the calculation of the contribution from specific sources to the air pollution levels, without assuming linearity in the source-receptor relationships and by using a tagging method diminishing the noise to signal ratio. Since all scenarios are calculated with the same methodology and assumptions, the relative uncertainty between the results obtained in this work is relatively smaller than the absolute uncertainty.

The results in this report emphasize the importance of defining the right questions for decision making, since most of the atmospheric chemical compounds are linked via non-linear chemical reactions. The resulting cost per kg in this report represents the case where all the emissions from the sector of interest are reduced simultaneously – e.g. if the traffic is reduced. In the case where one would like to examine the cost per kg for the impacts of sulphur alone (e.g. by reducing the sulphur content in the fuel), the model system should be run with the individual emitted compounds one at the time, e.g. the sulphur emissions from traffic alone. This would result in different costs per kg of emitted chemical compounds, especially for the countries surrounded by large sulphur emissions from other sources and where the NO_x emissions are relatively high compared to the SO_2 emissions from the traffic sector, as is the case for the Scandinavian countries. The atmospheric system is highly non-linear, complex and interdependent. Therefore the results from assessing the impacts from emission each emission sector depend clearly on the assumption that the other emission sectors are not changed. As an example, will the impacts of emitting ammonia from the agricultural sector be much lower if all the other emissions from burning fossil fuels are removed. If there is not any available sulphur- or nitrogen-oxides the ammonia can not be formed into ammonium particles. Another example in this work is the high kg price of sulphur emissions from the road traffic in Denmark, which is related to life time of sulphur-dioxides from other sources (in this case the international ship traffic) in the area altered by the emissions of nitrogen-oxides from the same sector (road traffic). The emissions are all linked in the atmospheric chemical soup via non-linear chemical processes.

The results in the report show that the integrated EVA model system can be used as a strong tool for decision making. However, the results also emphasize that atmospheric chemistry is highly non-linear and that it is impossible without comprehensive, appropriate and well tested atmospheric models to foresee the result of specific emission reduction scenarios. The results depend highly on geography, emission sector and on how and by how much the emissions are reduced. Therefore, we recommend that health impacts and related external costs should be calculated for specific emission reduction scenarios if precise estimates of the outcome of specific regulations are required.

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Appendix A: Figures including DEHM model results for the different scenarios

In this appendix, the DEHM model results for the different scenarios are shown. To give an overview of which figures belongs to which scenarios, the figure numbers are included in table 2.

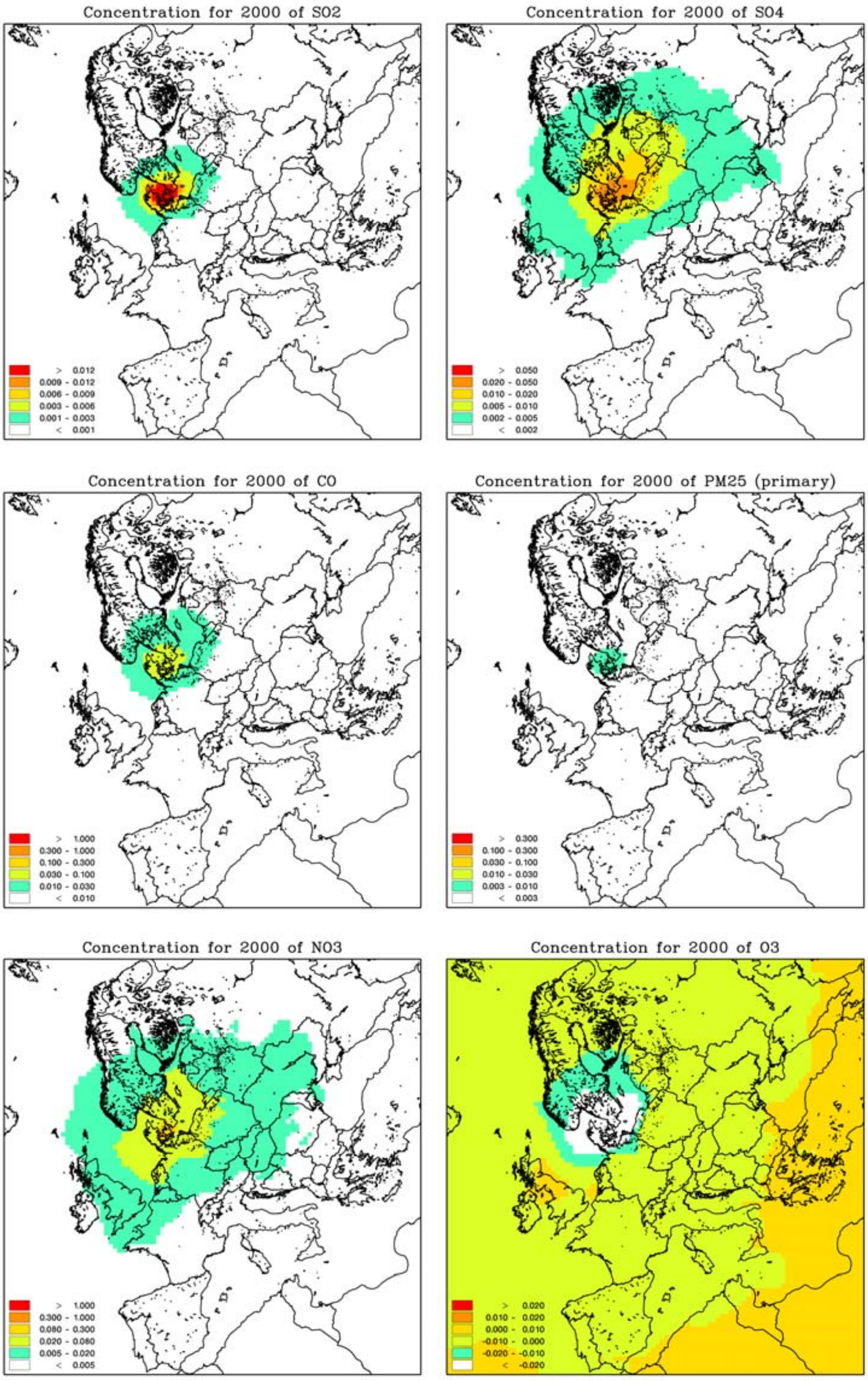

Figure A1: Contribution to the mean annual air pollution levels (δ-concentrations) calculated using the DEHM model due to emission from the whole of Denmark for SNAP category 1 (combustion in energy and transformation industries) for the year 2000. The compounds are: SO_2 [ppb], SO_4^{2-} [μg/m^3], CO {ppm], $PM_{2.5}$ (primary part) [μg/m^3], NO_3^- [μg/m^3] and O_3 [ppb]. Results are shown for DEHM domain number 2.

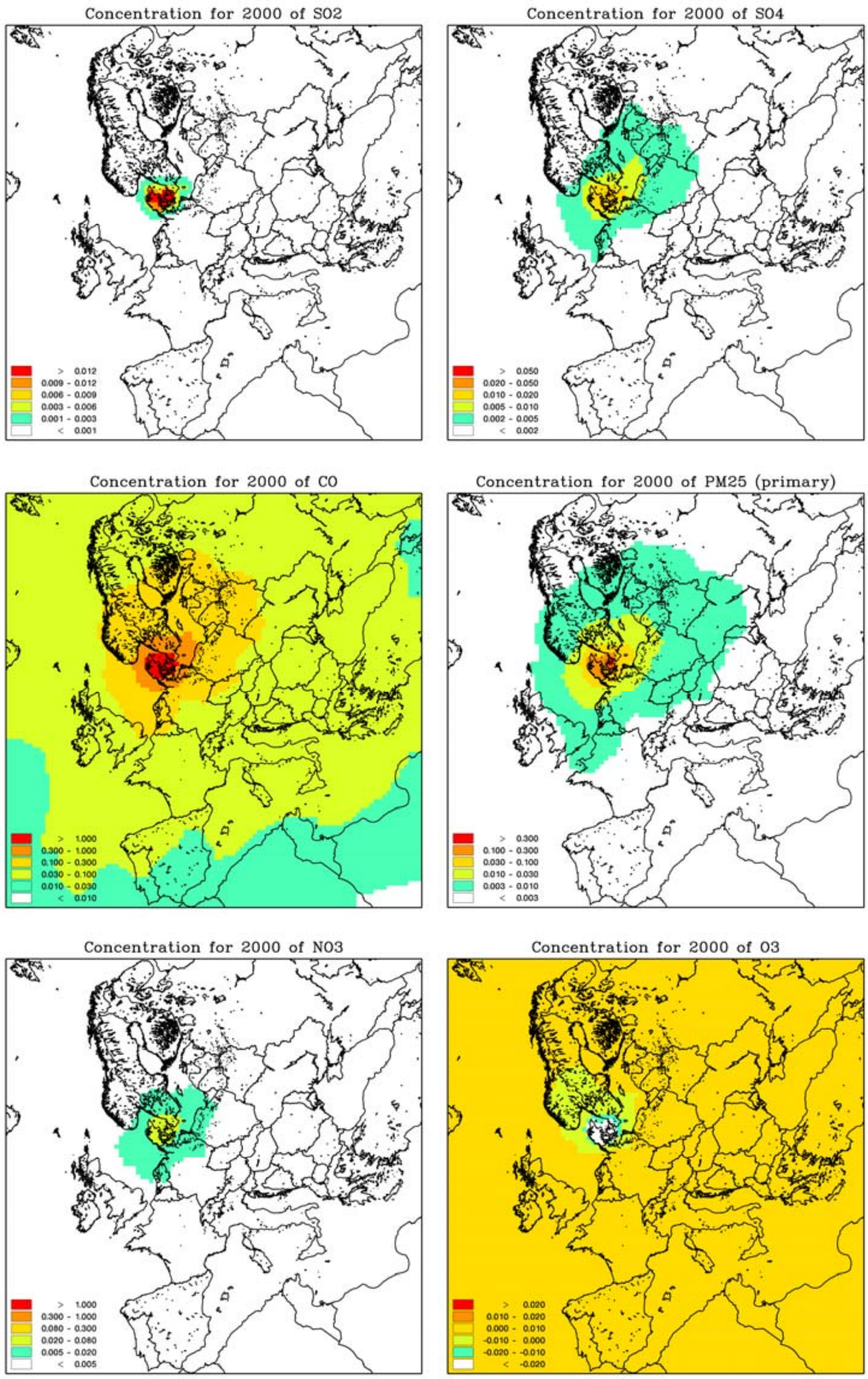

Figure A2: As figure A1 but for SNAP category 2 (non-industrial combustion plants - in Denmark this equals the wood stoves).

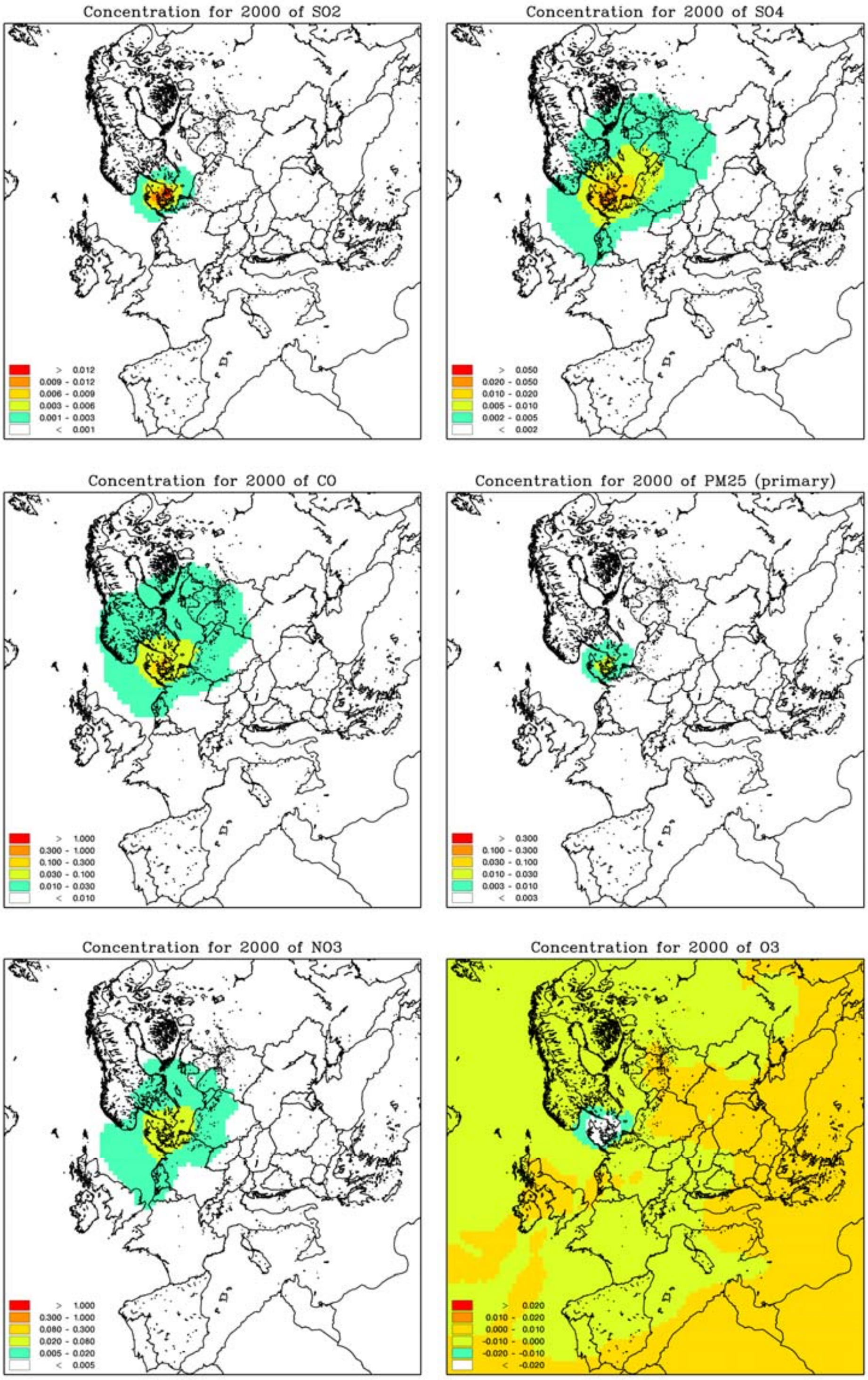

Figure A3: As figure A1 but for SNAP category 3 (combustion in manufacturing industry).

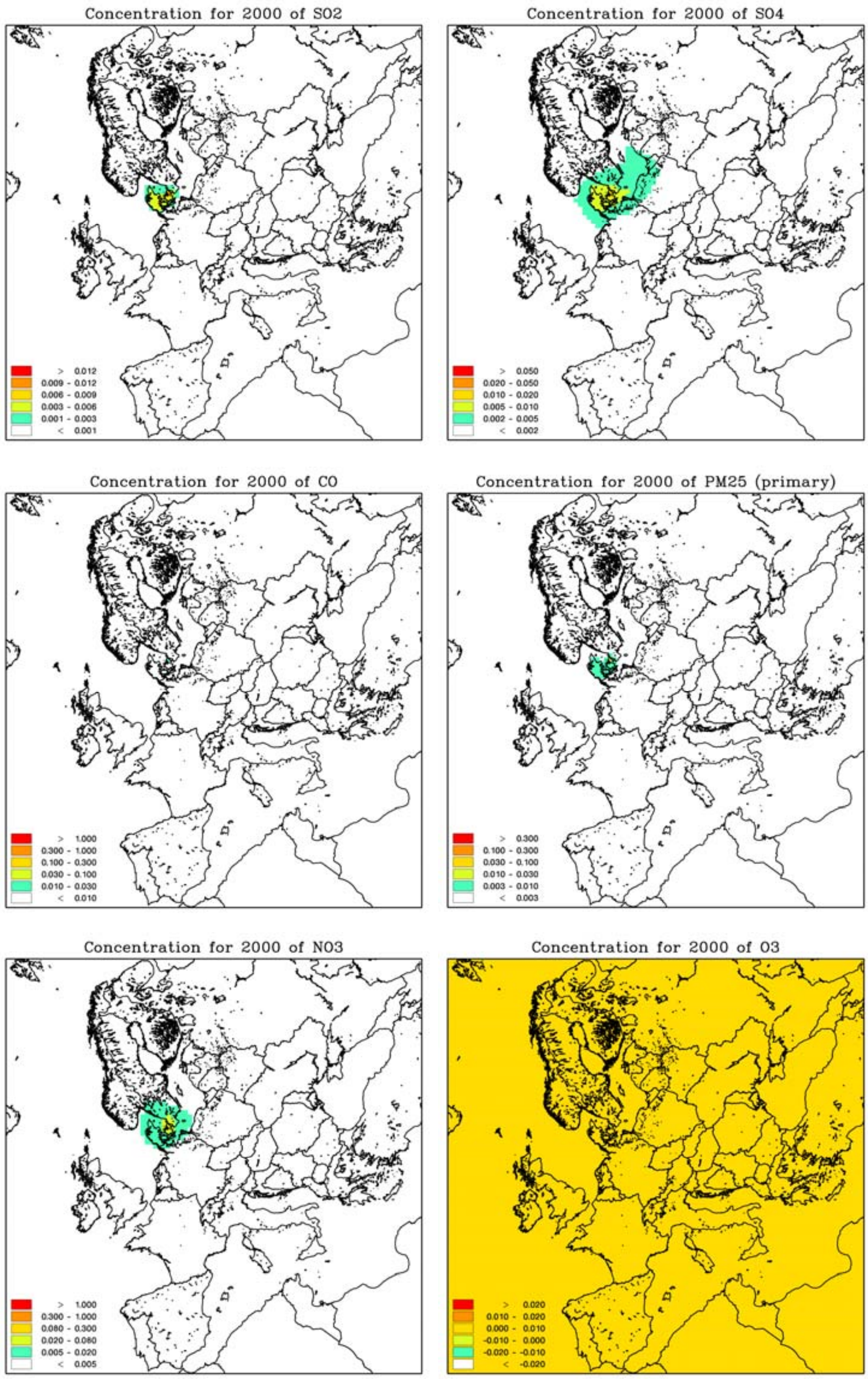

Figure A4: As figure A1 but for SNAP category 4 (production processes).

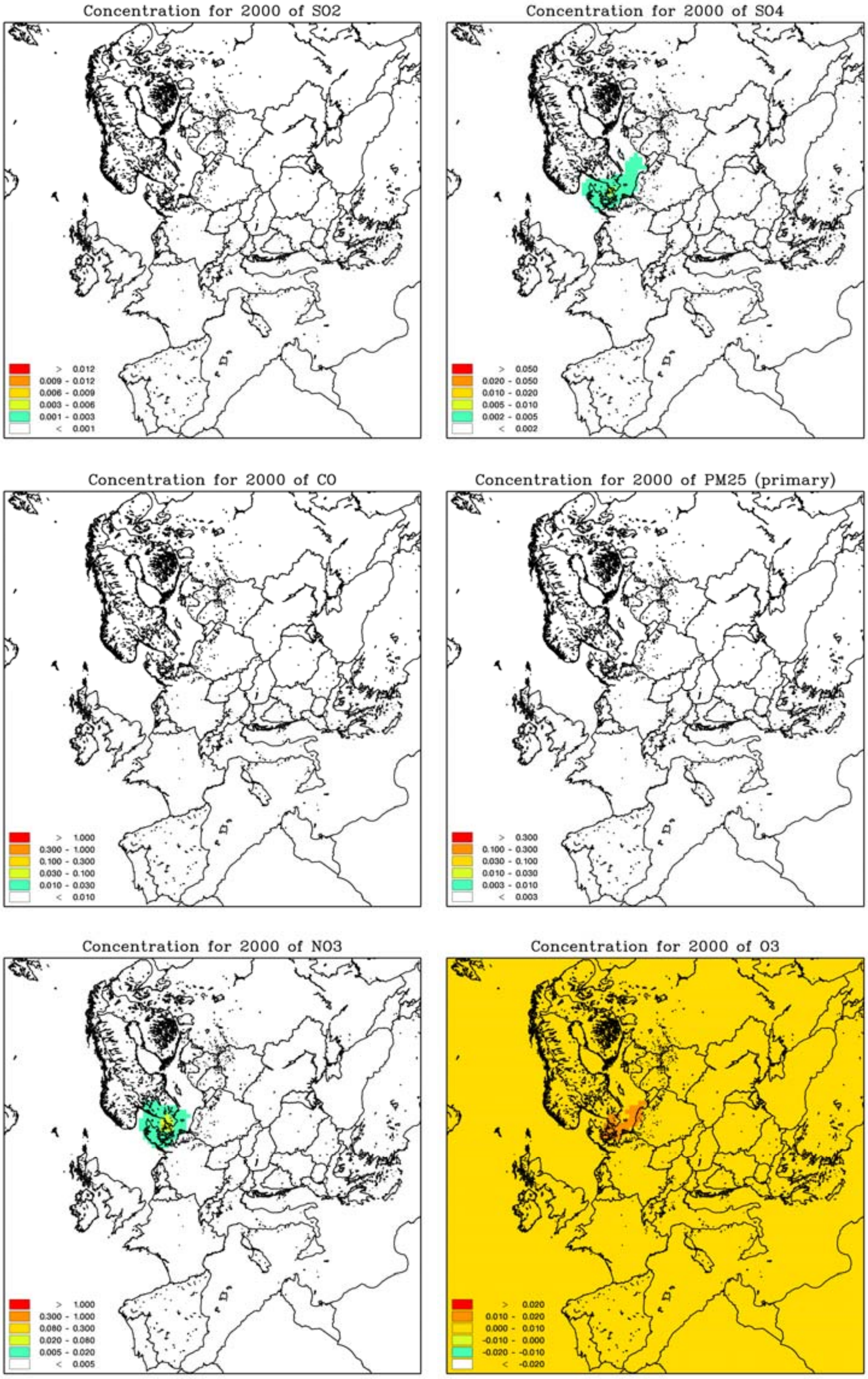

Figure A5: As figure A1 but for SNAP category 5 (extraction and distribution of fossil fuels and geothermal energy).

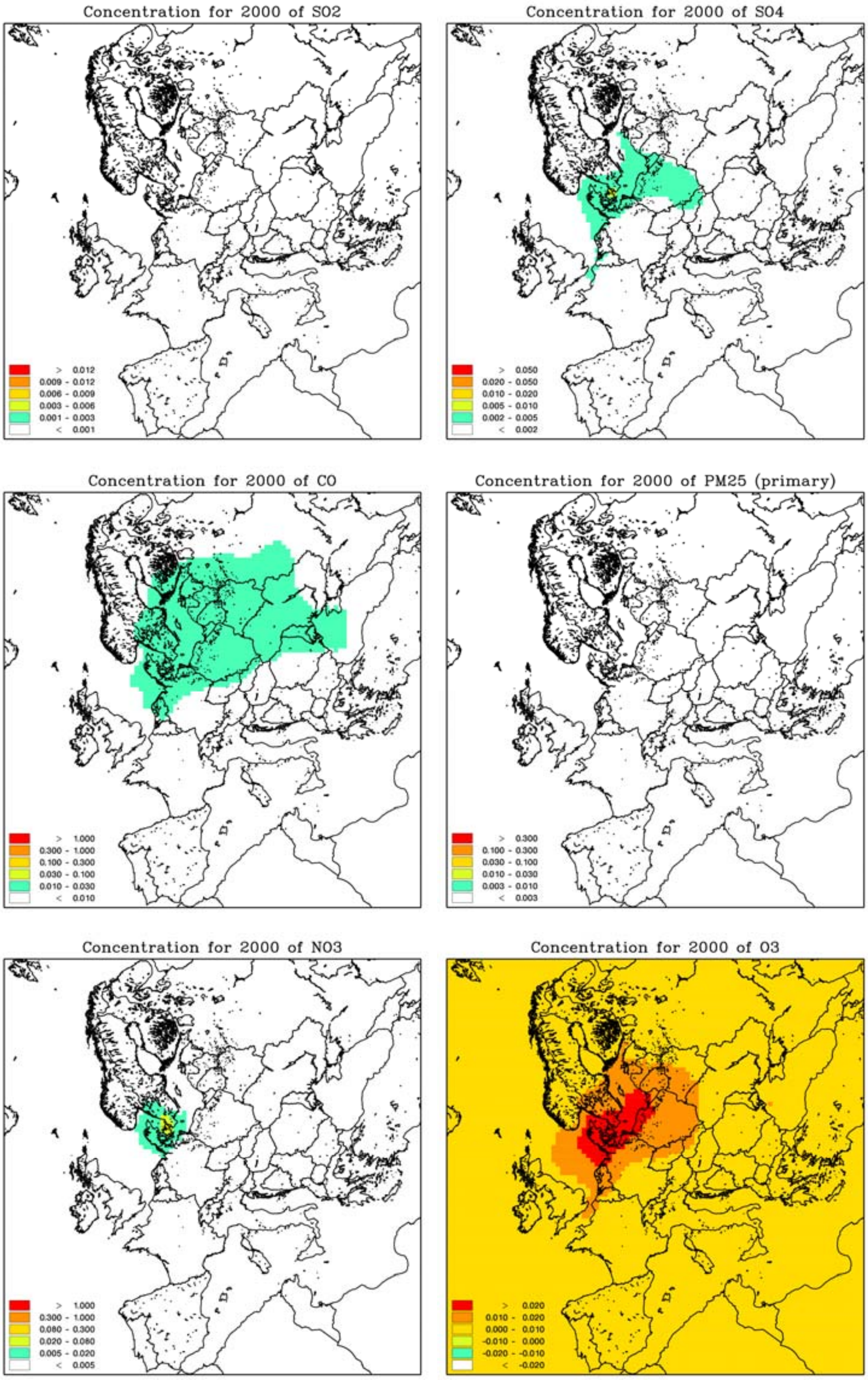

Figure A6: As figure A1 but for SNAP category 6 (solvents and other product use).

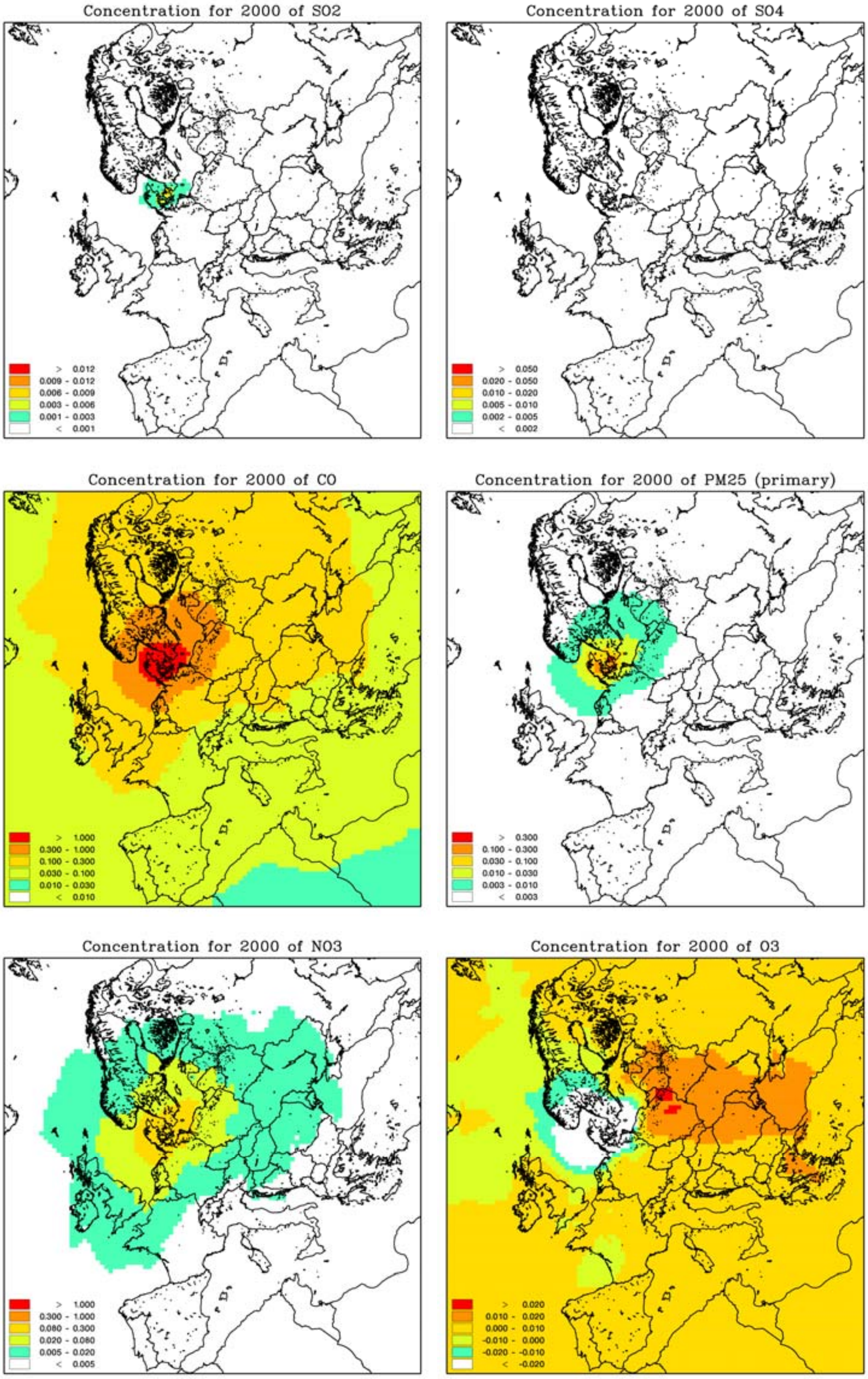

Figure A7: As figure A1 but for SNAP category 7 (road transport).

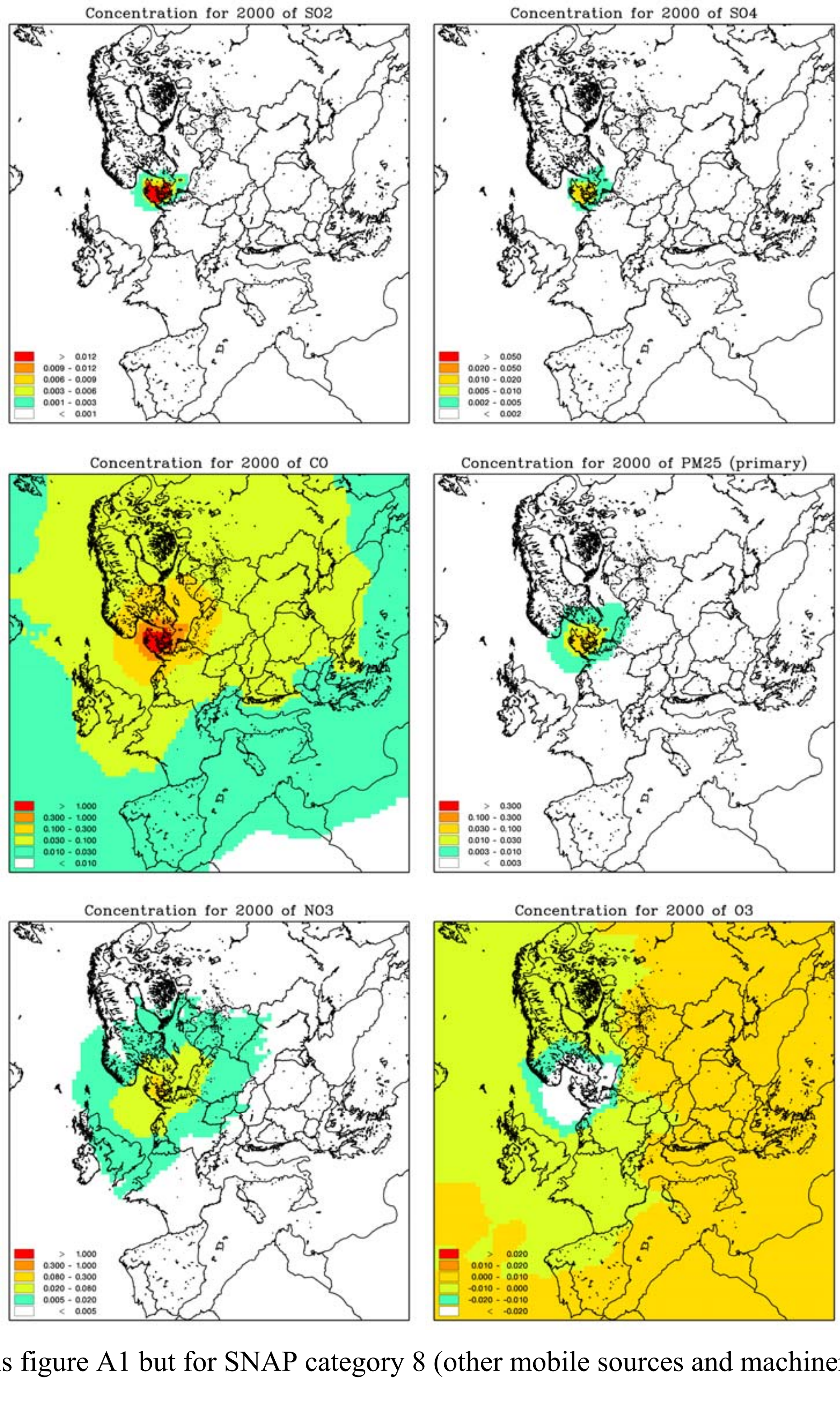

Figure A8: As figure A1 but for SNAP category 8 (other mobile sources and machinery).

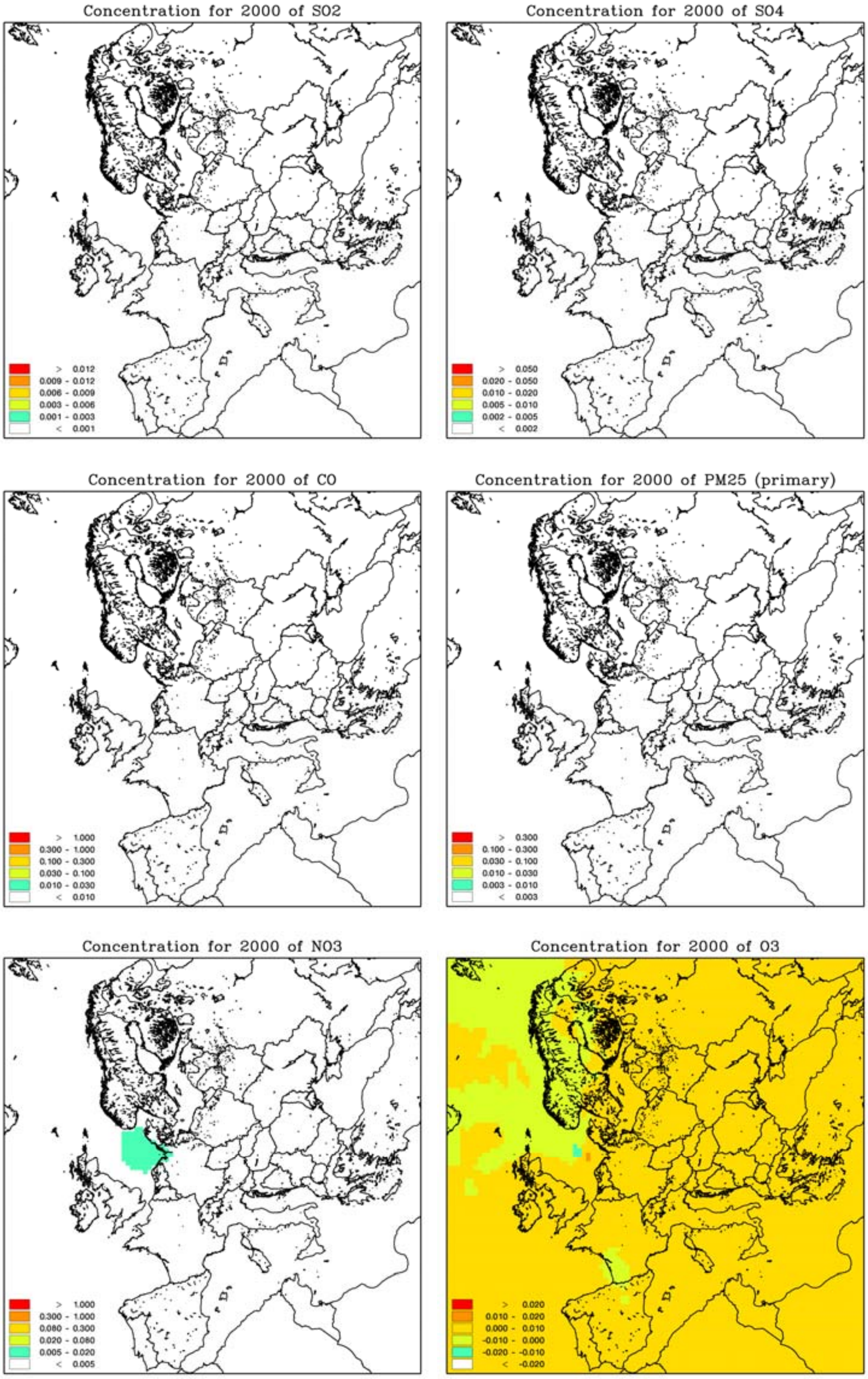

Figure A9: As figure A1 but for SNAP category 9 (waste treatment and disposal).

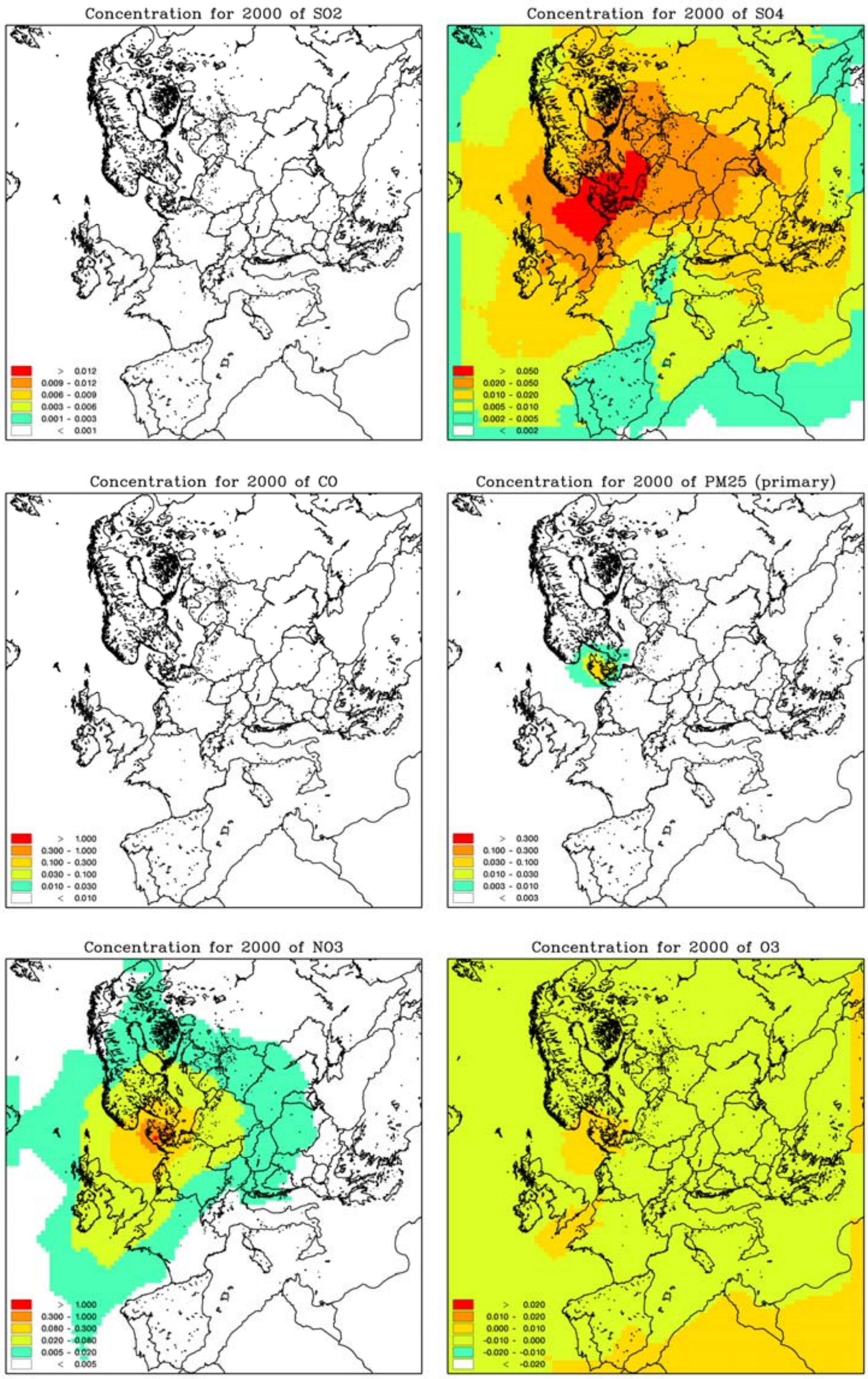

Figure A10: As figure A1 but for SNAP category 10 (agriculture).

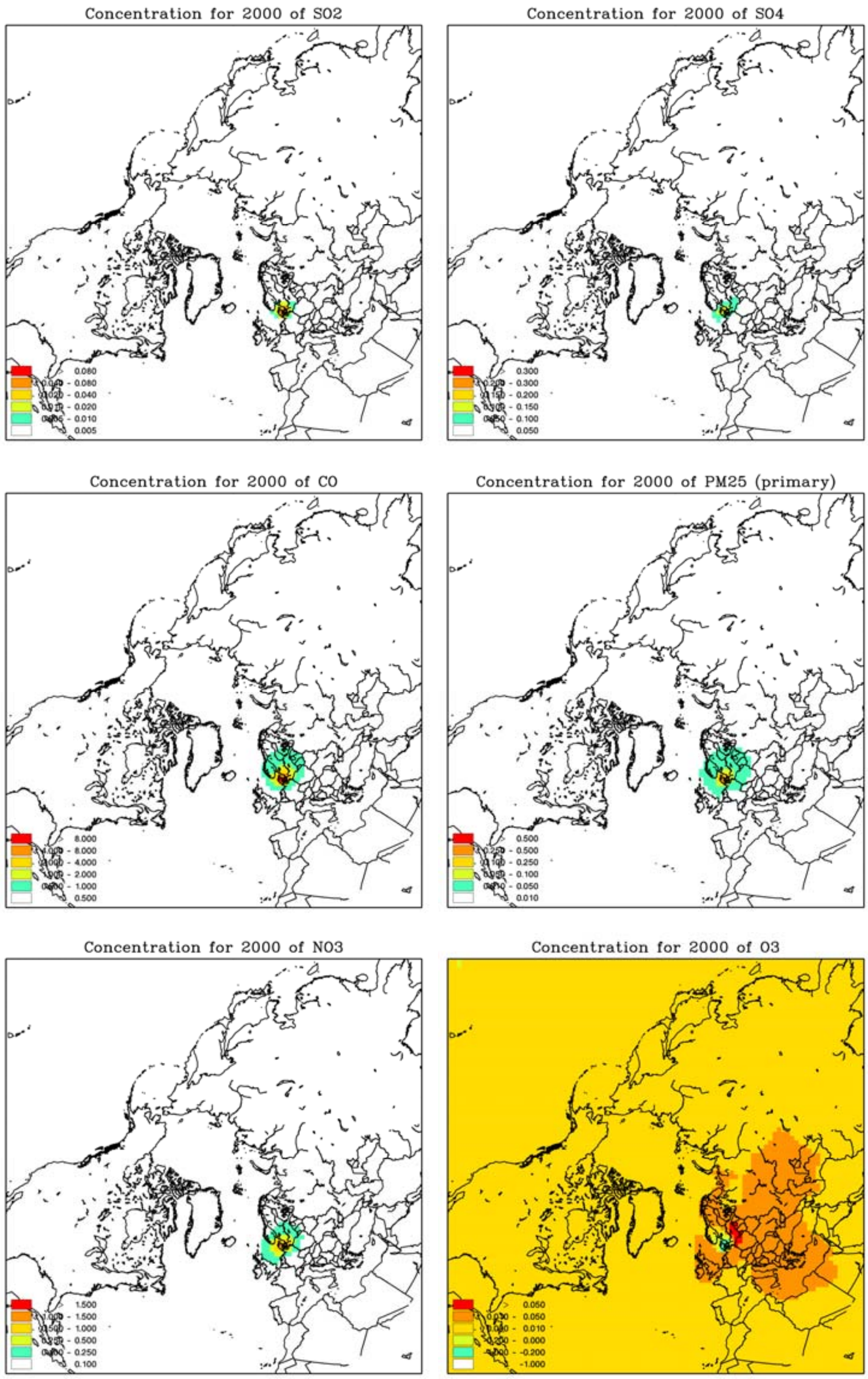

Figure A11: Contribution to the mean annual air pollution levels (δ-concentrations) calculated using the DEHM model due to emission from the whole of Denmark for all SNAP categories 1 to 10 simultaneously, for the year 2000. The compounds are: SO_2 [ppb], SO_4^{2-} [µg/m^3], CO {ppm], $PM_{2.5}$ (primary part) [µg/m^3], NO_3^- [µg/m^3] and O_3 [ppb]. Results are shown for DEHM domain number 1.

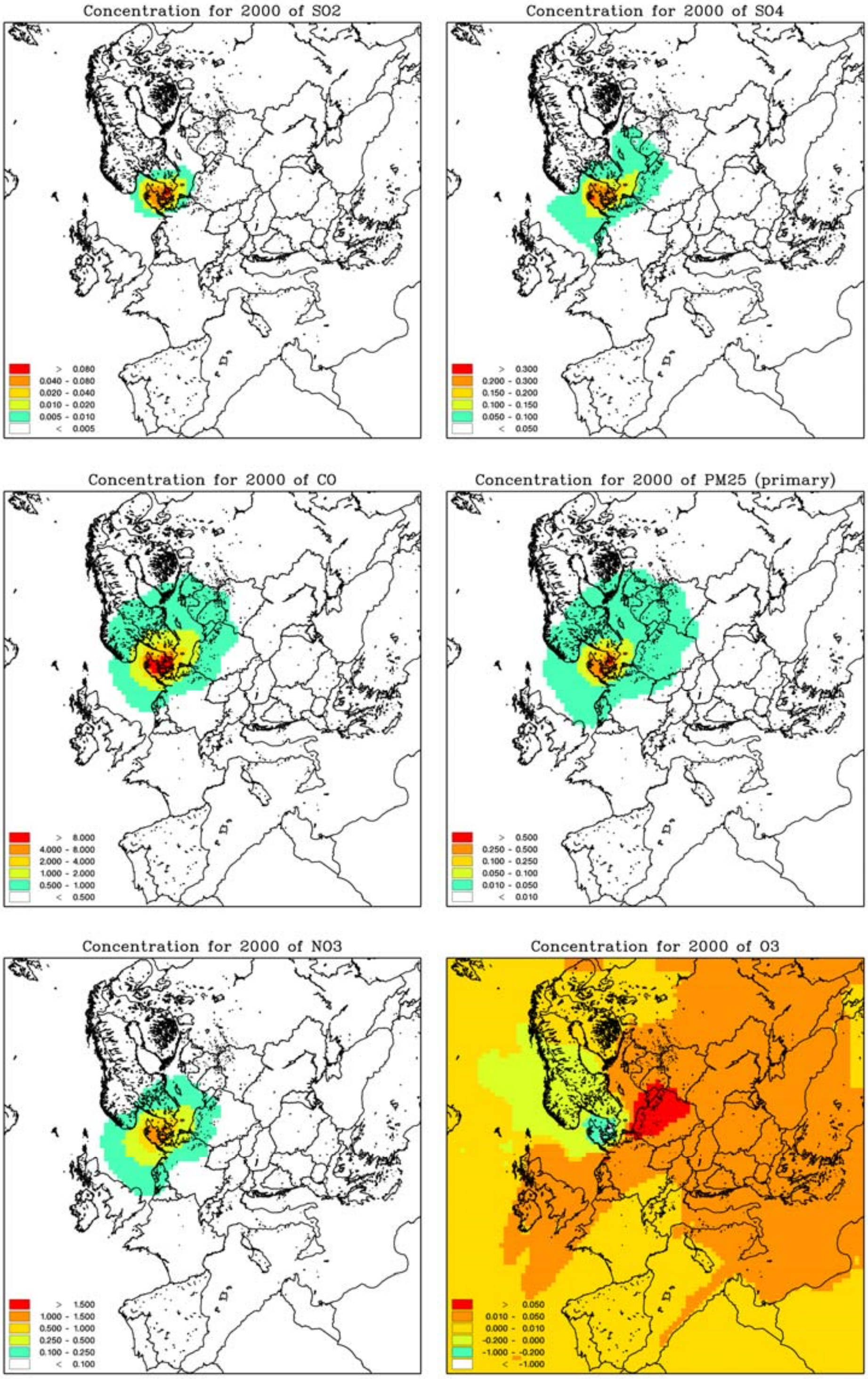

Figure A12: As figure A11, but for DEHM model domain 2.

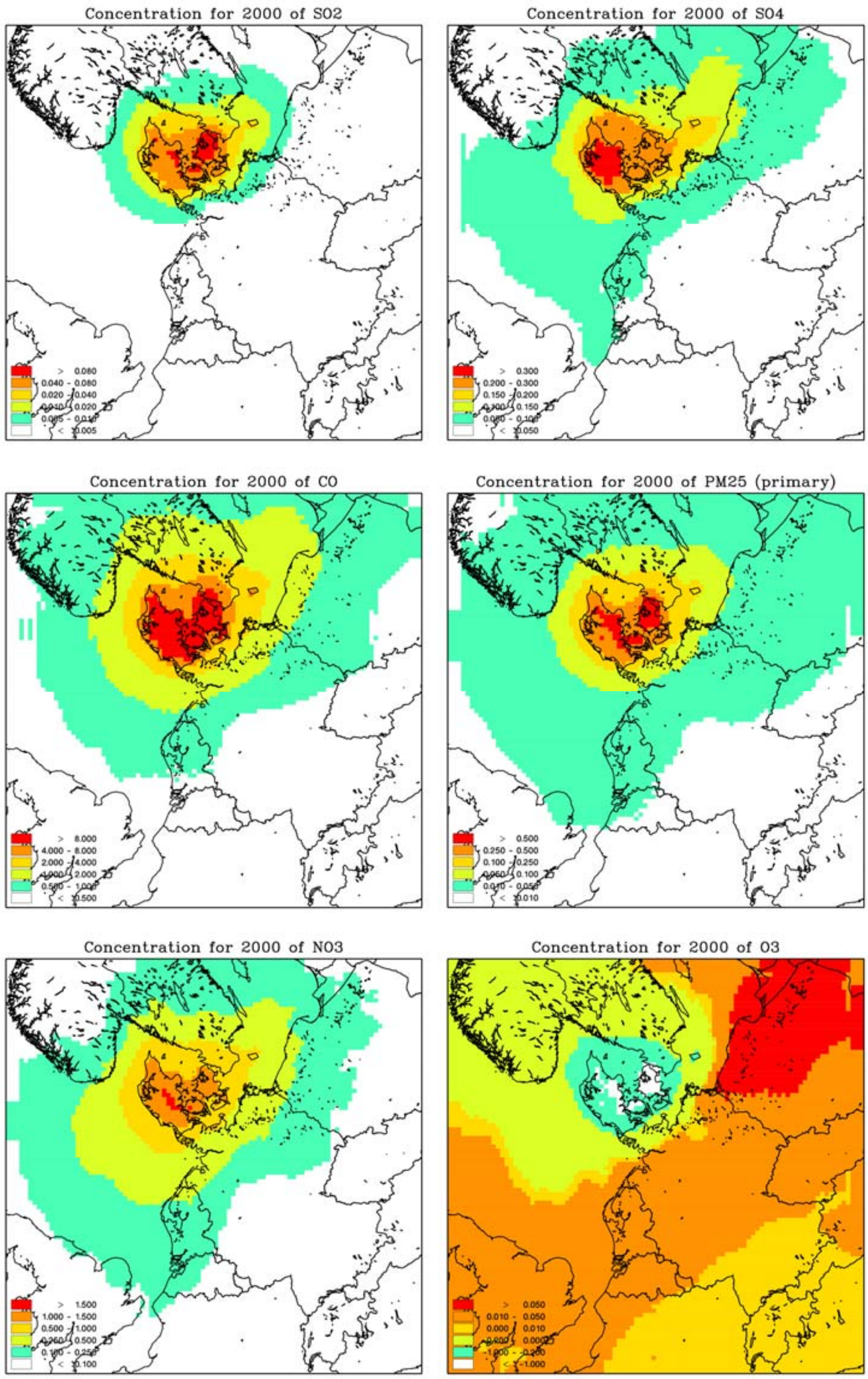

Figure A13: As figure A11, but for DEHM model domain 3.

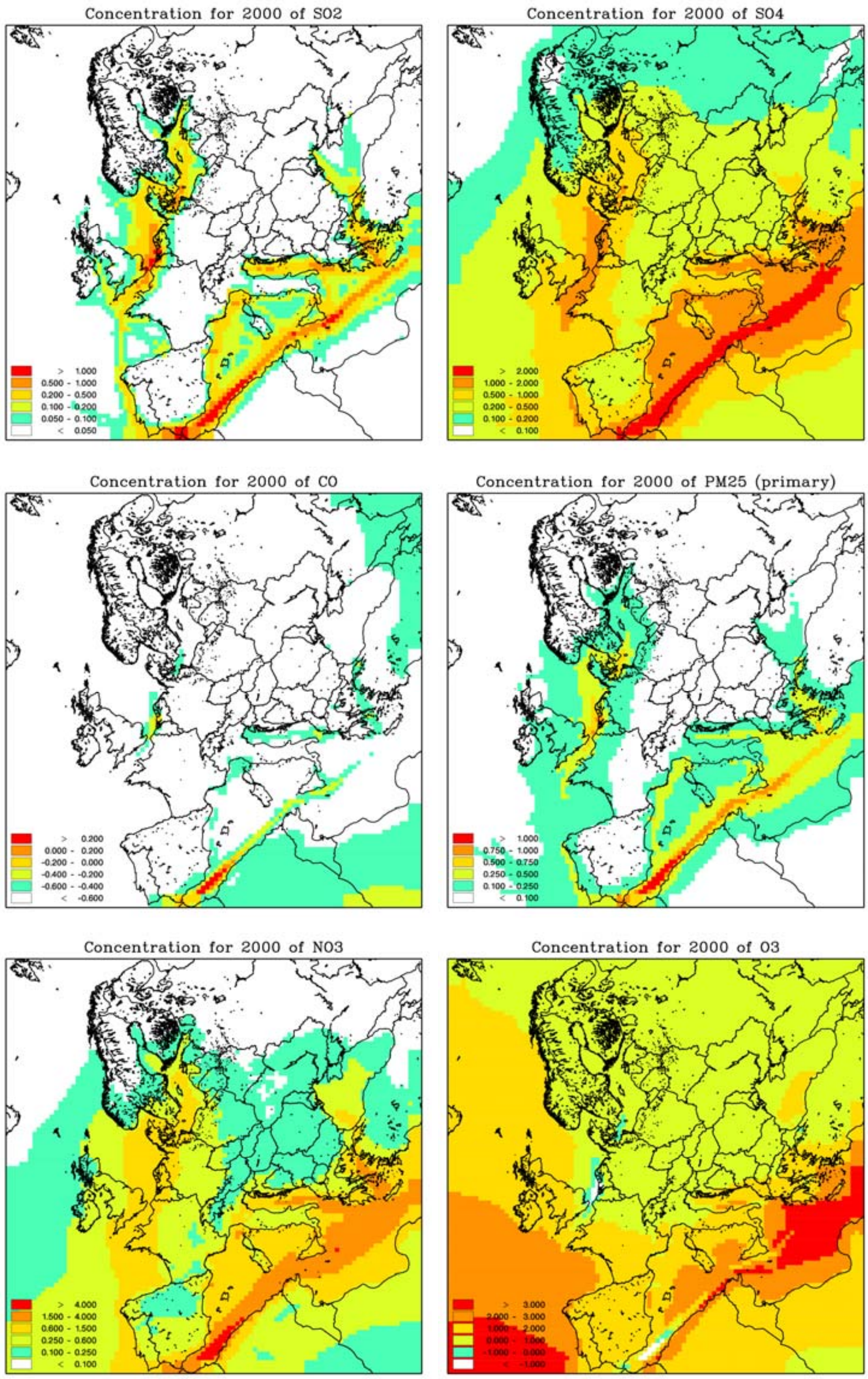

Figure A14: Contribution to the mean annual air pollution levels (δ-concentrations) calculated using the DEHM model due to emission from the Northern Hemisphere for SNAP category 15 (international ship traffic) for the year 2000. The compounds are: SO_2 [ppb], SO_4^{2-} [μg/m^3], CO {ppm], $PM_{2.5}$ (primary part) [μg/m^3], NO_3^- [μg/m^3] and O_3 [ppb]. Results are shown for DEHM domain number 2.

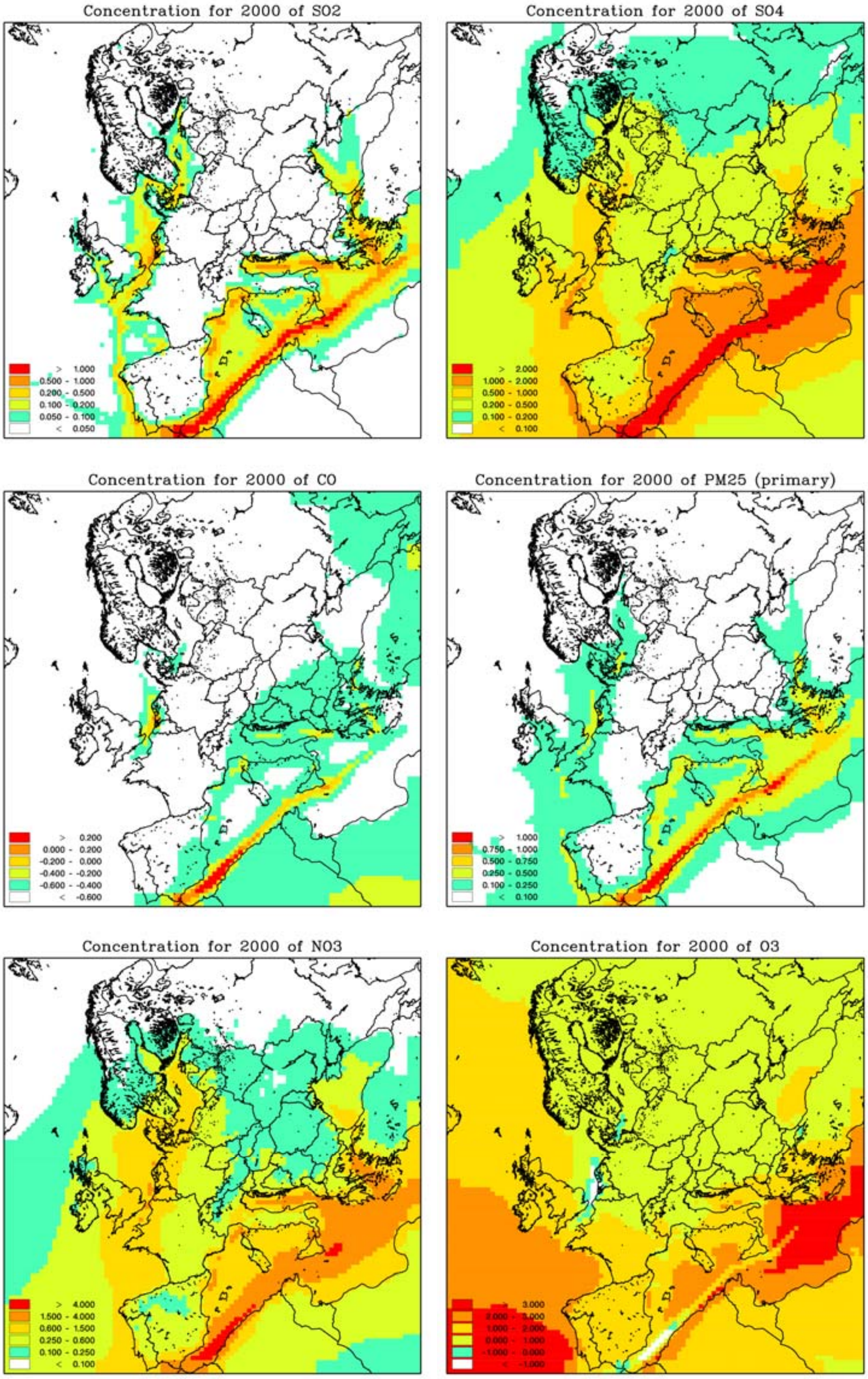

Figure A15: As figure A14, but for the year 2007.

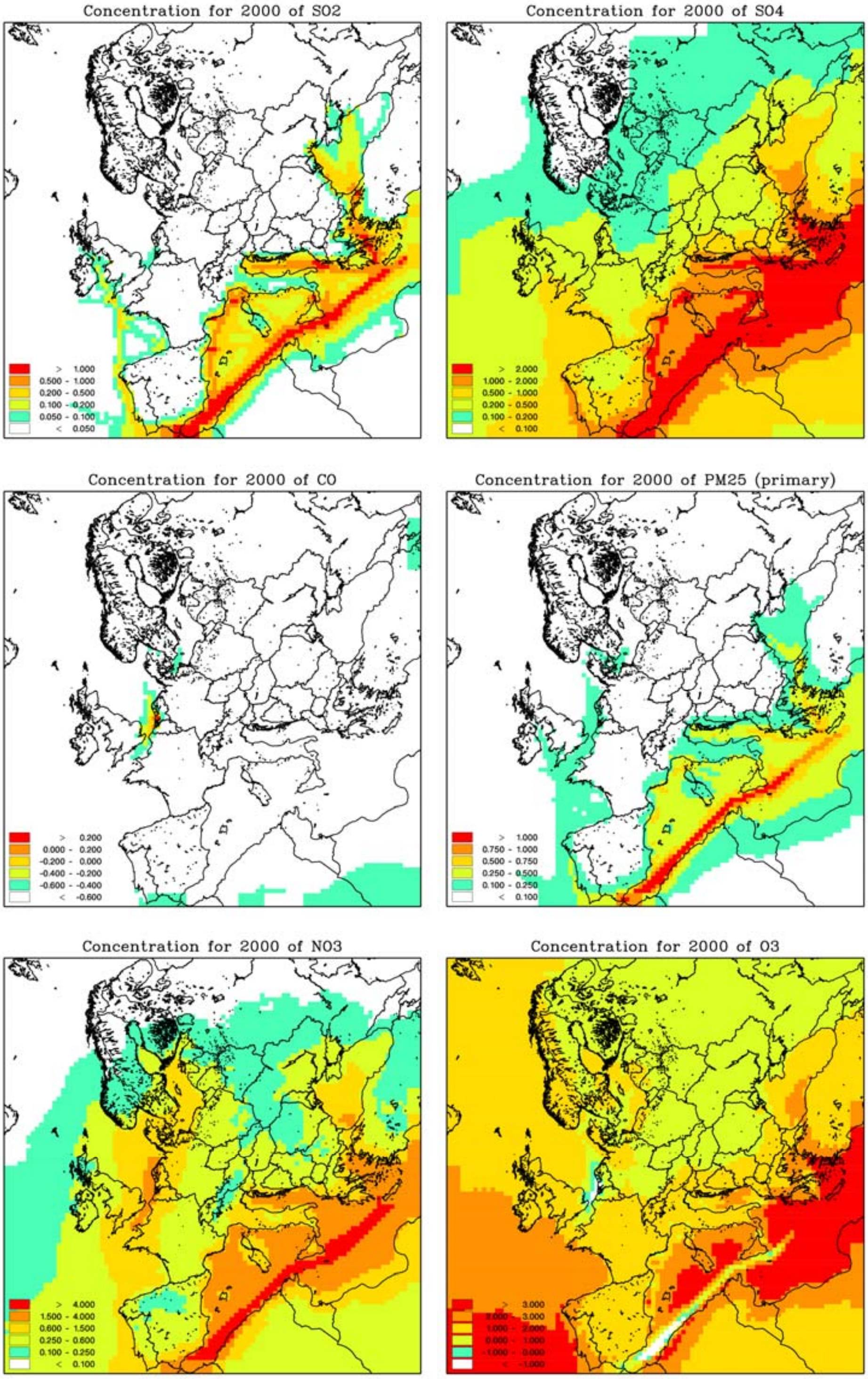

Figure A16: As figure A14, but for the year 2020.

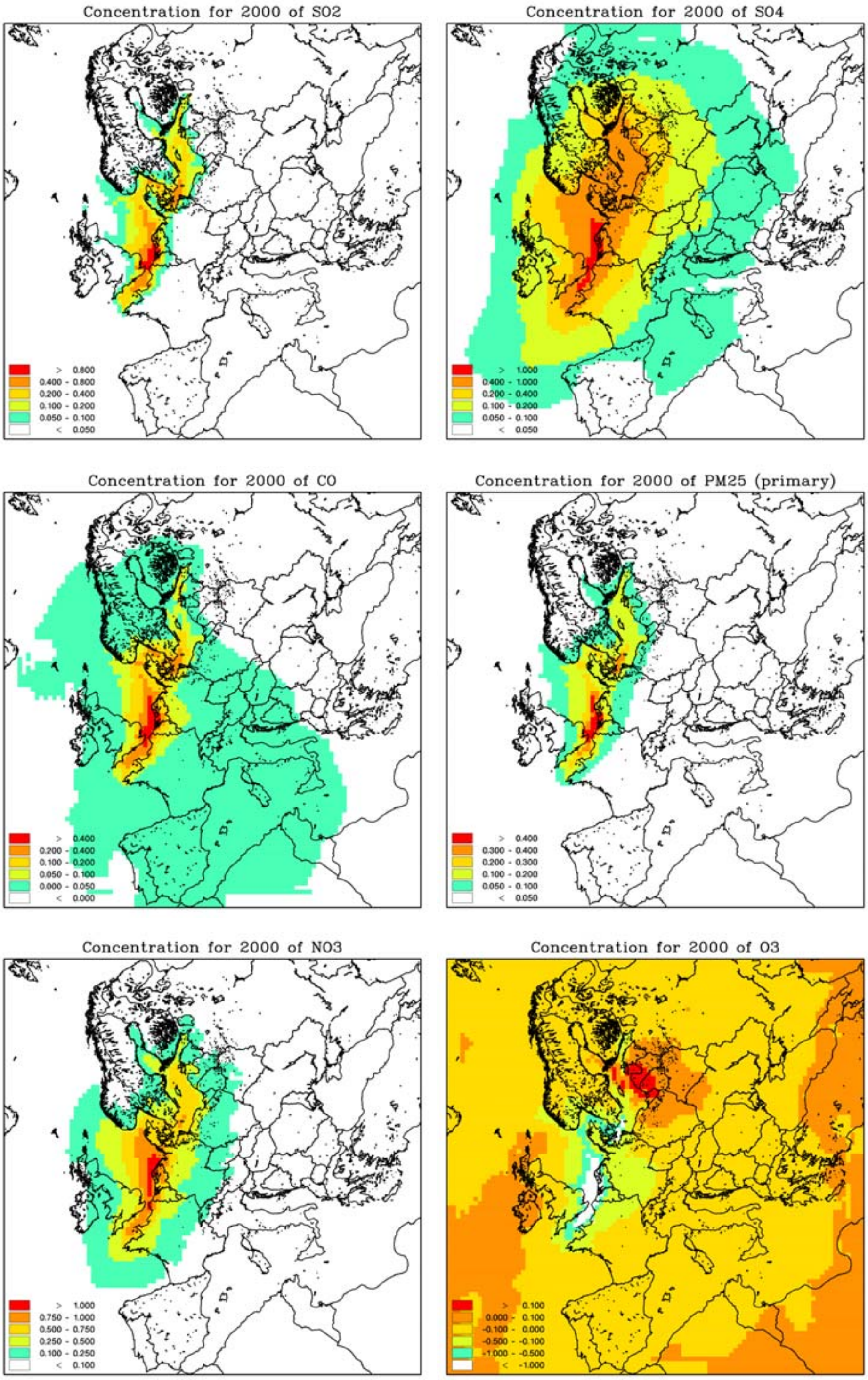

Figure A17: Contribution to the mean annual air pollution levels (δ-concentrations) calculated using the DEHM model due to emission from the Baltic Sea and the North Sea (BaS-NoS) for SNAP category 15 (international ship traffic) for the year 2000. The compounds are: SO_2 [ppb], SO_4^{2-} [μg/m^3], CO {ppm], $PM_{2.5}$ (primary part) [μg/m^3], NO_3^- [μg/m^3] and O_3 [ppb]. Results are shown for DEHM domain number 2.

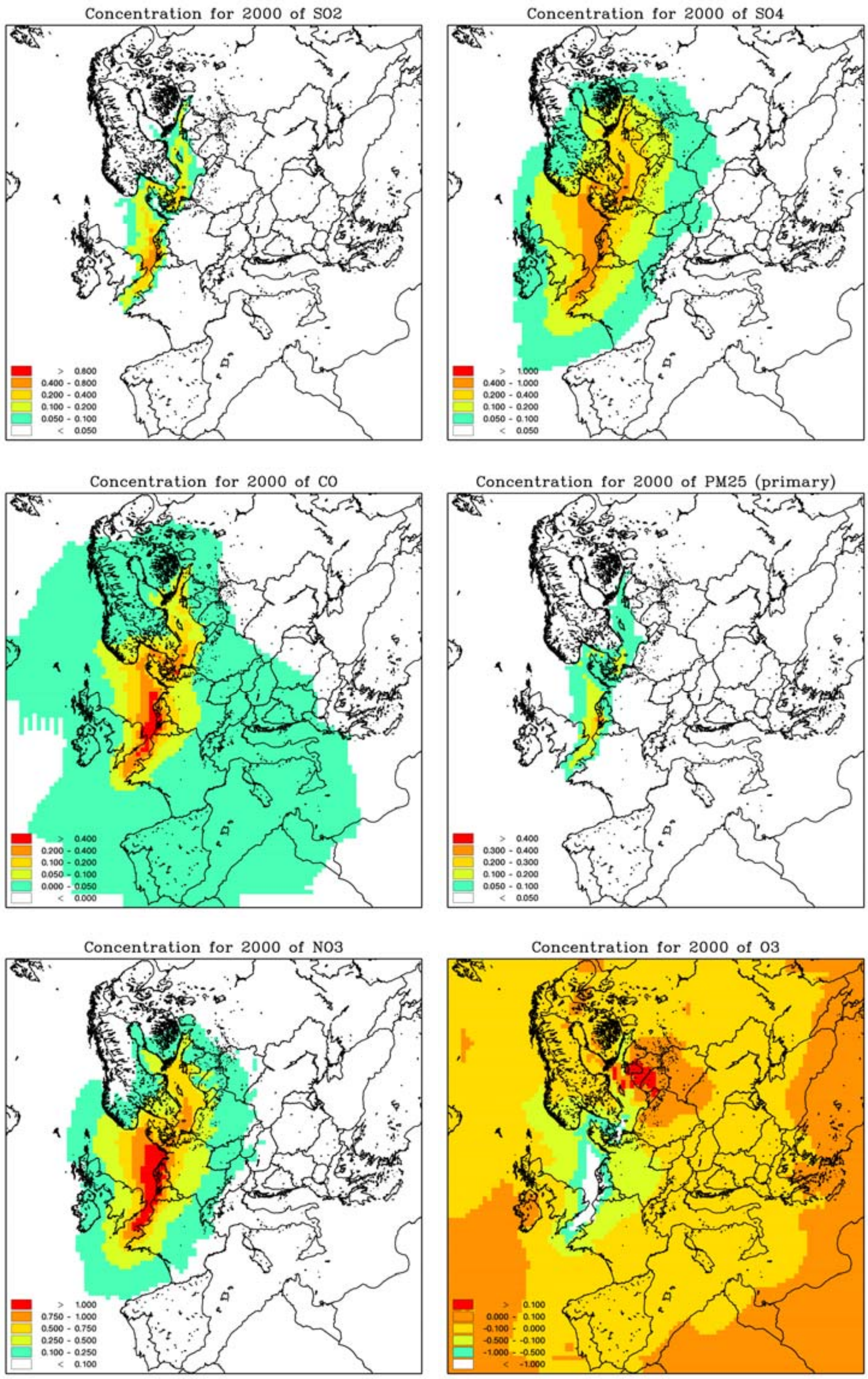

Figure A18: As figure A17, but for the year 2007.

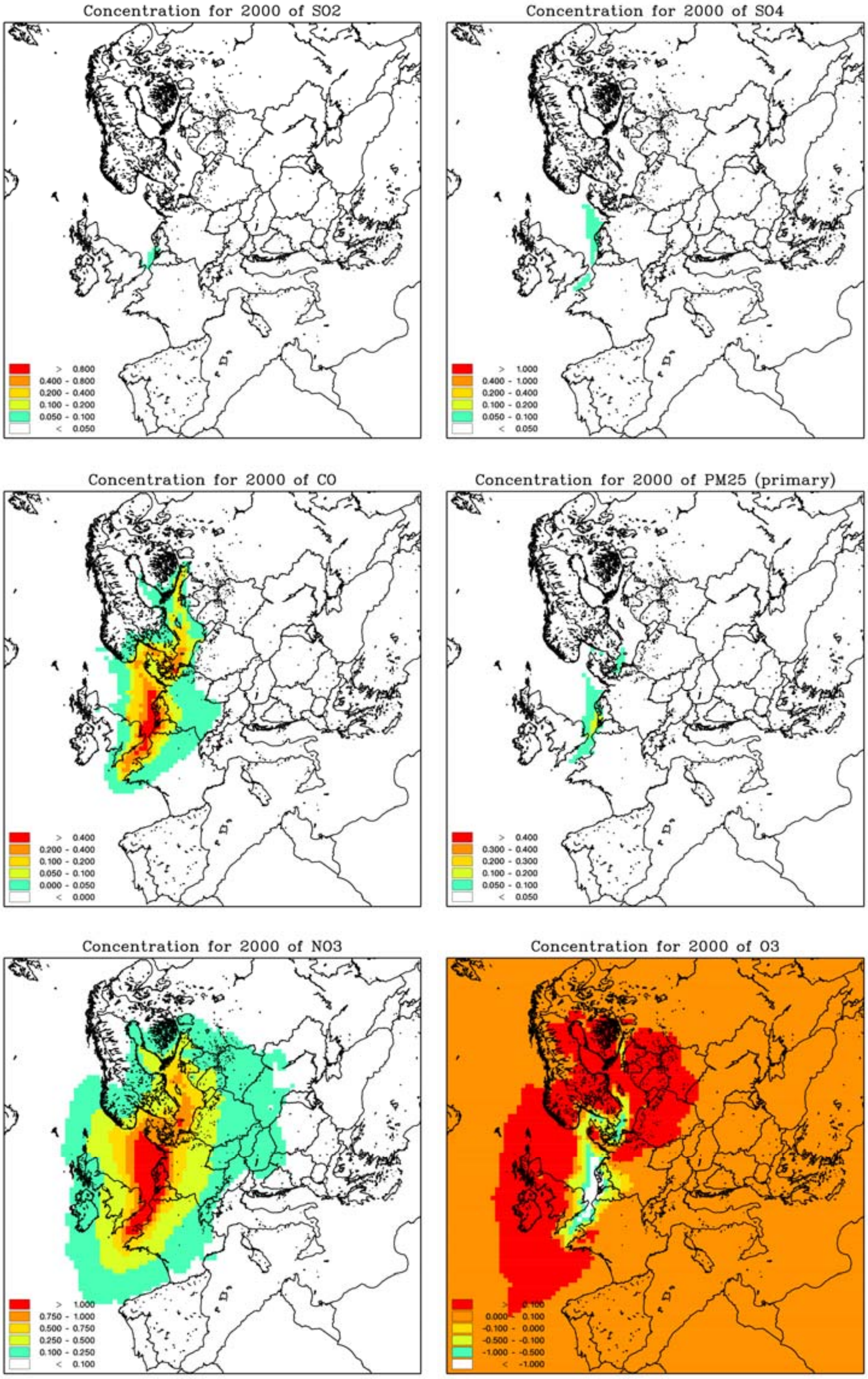

Figure A19: As figure A17, but for the year 2020.

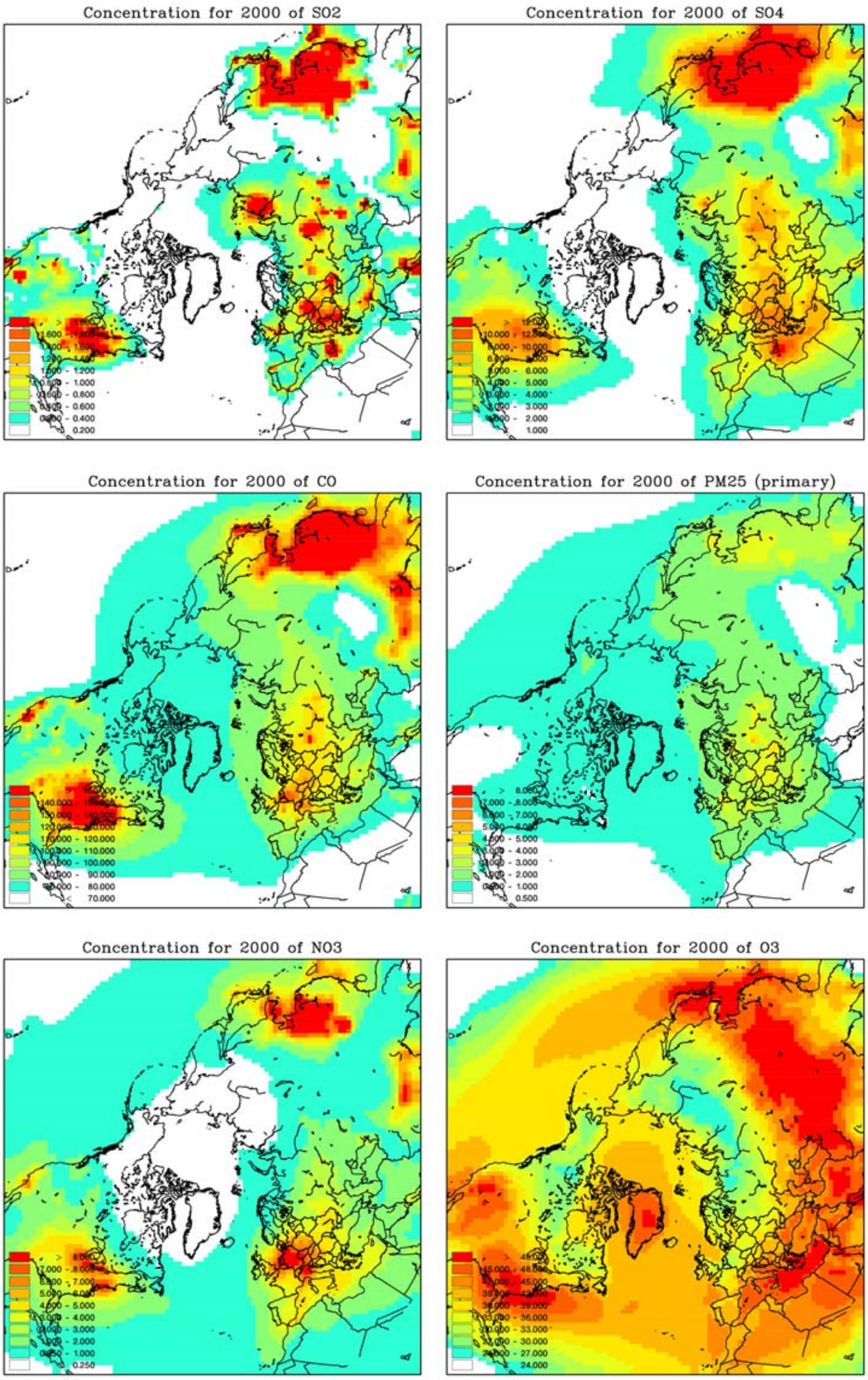

Figure A20: Mean annual air pollution levels calculated using the DEHM model due to emission from the Northern Hemisphere for the year 2000. The compounds are: SO_2 [ppb], SO_4^{2-} [µg/m^3], CO {ppm], $PM_{2.5}$ (primary part) [µg/m^3], NO_3^- [µg/m^3] and O_3 [ppb]. Results are shown for DEHM domain number 1 (the Northern Hemisphere).

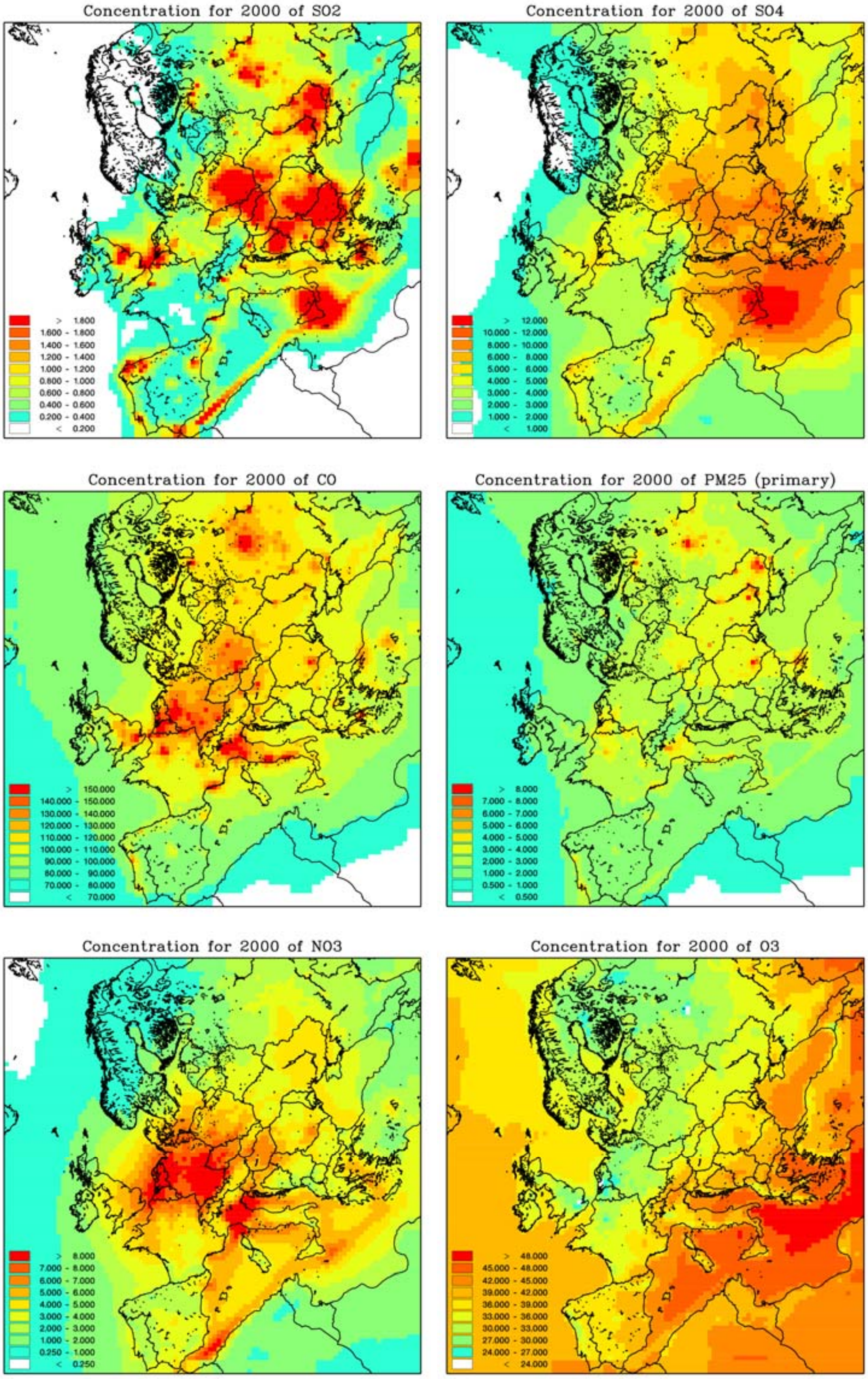

Figure A21: As figure A20, but for DEHM model domain 2 (Europe).

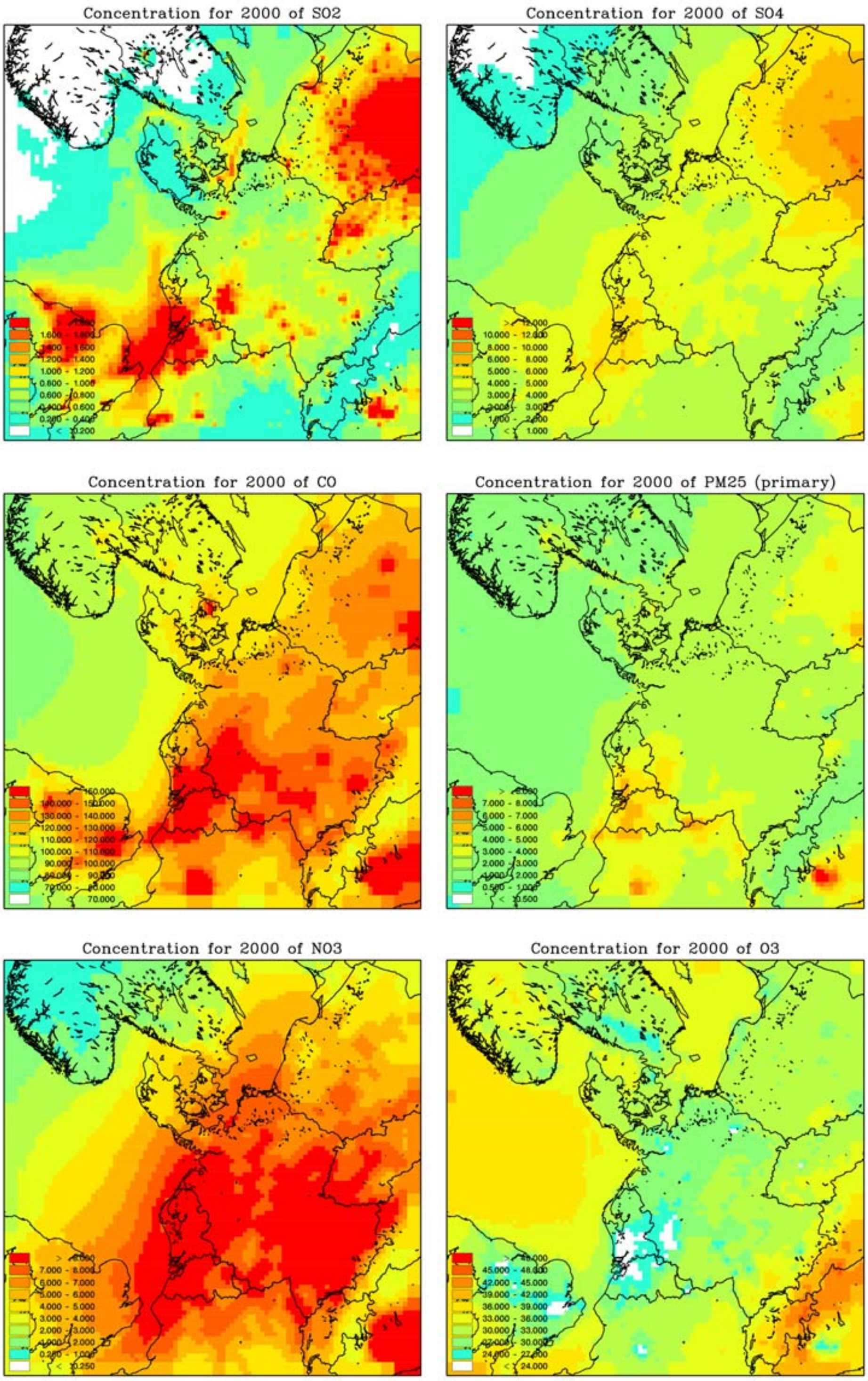

Figure A22: As figure A20, but for DEHM model domain 3 (northern Europe).

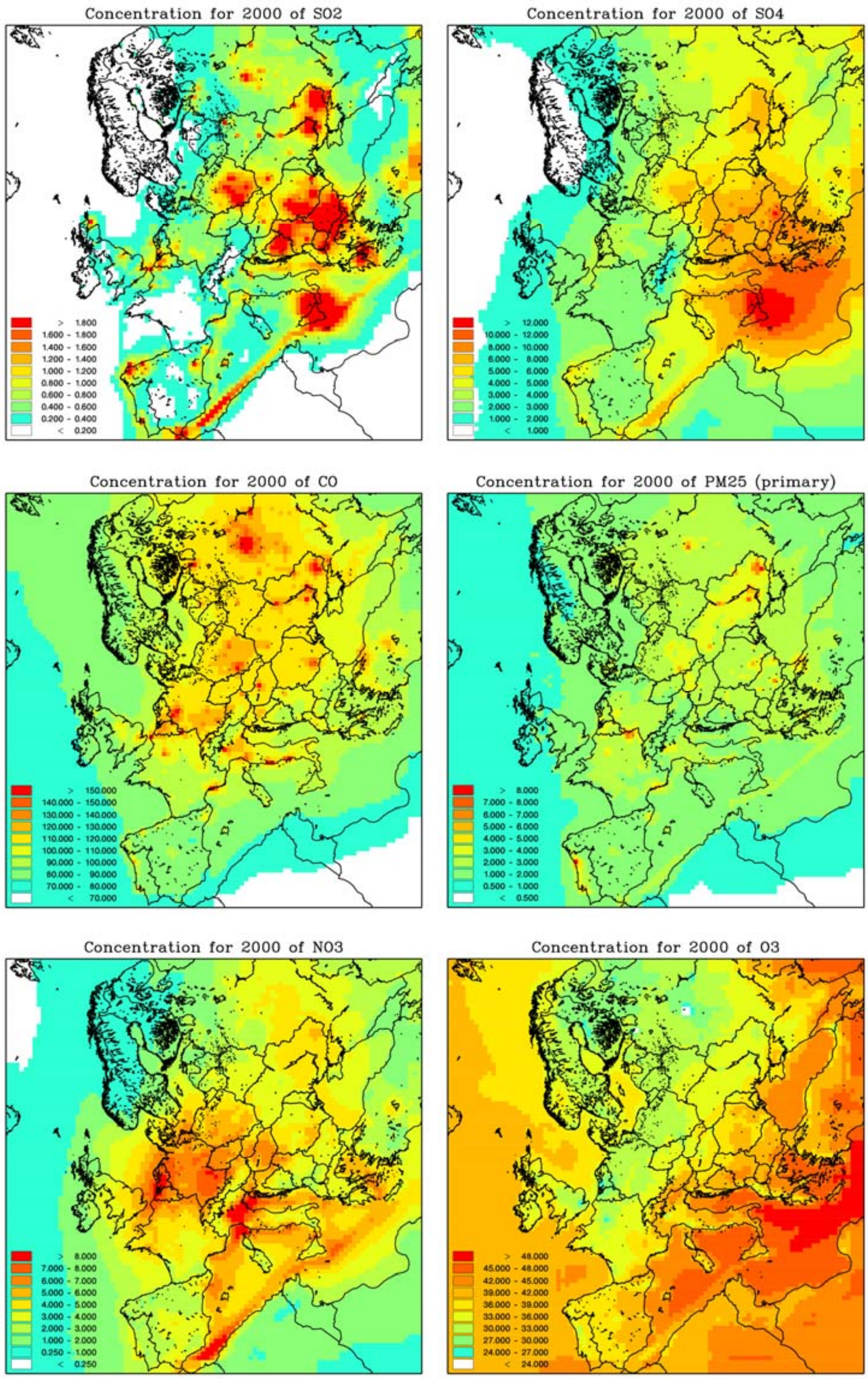

Figure A23: As figure A21, but for the year 2007.

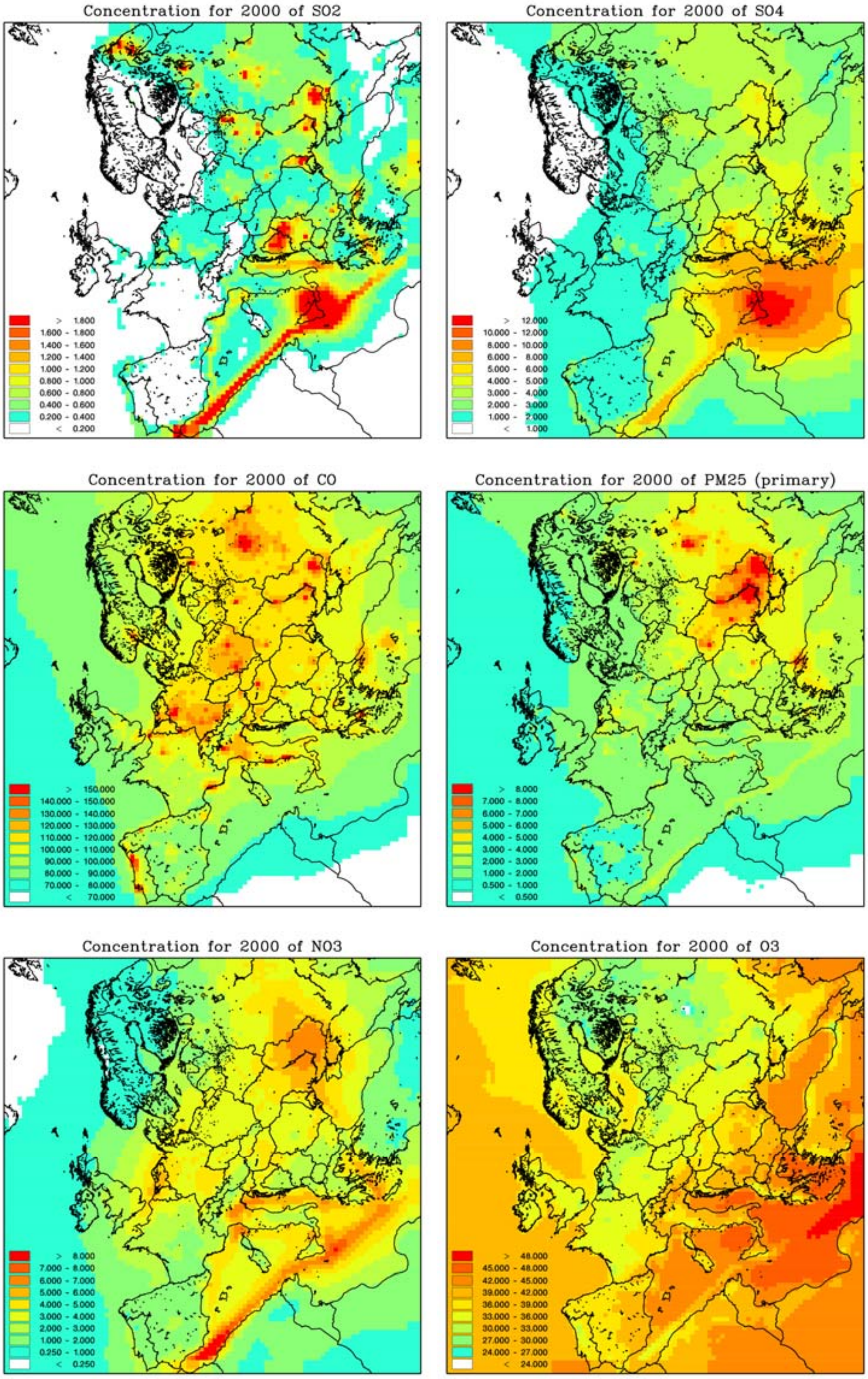

Figure A24: As figure A21, but for the year 2020.

Appendix B: Tables including the individual impacts and external cost from the different scenario runs

In this appendix, the detailed EVA model results for the different scenarios are shown. In all tables the impacts on human health and the related external costs are given per chemical compound for all the scenarios. Furthermore, results are presented both for the whole of Europe and for Denmark only – the latter being part of the former.

In tables B1 to B12 the impacts and related external costs for morbidity are given:
- Tables B1-B2: Chronic Bronchitis (PM).
- Tables B3-B4: Restricted Activity Days (PM).
- Tables B5-B6: Respiratory Hospital Admissions (PM and SO_2).
- Tables B7-B8: Cerebrovascular Hospital Admissions (PM).
- Tables B9-B10: Congestive Heart Failure (PM and CO).
- Tables B11-B12: Lung Cancer (PM).

In tables B13 to B18 the impacts and related external costs for asthma are given:
- Tables B13-B14: Bronchodilator Use (PM).
- Tables B15-B16: Cough (PM).
- Tables B17-B18: Lower Respiratory Symptoms (PM).

In tables B19 to B24 the impacts and related external costs for mortality are given:
- Tables B19-B20: Acute YOLL (SO_2 and O_3).
- Tables B21-B22: Chronic YOLL PM).
- Tables B23-B24: Infant mortality (PM).

In tables B25 and B26 the total external costs per chemical compound is given both for Europe and for Denmark alone.

Table B1: Total number of cases and external costs in Euros for the whole of Europe per chemical compound for all the different scenarios related to **chronic bronchitis.**

Region/SNAP	Year	Cases			Costs		
		$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	1.4E+01	3.8E+02	1.2E+02	7.35E+05	2.00E+07	6.41E+06
DK/2	2000	3.0E+02	1.0E+02	6.8E+01	1.59E+07	5.47E+06	3.61E+06
DK/3	2000	2.4E+01	1.6E+02	7.8E+01	1.28E+06	8.71E+06	4.12E+06
DK/4	2000	9.6E+00	4.8E+01	3.7E+01	5.07E+05	2.53E+06	1.95E+06
DK/5	2000	1.2E+00	4.6E+01	3.2E+01	6.55E+04	2.45E+06	1.70E+06
DK/6	2000	0.0E+00	5.0E+01	5.3E+01	1.88E+03	2.66E+06	2.81E+06
DK/7	2000	2.0E+02	6.7E+02	2.6E+01	1.04E+07	3.57E+07	1.39E+06
DK/8	2000	7.4E+01	3.0E+02	2.0E+01	3.94E+06	1.61E+07	1.06E+06
DK/9	2000	1.0E-01	2.6E+01	1.0E-01	7.79E+03	1.37E+06	5.30E+03
DK/10	2000	3.0E+01	1.3E+03	9.1E+02	1.58E+06	6.77E+07	4.84E+07
DK/all	2000	6.6E+02	2.5E+03	1.1E+03	3.48E+07	1.35E+08	6.05E+07
All/15	2000	5.5E+03	1.8E+04	2.3E+04	2.94E+08	9.38E+08	1.20E+09
All/15	2007	4.5E+03	2.0E+04	2.0E+04	2.41E+08	1.08E+09	1.05E+09
All/15	2011	4.2E+03	2.1E+04	1.8E+04	2.21E+08	1.10E+09	9.49E+08
All/15	2020	4.0E+03	2.5E+04	2.1E+04	2.14E+08	1.31E+09	1.10E+09
BaS-NoS/15	2000	2.1E+03	7.6E+03	9.3E+03	1.09E+08	4.00E+08	4.94E+08
BaS-NoS/15	2007	9.5E+02	9.4E+03	4.8E+03	5.06E+07	4.96E+08	2.54E+08
BaS-NoS/15	2011	6.6E+02	9.6E+03	2.8E+03	3.49E+07	5.09E+08	1.48E+08
BaS-NoS/15	2020	4.5E+02	1.2E+04	2.4E+02	2.36E+07	6.15E+08	1.30E+07
All/all	2000	1.4E+05	2.4E+05	2.6E+05	7.27E+09	1.26E+10	1.37E+10
All/all	2007	1.2E+05	2.2E+05	2.0E+05	6.17E+09	1.15E+10	1.06E+10
All/all	2011	1.2E+05	2.2E+05	2.0E+05	6.15E+09	1.16E+10	1.04E+10
All/all	2020	1.3E+05	1.6E+05	1.3E+05	6.84E+09	8.30E+09	7.00E+09

Table B2: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **chronic bronchitis**.

Region/SNAP	Year	Cases			Costs		
		$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	2.1E+00	3.7E+01	1.1E+01	1.13E+05	1.98E+06	5.62E+05
DK/2	2000	1.2E+02	2.2E+01	8.4E+00	6.18E+06	1.18E+06	4.43E+05
DK/3	2000	4.2E+00	2.6E+01	7.7E+00	2.23E+05	1.38E+06	4.10E+05
DK/4	2000	4.3E+00	1.8E+01	4.5E+00	2.29E+05	9.48E+05	2.36E+05
DK/5	2000	6.0E-01	1.8E+01	2.1E+00	3.02E+04	9.55E+05	1.11E+05
DK/6	2000	0.0E+00	2.0E+01	2.3E+00	1.13E+01	1.04E+06	1.21E+05
DK/7	2000	1.2E+02	8.9E+01	-5.0E-01	6.20E+06	4.73E+06	-2.48E+04
DK/8	2000	3.6E+01	2.6E+01	5.3E+00	1.92E+06	1.40E+06	2.78E+05
DK/9	2000	0.0E+00	1.0E+00	0.0E+00	7.28E+02	5.11E+04	-7.92E+02
DK/10	2000	1.2E+01	2.9E+02	6.0E+01	6.11E+05	1.55E+07	3.21E+06
DK/all	2000	2.9E+02	4.1E+02	9.5E+01	1.56E+07	2.19E+07	5.01E+06
All/15	2000	1.2E+02	2.8E+02	3.0E+02	6.15E+06	1.47E+07	1.61E+07
All/15	2007	5.9E+01	3.0E+02	1.9E+02	3.12E+06	1.59E+07	9.86E+06
All/15	2011	4.5E+01	3.2E+02	1.3E+02	2.38E+06	1.67E+07	6.98E+06
All/15	2020	3.3E+01	3.4E+02	5.1E+01	1.75E+06	1.80E+07	2.68E+06
BaS-NoS/15	2000	6.6E+01	2.3E+02	2.6E+02	3.50E+06	1.22E+07	1.38E+07
BaS-NoS/15	2007	2.9E+01	2.6E+02	1.4E+02	1.55E+06	1.38E+07	7.58E+06
BaS-NoS/15	2011	2.0E+01	2.8E+02	8.9E+01	1.07E+06	1.46E+07	4.73E+06
BaS-NoS/15	2020	1.4E+01	3.1E+02	1.1E+01	7.22E+05	1.64E+07	5.78E+05
All/all	2000	9.4E+02	1.9E+03	1.2E+03	4.96E+07	9.98E+07	6.24E+07
All/all	2007	8.8E+02	1.6E+03	8.1E+02	4.68E+07	8.74E+07	4.28E+07
All/all	2011	8.7E+02	1.7E+03	7.5E+02	4.60E+07	8.93E+07	3.97E+07
All/all	2020	6.4E+02	1.1E+03	4.3E+02	3.37E+07	5.85E+07	2.27E+07

Table B3: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **restricted activity days**.

		Cases			Costs		
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	1.4E+04	3.9E+05	1.2E+05	1.86E+06	5.05E+07	1.62E+07
DK/2	2000	3.1E+05	1.1E+05	7.0E+04	4.02E+07	1.38E+07	9.13E+06
DK/3	2000	2.5E+04	1.7E+05	8.0E+04	3.23E+06	2.20E+07	1.04E+07
DK/4	2000	9.8E+03	4.9E+04	3.8E+04	1.28E+06	6.39E+06	4.92E+06
DK/5	2000	1.3E+03	4.7E+04	3.3E+04	1.66E+05	6.20E+06	4.31E+06
DK/6	2000	3.6E+01	5.1E+04	5.4E+04	4.76E+03	6.72E+06	7.10E+06
DK/7	2000	2.0E+05	6.9E+05	2.7E+04	2.63E+07	9.02E+07	3.52E+06
DK/8	2000	7.6E+04	3.1E+05	2.1E+04	9.96E+06	4.08E+07	2.69E+06
DK/9	2000	1.5E+02	2.6E+04	1.0E+02	1.97E+04	3.47E+06	1.34E+04
DK/10	2000	3.1E+04	1.3E+06	9.4E+05	4.00E+06	1.71E+08	1.22E+08
DK/all	2000	6.7E+05	2.6E+06	1.2E+06	8.80E+07	3.41E+08	1.53E+08
All/15	2000	5.7E+06	1.8E+07	2.3E+07	7.43E+08	2.37E+09	3.05E+09
All/15	2007	4.6E+06	2.1E+07	2.0E+07	6.08E+08	2.74E+09	2.67E+09
All/15	2011	4.3E+06	2.1E+07	1.8E+07	5.59E+08	2.77E+09	2.40E+09
All/15	2020	4.1E+06	2.5E+07	2.1E+07	5.42E+08	3.31E+09	2.80E+09
BaS-NoS/15	2000	2.1E+06	7.7E+06	9.5E+06	2.76E+08	1.01E+09	1.25E+09
BaS-NoS/15	2007	9.8E+05	9.6E+06	4.9E+06	1.28E+08	1.26E+09	6.43E+08
BaS-NoS/15	2011	6.7E+05	9.8E+06	2.9E+06	8.83E+07	1.29E+09	3.76E+08
BaS-NoS/15	2020	4.6E+05	1.2E+07	2.5E+05	5.96E+07	1.56E+09	3.28E+07
All/all	2000	1.4E+08	2.4E+08	2.6E+08	1.84E+10	3.19E+10	3.45E+10
All/all	2007	1.2E+08	2.2E+08	2.0E+08	1.56E+10	2.92E+10	2.68E+10
All/all	2011	1.2E+08	2.2E+08	2.0E+08	1.56E+10	2.92E+10	2.64E+10
All/all	2020	1.3E+08	1.6E+08	1.4E+08	1.73E+10	2.10E+10	1.77E+10

Table B4: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **restricted activity days**.

		Cases			Costs		
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	2.2E+03	3.8E+04	1.1E+04	2.86E+05	5.01E+06	1.42E+06
DK/2	2000	1.2E+05	2.3E+04	8.6E+03	1.56E+07	2.97E+06	1.12E+06
DK/3	2000	4.3E+03	2.7E+04	7.9E+03	5.65E+05	3.48E+06	1.04E+06
DK/4	2000	4.4E+03	1.8E+04	4.6E+03	5.80E+05	2.40E+06	5.98E+05
DK/5	2000	5.8E+02	1.8E+04	2.1E+03	7.63E+04	2.42E+06	2.80E+05
DK/6	2000	2.0E-01	2.0E+04	2.3E+03	2.86E+01	2.64E+06	3.06E+05
DK/7	2000	1.2E+05	9.1E+04	-4.8E+02	1.57E+07	1.20E+07	-6.27E+04
DK/8	2000	3.7E+04	2.7E+04	5.4E+03	4.84E+06	3.54E+06	7.03E+05
DK/9	2000	1.4E+01	9.9E+02	-1.5E+01	1.84E+03	1.29E+05	-2.00E+03
DK/10	2000	1.2E+04	3.0E+05	6.2E+04	1.54E+06	3.92E+07	8.11E+06
DK/all	2000	3.0E+05	4.2E+05	9.7E+04	3.94E+07	5.54E+07	1.27E+07
All/15	2000	1.2E+05	2.8E+05	3.1E+05	1.56E+07	3.71E+07	4.07E+07
All/15	2007	6.0E+04	3.1E+05	1.9E+05	7.90E+06	4.02E+07	2.49E+07
All/15	2011	4.6E+04	3.2E+05	1.3E+05	6.02E+06	4.23E+07	1.77E+07
All/15	2020	3.4E+04	3.5E+05	5.2E+04	4.43E+06	4.54E+07	6.78E+06
BaS-NoS/15	2000	6.7E+04	2.3E+05	2.7E+05	8.84E+06	3.08E+07	3.49E+07
BaS-NoS/15	2007	3.0E+04	2.7E+05	1.5E+05	3.92E+06	3.48E+07	1.92E+07
BaS-NoS/15	2011	2.1E+04	2.8E+05	9.1E+04	2.72E+06	3.68E+07	1.20E+07
BaS-NoS/15	2020	1.4E+04	3.2E+05	1.1E+04	1.83E+06	4.16E+07	1.46E+06
All/all	2000	9.6E+05	1.9E+06	1.2E+06	1.26E+08	2.52E+08	1.58E+08
All/all	2007	9.0E+05	1.7E+06	8.3E+05	1.18E+08	2.21E+08	1.08E+08
All/all	2011	8.9E+05	1.7E+06	7.7E+05	1.16E+08	2.26E+08	1.00E+08
All/all	2020	6.5E+05	1.1E+06	4.4E+05	8.52E+07	1.48E+08	5.75E+07

Table B5: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **respiratory hospital admissions**.

Region/SNAP	Year	Cases				Costs			
		SO_2	$PM_{2.5}$	NO_3	SO_4	SO_2	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	1.9E+00	7.0E-01	2.0E+01	6.4E+00	1.53E+04	5.78E+03	1.57E+05	5.05E+04
DK/2	2000	9.0E-01	1.6E+01	5.4E+00	3.6E+00	7.30E+03	1.25E+05	4.30E+04	2.84E+04
DK/3	2000	8.0E-01	1.3E+00	8.6E+00	4.1E+00	6.28E+03	1.01E+04	6.85E+04	3.25E+04
DK/4	2000	3.0E-01	5.0E-01	2.5E+00	1.9E+00	2.77E+03	3.96E+03	1.98E+04	1.53E+04
DK/5	2000	-1.0E-01	1.0E-01	2.4E+00	1.7E+00	-7.25E+02	5.09E+02	1.92E+04	1.34E+04
DK/6	2000	-3.0E-01	0.0E+00	2.6E+00	2.8E+00	-2.26E+03	1.49E+01	2.08E+04	2.22E+04
DK/7	2000	5.0E-01	1.0E+01	3.5E+01	1.4E+00	3.84E+03	8.08E+04	2.81E+05	1.10E+04
DK/8	2000	1.2E+00	3.9E+00	1.6E+01	1.1E+00	9.33E+03	3.07E+04	1.27E+05	8.35E+03
DK/9	2000	0.0E+00	0.0E+00	1.4E+00	0.0E+00	1.65E+02	6.14E+01	1.08E+04	4.20E+01
DK/10	2000	0.0E+00	1.6E+00	6.7E+01	4.8E+01	-3.87E+02	1.24E+04	5.33E+05	3.82E+05
DK/all	2000	5.2E+00	3.4E+01	1.3E+02	6.0E+01	4.15E+04	2.72E+05	1.06E+06	4.77E+05
All/15	2000	2.4E+02	2.9E+02	9.3E+02	1.2E+03	1.92E+06	2.32E+06	7.41E+06	9.52E+06
All/15	2007	1.8E+02	2.4E+02	1.1E+03	1.0E+03	1.46E+06	1.90E+06	8.56E+06	8.33E+06
All/15	2011	1.6E+02	2.2E+02	1.1E+03	9.4E+02	1.24E+06	1.74E+06	8.66E+06	7.49E+06
All/15	2020	1.5E+02	2.1E+02	1.3E+03	1.1E+03	1.22E+06	1.69E+06	1.03E+07	8.73E+06
BaS-NoS/15	2000	1.6E+02	1.1E+02	4.0E+02	4.9E+02	1.28E+06	8.61E+05	3.16E+06	3.90E+06
BaS-NoS/15	2007	8.5E+01	5.0E+01	4.9E+02	2.5E+02	6.72E+05	3.99E+05	3.92E+06	2.01E+06
BaS-NoS/15	2011	5.6E+01	3.5E+01	5.1E+02	1.5E+02	4.48E+05	2.76E+05	4.02E+06	1.17E+06
BaS-NoS/15	2020	1.1E+01	2.4E+01	6.1E+02	1.3E+01	8.82E+04	1.86E+05	4.86E+06	1.02E+05
All/all	2000	4.4E+03	7.2E+03	1.3E+04	1.4E+04	3.52E+07	5.74E+07	9.95E+07	1.08E+08
All/all	2007	3.2E+03	6.1E+03	1.1E+04	1.1E+04	2.53E+07	4.88E+07	9.11E+07	8.37E+07
All/all	2011	3.2E+03	6.1E+03	1.2E+04	1.0E+04	2.50E+07	4.86E+07	9.13E+07	8.25E+07
All/all	2020	1.8E+03	6.8E+03	8.3E+03	7.0E+03	1.41E+07	5.40E+07	6.55E+07	5.53E+07

Table B6: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **respiratory hospital admissions**.

Region/SNAP	Year	Cases				Costs			
		SO_2	$PM_{2.5}$	NO_3	SO_4	SO_2	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	6.0E-01	1.0E-01	1.9E+00	5.0E-01	4.74E+03	8.70E+02	1.53E+04	4.34E+03
DK/2	2000	7.0E-01	6.0E+00	1.1E+00	4.0E-01	5.73E+03	4.77E+04	9.05E+03	3.42E+03
DK/3	2000	3.0E-01	2.0E-01	1.3E+00	4.0E-01	2.64E+03	1.73E+03	1.06E+04	3.17E+03
DK/4	2000	3.0E-01	2.0E-01	9.0E-01	2.0E-01	2.66E+03	1.76E+03	7.28E+03	1.82E+03
DK/5	2000	0.0E+00	0.0E+00	9.0E-01	1.0E-01	-5.70E+00	2.31E+02	7.34E+03	8.51E+02
DK/6	2000	0.0E+00	0.0E+00	1.0E+00	1.0E-01	-1.89E+01	8.76E-02	8.01E+03	9.30E+02
DK/7	2000	2.0E-01	6.0E+00	4.6E+00	0.0E+00	1.78E+03	4.75E+04	3.66E+04	-2.01E+02
DK/8	2000	8.0E-01	1.9E+00	1.4E+00	3.0E-01	6.30E+03	1.48E+04	1.09E+04	2.15E+03
DK/9	2000	0.0E+00	0.0E+00	1.0E-01	0.0E+00	6.33E+00	5.63E+00	3.97E+02	-6.19E+00
DK/10	2000	0.0E+00	6.0E-01	1.5E+01	3.1E+00	-5.89E+00	4.76E+03	1.21E+05	2.49E+04
DK/all	2000	3.0E+00	1.5E+01	2.1E+01	4.9E+00	2.35E+04	1.20E+05	1.70E+05	3.89E+04
All/15	2000	6.0E+00	6.0E+00	1.4E+01	1.6E+01	4.77E+04	4.75E+04	1.14E+05	1.25E+05
All/15	2007	3.3E+00	3.0E+00	1.6E+01	9.6E+00	2.60E+04	2.41E+04	1.23E+05	7.64E+04
All/15	2011	2.1E+00	2.3E+00	1.6E+01	6.8E+00	1.67E+04	1.84E+04	1.30E+05	5.41E+04
All/15	2020	3.0E-01	1.7E+00	1.8E+01	2.6E+00	2.64E+03	1.35E+04	1.39E+05	2.08E+04
BaS-NoS/15	2000	6.1E+00	3.4E+00	1.2E+01	1.4E+01	4.84E+04	2.70E+04	9.44E+04	1.07E+05
BaS-NoS/15	2007	3.3E+00	1.5E+00	1.4E+01	7.4E+00	2.63E+04	1.20E+04	1.07E+05	5.88E+04
BaS-NoS/15	2011	2.1E+00	1.0E+00	1.4E+01	4.6E+00	1.69E+04	8.30E+03	1.13E+05	3.67E+04
BaS-NoS/15	2020	3.0E-01	7.0E-01	1.6E+01	6.0E-01	2.67E+03	5.58E+03	1.28E+05	4.48E+03
All/all	2000	1.5E+01	4.8E+01	9.7E+01	6.1E+01	1.19E+05	3.83E+05	7.72E+05	4.83E+05
All/all	2007	9.5E+00	4.6E+01	8.5E+01	4.2E+01	7.50E+04	3.61E+05	6.77E+05	3.31E+05
All/all	2011	8.2E+00	4.5E+01	8.7E+01	3.9E+01	6.54E+04	3.56E+05	6.92E+05	3.08E+05
All/all	2020	4.2E+00	3.3E+01	5.7E+01	2.2E+01	3.31E+04	2.60E+05	4.53E+05	1.76E+05

Table B7: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **cerebrovascular hospital admissions.**

		Cases			Costs		
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	1.8E+00	4.8E+01	1.6E+01	1.78E+04	4.85E+05	1.56E+05
DK/2	2000	3.8E+01	1.3E+01	8.7E+00	3.84E+05	1.32E+05	8.76E+04
DK/3	2000	3.1E+00	2.1E+01	1.0E+01	3.10E+04	2.11E+05	1.00E+05
DK/4	2000	1.2E+00	6.1E+00	4.7E+00	1.22E+04	6.09E+04	4.72E+04
DK/5	2000	2.0E-01	5.9E+00	4.1E+00	1.57E+03	5.90E+04	4.14E+04
DK/6	2000	0.0E+00	6.4E+00	6.8E+00	4.58E+01	6.40E+04	6.83E+04
DK/7	2000	2.5E+01	8.6E+01	3.4E+00	2.49E+05	8.66E+05	3.39E+04
DK/8	2000	9.4E+00	3.9E+01	2.6E+00	9.47E+04	3.92E+05	2.57E+04
DK/9	2000	0.0E+00	3.3E+00	0.0E+00	1.89E+02	3.34E+04	1.29E+02
DK/10	2000	3.8E+00	1.6E+02	1.2E+02	3.83E+04	1.64E+06	1.18E+06
DK/all	2000	8.3E+01	3.3E+02	1.5E+02	8.37E+05	3.28E+06	1.47E+06
All/15	2000	7.1E+02	2.3E+03	2.9E+03	7.15E+06	2.28E+07	2.93E+07
All/15	2007	5.8E+02	2.6E+03	2.6E+03	5.85E+06	2.64E+07	2.57E+07
All/15	2011	5.4E+02	2.7E+03	2.3E+03	5.38E+06	2.67E+07	2.31E+07
All/15	2020	5.2E+02	3.2E+03	2.7E+03	5.21E+06	3.18E+07	2.69E+07
BaS-NoS/15	2000	2.6E+02	9.7E+02	1.2E+03	2.65E+06	9.73E+06	1.20E+07
BaS-NoS/15	2007	1.2E+02	1.2E+03	6.2E+02	1.23E+06	1.21E+07	6.18E+06
BaS-NoS/15	2011	8.4E+01	1.2E+03	3.6E+02	8.49E+05	1.24E+07	3.61E+06
BaS-NoS/15	2020	5.7E+01	1.5E+03	3.1E+01	5.74E+05	1.50E+07	3.15E+05
All/all	2000	1.8E+04	3.1E+04	3.3E+04	1.77E+08	3.07E+08	3.32E+08
All/all	2007	1.5E+04	2.8E+04	2.6E+04	1.50E+08	2.81E+08	2.58E+08
All/all	2011	1.5E+04	2.8E+04	2.5E+04	1.50E+08	2.81E+08	2.54E+08
All/all	2020	1.7E+04	2.0E+04	1.7E+04	1.66E+08	2.02E+08	1.70E+08

Table B8: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **cerebrovascular hospital admissions**

		Cases			Costs		
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	3.0E-01	4.7E+00	1.3E+00	2.68E+03	4.71E+04	1.34E+04
DK/2	2000	1.5E+01	2.8E+00	1.0E+00	1.47E+05	2.79E+04	1.05E+04
DK/3	2000	5.0E-01	3.2E+00	1.0E+00	5.32E+03	3.26E+04	9.76E+03
DK/4	2000	5.0E-01	2.2E+00	6.0E-01	5.42E+03	2.24E+04	5.60E+03
DK/5	2000	1.0E-01	2.3E+00	3.0E-01	7.11E+02	2.26E+04	2.62E+03
DK/6	2000	0.0E+00	2.5E+00	3.0E-01	2.70E-01	2.47E+04	2.86E+03
DK/7	2000	1.5E+01	1.1E+01	-1.0E-01	1.46E+05	1.13E+05	-6.20E+02
DK/8	2000	4.5E+00	3.3E+00	7.0E-01	4.55E+04	3.35E+04	6.62E+03
DK/9	2000	0.0E+00	1.0E-01	0.0E+00	1.74E+01	1.22E+03	-1.91E+01
DK/10	2000	1.5E+00	3.7E+01	7.7E+00	1.47E+04	3.72E+05	7.69E+04
DK/all	2000	3.7E+01	5.2E+01	1.2E+01	3.70E+05	5.24E+05	1.20E+05
All/15	2000	1.5E+01	3.5E+01	3.8E+01	1.46E+05	3.51E+05	3.84E+05
All/15	2007	7.4E+00	3.8E+01	2.3E+01	7.44E+04	3.80E+05	2.35E+05
All/15	2011	5.6E+00	4.0E+01	1.7E+01	5.67E+04	4.00E+05	1.67E+05
All/15	2020	4.2E+00	4.3E+01	6.4E+00	4.17E+04	4.29E+05	6.40E+04
BaS-NoS/15	2000	8.3E+00	2.9E+01	3.3E+01	8.32E+04	2.91E+05	3.30E+05
BaS-NoS/15	2007	3.7E+00	3.3E+01	1.8E+01	3.69E+04	3.29E+05	1.81E+05
BaS-NoS/15	2011	2.5E+00	3.5E+01	1.1E+01	2.56E+04	3.48E+05	1.13E+05
BaS-NoS/15	2020	1.7E+00	3.9E+01	1.4E+00	1.72E+04	3.93E+05	1.38E+04
All/all	2000	1.2E+02	2.4E+02	1.5E+02	1.18E+06	2.38E+06	1.49E+06
All/all	2007	1.1E+02	2.1E+02	1.0E+02	1.11E+06	2.09E+06	1.02E+06
All/all	2011	1.1E+02	2.1E+02	9.4E+01	1.10E+06	2.13E+06	9.48E+05
All/all	2020	8.0E+01	1.4E+02	5.4E+01	8.03E+05	1.40E+06	5.42E+05

Table B9: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **congestive heart failure.**

		Cases				Costs			
Region/SNAP	Year	CO	$PM_{2.5}$	NO_3	SO_4	CO	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	3.0E-01	9.0E-01	2.5E+01	8.0E+00	4.77E+03	1.50E+04	4.09E+05	1.31E+05
DK/2	2000	7.5E+00	2.0E+01	6.9E+00	4.5E+00	1.23E+05	3.28E+05	1.12E+05	7.40E+04
DK/3	2000	5.0E-01	1.6E+00	1.1E+01	5.1E+00	8.53E+03	2.62E+04	1.79E+05	8.44E+04
DK/4	2000	1.0E-01	6.0E-01	3.2E+00	2.4E+00	1.32E+03	1.04E+04	5.22E+04	3.99E+04
DK/5	2000	2.0E-01	1.0E-01	3.1E+00	2.1E+00	2.49E+03	1.33E+03	5.06E+04	3.49E+04
DK/6	2000	5.0E-01	0.0E+00	3.3E+00	3.5E+00	8.81E+03	3.85E+01	5.48E+04	5.74E+04
DK/7	2000	2.2E+01	1.3E+01	4.5E+01	1.7E+00	3.59E+05	2.16E+05	7.32E+05	2.84E+04
DK/8	2000	5.4E+00	4.9E+00	2.0E+01	1.3E+00	8.90E+04	8.12E+04	3.31E+05	2.18E+04
DK/9	2000	0.0E+00	0.0E+00	1.7E+00	0.0E+00	-1.26E+01	1.60E+02	2.81E+04	1.07E+02
DK/10	2000	1.0E-01	2.0E+00	8.5E+01	6.0E+01	1.18E+03	3.28E+04	1.39E+06	9.92E+05
DK/all	2000	3.6E+01	4.4E+01	1.7E+02	7.6E+01	5.93E+05	7.18E+05	2.77E+06	1.24E+06
All/15	2000	-4.7E+01	3.7E+02	1.2E+03	1.5E+03	-7.75E+05	6.01E+06	1.92E+07	2.46E+07
All/15	2007	-4.3E+01	3.0E+02	1.4E+03	1.3E+03	-7.07E+05	4.92E+06	2.22E+07	2.16E+07
All/15	2011	-4.2E+01	2.8E+02	1.4E+03	1.2E+03	-6.88E+05	4.52E+06	2.24E+07	1.94E+07
All/15	2020	-5.2E+01	2.7E+02	1.6E+03	1.4E+03	-8.49E+05	4.38E+06	2.67E+07	2.26E+07
BaS-NoS/15	2000	2.3E+00	1.4E+02	5.0E+02	6.2E+02	3.76E+04	2.23E+06	8.18E+06	1.01E+07
BaS-NoS/15	2007	3.1E+00	6.3E+01	6.2E+02	3.2E+02	5.14E+04	1.04E+06	1.02E+07	5.20E+06
BaS-NoS/15	2011	3.1E+00	4.4E+01	6.3E+02	1.9E+02	5.05E+04	7.14E+05	1.04E+07	3.04E+06
BaS-NoS/15	2020	1.3E+00	2.9E+01	7.7E+02	1.6E+01	2.16E+04	4.82E+05	1.26E+07	2.65E+05
All/all	2000	8.5E+03	9.1E+03	1.6E+04	1.7E+04	1.39E+08	1.48E+08	2.58E+08	2.79E+08
All/all	2007	7.5E+03	7.7E+03	1.4E+04	1.3E+04	1.22E+08	1.26E+08	2.36E+08	2.17E+08
All/all	2011	7.4E+03	7.7E+03	1.4E+04	1.3E+04	1.22E+08	1.26E+08	2.36E+08	2.14E+08
All/all	2020	7.6E+03	8.5E+03	1.0E+04	8.7E+03	1.25E+08	1.40E+08	1.70E+08	1.43E+08

Table B10: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **congestive heart failure.**

		Cases				Costs			
Region/SNAP	Year	CO	$PM_{2.5}$	NO_3	SO_4	CO	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	0.0E+00	1.0E-01	2.5E+00	7.0E-01	6.01E+02	2.34E+03	4.17E+04	1.18E+04
DK/2	2000	1.9E+00	7.9E+00	1.5E+00	6.0E-01	3.16E+04	1.29E+05	2.47E+04	9.25E+03
DK/3	2000	1.0E-01	3.0E-01	1.8E+00	5.0E-01	1.01E+03	4.65E+03	2.89E+04	8.58E+03
DK/4	2000	0.0E+00	3.0E-01	1.2E+00	3.0E-01	1.02E+02	4.76E+03	1.99E+04	4.92E+03
DK/5	2000	0.0E+00	0.0E+00	1.2E+00	1.0E-01	4.19E+01	6.13E+02	2.01E+04	2.31E+03
DK/6	2000	0.0E+00	0.0E+00	1.3E+00	2.0E-01	1.68E+02	2.40E-01	2.18E+04	2.52E+03
DK/7	2000	1.1E+01	7.9E+00	6.1E+00	0.0E+00	1.77E+05	1.30E+05	9.95E+04	-5.31E+02
DK/8	2000	1.9E+00	2.4E+00	1.8E+00	4.0E-01	3.07E+04	3.99E+04	2.96E+04	5.80E+03
DK/9	2000	0.0E+00	0.0E+00	1.0E-01	0.0E+00	1.18E+00	1.52E+01	1.08E+03	-1.72E+01
DK/10	2000	0.0E+00	8.0E-01	2.0E+01	4.1E+00	1.49E+01	1.29E+04	3.26E+05	6.77E+04
DK/all	2000	1.5E+01	2.0E+01	2.8E+01	6.4E+00	2.42E+05	3.25E+05	4.60E+05	1.05E+05
All/15	2000	-4.0E-01	8.0E+00	1.9E+01	2.1E+01	-5.84E+03	1.31E+05	3.12E+05	3.41E+05
All/15	2007	-3.0E-01	4.0E+00	2.1E+01	1.3E+01	-5.25E+03	6.63E+04	3.37E+05	2.09E+05
All/15	2011	-3.0E-01	3.1E+00	2.2E+01	9.0E+00	-5.09E+03	5.05E+04	3.55E+05	1.48E+05
All/15	2020	-3.0E-01	2.3E+00	2.3E+01	3.5E+00	-5.69E+03	3.71E+04	3.81E+05	5.68E+04
BaS-NoS/15	2000	1.0E-01	4.5E+00	1.6E+01	1.8E+01	1.62E+03	7.42E+04	2.58E+05	2.93E+05
BaS-NoS/15	2007	1.0E-01	2.0E+00	1.8E+01	9.8E+00	1.86E+03	3.29E+04	2.93E+05	1.61E+05
BaS-NoS/15	2011	1.0E-01	1.4E+00	1.9E+01	6.1E+00	1.86E+03	2.28E+04	3.09E+05	1.00E+05
BaS-NoS/15	2020	1.0E-01	9.0E-01	2.1E+01	7.0E-01	1.71E+03	1.53E+04	3.49E+05	1.23E+04
All/all	2000	7.0E+01	6.4E+01	1.3E+02	8.0E+01	1.15E+06	1.05E+06	2.11E+06	1.32E+06
All/all	2007	6.0E+01	6.0E+01	1.1E+02	5.5E+01	9.76E+05	9.84E+05	1.85E+06	9.05E+05
All/all	2011	5.9E+01	5.9E+01	1.2E+02	5.1E+01	9.70E+05	9.69E+05	1.89E+06	8.40E+05
All/all	2020	5.8E+01	4.3E+01	7.6E+01	2.9E+01	9.53E+05	7.11E+05	1.24E+06	4.81E+05

Table B11: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **lung cancer.**

Region/SNAP	Year	Cases			Costs		
		$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	2.1E+00	5.8E+01	1.8E+01	4.50E+04	1.22E+06	3.92E+05
DK/2	2000	4.6E+01	1.6E+01	1.0E+01	9.73E+05	3.35E+05	2.21E+05
DK/3	2000	3.7E+00	2.5E+01	1.2E+01	7.82E+04	5.33E+05	2.52E+05
DK/4	2000	1.5E+00	7.3E+00	5.6E+00	3.10E+04	1.55E+05	1.19E+05
DK/5	2000	2.0E-01	7.1E+00	4.9E+00	4.00E+03	1.50E+05	1.04E+05
DK/6	2000	0.0E+00	7.7E+00	8.1E+00	1.15E+02	1.62E+05	1.72E+05
DK/7	2000	3.0E+01	1.0E+02	4.0E+00	6.37E+05	2.18E+06	8.51E+04
DK/8	2000	1.1E+01	4.7E+01	3.1E+00	2.41E+05	9.87E+05	6.51E+04
DK/9	2000	0.0E+00	4.0E+00	0.0E+00	4.76E+02	8.40E+04	3.24E+02
DK/10	2000	4.6E+00	2.0E+02	1.4E+02	9.67E+04	4.14E+06	2.96E+06
DK/all	2000	1.0E+02	3.9E+02	1.7E+02	2.13E+06	8.25E+06	3.70E+06
All/15	2000	8.5E+02	2.7E+03	3.5E+03	1.80E+07	5.74E+07	7.37E+07
All/15	2007	7.0E+02	3.1E+03	3.0E+03	1.47E+07	6.63E+07	6.45E+07
All/15	2011	6.4E+02	3.2E+03	2.7E+03	1.35E+07	6.71E+07	5.80E+07
All/15	2020	6.2E+02	3.8E+03	3.2E+03	1.31E+07	8.00E+07	6.76E+07
BaS-NoS/15	2000	3.2E+02	1.2E+03	1.4E+03	6.67E+06	2.45E+07	3.02E+07
BaS-NoS/15	2007	1.5E+02	1.4E+03	7.3E+02	3.09E+06	3.04E+07	1.55E+07
BaS-NoS/15	2011	1.0E+02	1.5E+03	4.3E+02	2.14E+06	3.12E+07	9.08E+06
BaS-NoS/15	2020	6.8E+01	1.8E+03	3.8E+01	1.44E+06	3.76E+07	7.93E+05
All/all	2000	2.1E+04	3.6E+04	3.9E+04	4.44E+08	7.71E+08	8.35E+08
All/all	2007	1.8E+04	3.3E+04	3.1E+04	3.78E+08	7.06E+08	6.48E+08
All/all	2011	1.8E+04	3.3E+04	3.0E+04	3.76E+08	7.07E+08	6.39E+08
All/all	2020	2.0E+04	2.4E+04	2.0E+04	4.18E+08	5.08E+08	4.28E+08

Table B12: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **lung cancer.**

Region/SNAP	Year	Cases			Costs		
		$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	3.0E-01	5.7E+00	1.6E+00	6.91E+03	1.21E+05	3.44E+04
DK/2	2000	1.8E+01	3.4E+00	1.3E+00	3.78E+05	7.19E+04	2.71E+04
DK/3	2000	6.0E-01	4.0E+00	1.2E+00	1.37E+04	8.41E+04	2.51E+04
DK/4	2000	7.0E-01	2.7E+00	7.0E-01	1.40E+04	5.80E+04	1.44E+04
DK/5	2000	1.0E-01	2.8E+00	3.0E-01	1.85E+03	5.84E+04	6.78E+03
DK/6	2000	0.0E+00	3.0E+00	3.0E-01	6.91E-01	6.37E+04	7.40E+03
DK/7	2000	1.8E+01	1.4E+01	-1.0E-01	3.79E+05	2.90E+05	-1.52E+03
DK/8	2000	5.5E+00	4.1E+00	8.0E-01	1.17E+05	8.58E+04	1.70E+04
DK/9	2000	0.0E+00	1.0E-01	0.0E+00	4.45E+01	3.12E+03	-4.85E+01
DK/10	2000	1.8E+00	4.5E+01	9.3E+00	3.74E+04	9.48E+05	1.96E+05
DK/all	2000	4.5E+01	6.3E+01	1.4E+01	9.53E+05	1.34E+06	3.06E+05
All/15	2000	1.8E+01	4.2E+01	4.6E+01	3.76E+05	8.98E+05	9.84E+05
All/15	2007	9.0E+00	4.6E+01	2.8E+01	1.91E+05	9.72E+05	6.03E+05
All/15	2011	6.9E+00	4.8E+01	2.0E+01	1.46E+05	1.02E+06	4.27E+05
All/15	2020	5.1E+00	5.2E+01	7.7E+00	1.07E+05	1.10E+06	1.64E+05
BaS-NoS/15	2000	1.0E+01	3.5E+01	4.0E+01	2.14E+05	7.44E+05	8.45E+05
BaS-NoS/15	2007	4.5E+00	4.0E+01	2.2E+01	9.48E+04	8.43E+05	4.64E+05
BaS-NoS/15	2011	3.1E+00	4.2E+01	1.4E+01	6.57E+04	8.91E+05	2.89E+05
BaS-NoS/15	2020	2.1E+00	4.8E+01	1.7E+00	4.42E+04	1.01E+06	3.54E+04
All/all	2000	1.4E+02	2.9E+02	1.8E+02	3.04E+06	6.10E+06	3.82E+06
All/all	2007	1.4E+02	2.5E+02	1.2E+02	2.86E+06	5.34E+06	2.62E+06
All/all	2011	1.3E+02	2.6E+02	1.1E+02	2.82E+06	5.46E+06	2.43E+06
All/all	2020	9.7E+01	1.7E+02	6.6E+01	2.06E+06	3.58E+06	1.39E+06

Table B13: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **bronchodilator use**.

		Cases						Costs		
		Children			Adults					
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	4.1E+02	1.1E+04	3.6E+03	2.7E+03	7.4E+04	2.4E+04	7.18E+04	1.95E+06	6.27E+05
DK/2	2000	8.6E+03	3.0E+03	2.0E+03	5.9E+04	2.0E+04	1.3E+04	1.55E+06	5.34E+05	3.53E+05
DK/3	2000	7.1E+02	4.8E+03	2.3E+03	4.7E+03	3.2E+04	1.5E+04	1.25E+05	8.51E+05	4.03E+05
DK/4	2000	2.7E+02	1.4E+03	1.1E+03	1.9E+03	9.3E+03	7.2E+03	4.93E+04	2.46E+05	1.90E+05
DK/5	2000	3.4E+01	1.3E+03	9.5E+02	2.4E+02	9.1E+03	6.3E+03	6.35E+03	2.38E+05	1.67E+05
DK/6	2000	1.1E+00	1.4E+03	1.6E+03	7.0E+00	9.8E+03	1.0E+04	1.84E+02	2.58E+05	2.75E+05
DK/7	2000	5.4E+03	2.0E+04	7.8E+02	3.8E+04	1.3E+05	5.1E+03	1.01E+06	3.49E+06	1.36E+05
DK/8	2000	2.1E+03	9.0E+03	5.8E+02	1.5E+04	6.0E+04	3.9E+03	3.83E+05	1.58E+06	1.04E+05
DK/9	2000	4.4E+00	7.7E+02	3.0E+00	2.9E+01	5.1E+03	2.0E+01	7.62E+02	1.34E+05	5.20E+02
DK/10	2000	8.7E+02	3.8E+04	2.7E+04	5.8E+03	2.5E+05	1.8E+05	1.54E+05	6.62E+06	4.74E+06
DK/all	2000	1.9E+04	7.5E+04	3.4E+04	1.3E+05	5.0E+05	2.2E+05	3.38E+06	1.32E+07	5.92E+06
All/15	2000	1.7E+05	5.3E+05	6.8E+05	1.1E+06	3.5E+06	4.5E+06	2.88E+07	9.19E+07	1.18E+08
All/15	2007	1.4E+05	6.1E+05	5.9E+05	8.9E+05	4.0E+06	3.9E+06	2.36E+07	1.06E+08	1.03E+08
All/15	2011	1.2E+05	6.2E+05	5.4E+05	8.2E+05	4.1E+06	3.5E+06	2.16E+07	1.07E+08	9.29E+07
All/15	2020	1.2E+05	7.4E+05	6.2E+05	7.9E+05	4.8E+06	4.1E+06	2.10E+07	1.28E+08	1.08E+08
BaS-NoS/15	2000	6.1E+04	2.3E+05	2.8E+05	4.0E+05	1.5E+06	1.8E+06	1.07E+07	3.92E+07	4.84E+07
BaS-NoS/15	2007	2.8E+04	2.8E+05	1.4E+05	1.9E+05	1.8E+06	9.4E+05	4.95E+06	4.86E+07	2.49E+07
BaS-NoS/15	2011	2.0E+04	2.9E+05	8.4E+04	1.3E+05	1.9E+06	5.5E+05	3.42E+06	4.99E+07	1.45E+07
BaS-NoS/15	2020	1.3E+04	3.5E+05	7.3E+03	8.7E+04	2.3E+06	4.8E+04	2.31E+06	6.02E+07	1.27E+06
All/all	2000	4.1E+06	7.1E+06	7.7E+06	2.7E+07	4.7E+07	5.0E+07	7.12E+08	1.24E+09	1.34E+09
All/all	2007	3.5E+06	6.5E+06	6.0E+06	2.3E+07	4.3E+07	3.9E+07	6.05E+08	1.13E+09	1.04E+09
All/all	2011	3.5E+06	6.5E+06	5.9E+06	2.3E+07	4.3E+07	3.9E+07	6.03E+08	1.13E+09	1.02E+09
All/all	2020	3.9E+06	4.7E+06	3.9E+06	2.5E+07	3.1E+07	2.6E+07	6.70E+08	8.13E+08	6.85E+08

Table B14: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **bronchodilator use**.

		Cases						Costs		
		Children			Adults					
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	5.6E+01	9.9E+02	2.8E+02	4.2E+02	7.3E+03	2.1E+03	1.09E+04	1.91E+05	5.42E+04
DK/2	2000	3.1E+03	5.8E+02	2.2E+02	2.3E+04	4.3E+03	1.6E+03	5.97E+05	1.13E+05	4.27E+04
DK/3	2000	1.1E+02	6.8E+02	2.1E+02	8.3E+02	5.1E+03	1.5E+03	2.16E+04	1.33E+05	3.96E+04
DK/4	2000	1.1E+02	4.6E+02	1.2E+02	8.5E+02	3.5E+03	8.7E+02	2.20E+04	9.12E+04	2.28E+04
DK/5	2000	1.4E+01	4.6E+02	5.4E+01	1.1E+02	3.5E+03	4.1E+02	2.89E+03	9.19E+04	1.07E+04
DK/6	2000	0.0E+00	5.1E+02	5.9E+01	0.0E+00	3.8E+03	4.5E+02	1.09E+00	1.00E+05	1.16E+04
DK/7	2000	3.0E+03	2.4E+03	-1.6E+01	2.3E+04	1.7E+04	-9.2E+01	5.95E+05	4.58E+05	-2.47E+03
DK/8	2000	9.5E+02	7.2E+02	1.4E+02	7.1E+03	5.2E+03	1.0E+03	1.85E+05	1.36E+05	2.68E+04
DK/9	2000	4.0E-01	2.7E+01	-4.0E-01	2.7E+00	1.9E+02	-2.9E+00	7.04E+01	4.95E+03	-7.71E+01
DK/10	2000	3.2E+02	8.1E+03	1.7E+03	2.3E+03	5.7E+04	1.2E+04	5.93E+04	1.50E+06	3.11E+05
DK/all	2000	7.7E+03	1.1E+04	2.6E+03	5.8E+04	8.1E+04	1.9E+04	1.50E+06	2.12E+06	4.85E+05
All/15	2000	3.1E+03	7.6E+03	8.2E+03	2.3E+04	5.4E+04	5.9E+04	5.94E+05	1.42E+06	1.56E+06
All/15	2007	1.6E+03	8.2E+03	5.0E+03	1.2E+04	5.9E+04	3.6E+04	3.02E+05	1.54E+06	9.54E+05
All/15	2011	1.2E+03	8.6E+03	3.6E+03	8.8E+03	6.2E+04	2.6E+04	2.30E+05	1.62E+06	6.76E+05
All/15	2020	8.8E+02	9.2E+03	1.4E+03	6.5E+03	6.6E+04	9.9E+03	1.69E+05	1.74E+06	2.59E+05
BaS-NoS/15	2000	1.8E+03	6.3E+03	7.1E+03	1.3E+04	4.5E+04	5.1E+04	3.37E+05	1.18E+06	1.34E+06
BaS-NoS/15	2007	7.8E+02	7.1E+03	3.9E+03	5.7E+03	5.1E+04	2.8E+04	1.50E+05	1.33E+06	7.33E+05
BaS-NoS/15	2011	5.4E+02	7.5E+03	2.4E+03	4.0E+03	5.4E+04	1.7E+04	1.04E+05	1.41E+06	4.58E+05
BaS-NoS/15	2020	3.6E+02	8.4E+03	3.0E+02	2.7E+03	6.1E+04	2.1E+03	6.97E+04	1.59E+06	5.60E+04
All/all	2000	2.5E+04	5.1E+04	3.2E+04	1.8E+05	3.7E+05	2.3E+05	4.79E+06	9.65E+06	6.04E+06
All/all	2007	2.4E+04	4.5E+04	2.2E+04	1.7E+05	3.2E+05	1.6E+05	4.52E+06	8.45E+06	4.14E+06
All/all	2011	2.3E+04	4.5E+04	2.0E+04	1.7E+05	3.3E+05	1.5E+05	4.44E+06	8.64E+06	3.84E+06
All/all	2020	1.7E+04	3.0E+04	1.2E+04	1.2E+05	2.2E+05	8.4E+04	3.26E+06	5.66E+06	2.20E+06

Table B15: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **cough**.

		Cases						Costs		
		Children			Adults					
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	1.4E+03	3.8E+04	1.2E+04	2.8E+03	7.6E+04	2.4E+04	2.48E+05	6.75E+06	2.17E+06
DK/2	2000	3.0E+04	1.0E+04	6.9E+03	6.1E+04	2.1E+04	1.4E+04	5.32E+06	1.84E+06	1.22E+06
DK/3	2000	2.4E+03	1.7E+04	7.9E+03	4.9E+03	3.3E+04	1.6E+04	4.31E+05	2.94E+06	1.39E+06
DK/4	2000	9.3E+02	4.7E+03	3.7E+03	1.9E+03	9.6E+03	7.4E+03	1.69E+05	8.43E+05	6.58E+05
DK/5	2000	1.2E+02	4.5E+03	3.3E+03	2.5E+02	9.3E+03	6.5E+03	2.17E+04	8.17E+05	5.77E+05
DK/6	2000	3.7E+00	4.9E+03	5.4E+03	7.2E+00	1.0E+04	1.1E+04	6.39E+02	8.85E+05	9.51E+05
DK/7	2000	1.9E+04	6.9E+04	2.7E+03	4.0E+04	1.4E+05	5.3E+03	3.43E+06	1.21E+07	4.72E+05
DK/8	2000	7.2E+03	3.1E+04	2.0E+03	1.5E+04	6.1E+04	4.0E+03	1.31E+06	5.46E+06	3.58E+05
DK/9	2000	1.5E+01	2.7E+03	1.0E+01	3.0E+01	5.2E+03	2.0E+01	2.64E+03	4.66E+05	1.80E+03
DK/10	2000	3.0E+03	1.3E+05	9.4E+04	6.0E+03	2.6E+05	1.8E+05	5.32E+05	2.28E+07	1.64E+07
DK/all	2000	6.4E+04	2.6E+05	1.2E+05	1.3E+05	5.1E+05	2.3E+05	1.16E+07	4.56E+07	2.05E+07
All/15	2000	5.7E+05	1.8E+06	2.3E+06	1.1E+06	3.6E+06	4.6E+06	9.97E+07	3.18E+08	4.09E+08
All/15	2007	4.7E+05	2.1E+06	2.1E+06	9.2E+05	4.1E+06	4.0E+06	8.16E+07	3.68E+08	3.58E+08
All/15	2011	4.3E+05	2.1E+06	1.8E+06	8.4E+05	4.2E+06	3.6E+06	7.50E+07	3.72E+08	3.22E+08
All/15	2020	4.2E+05	2.5E+06	2.2E+06	8.1E+05	5.0E+06	4.2E+06	7.27E+07	4.44E+08	3.75E+08
BaS-NoS/15	2000	2.1E+05	7.8E+05	9.6E+05	4.1E+05	1.5E+06	1.9E+06	3.70E+07	1.36E+08	1.68E+08
BaS-NoS/15	2007	9.8E+04	9.7E+05	4.9E+05	1.9E+05	1.9E+06	9.7E+05	1.72E+07	1.68E+08	8.62E+07
BaS-NoS/15	2011	6.8E+04	9.9E+05	2.9E+05	1.3E+05	1.9E+06	5.6E+05	1.18E+07	1.73E+08	5.04E+07
BaS-NoS/15	2020	4.6E+04	1.2E+06	2.5E+04	9.0E+04	2.3E+06	4.9E+04	8.00E+06	2.09E+08	4.40E+06
All/all	2000	1.4E+07	2.5E+07	2.7E+07	2.8E+07	4.8E+07	5.2E+07	2.47E+09	4.28E+09	4.64E+09
All/all	2007	1.2E+07	2.2E+07	2.1E+07	2.3E+07	4.4E+07	4.0E+07	2.10E+09	3.92E+09	3.60E+09
All/all	2011	1.2E+07	2.3E+07	2.0E+07	2.3E+07	4.4E+07	4.0E+07	2.09E+09	3.92E+09	3.55E+09
All/all	2020	1.3E+07	1.6E+07	1.4E+07	2.6E+07	3.2E+07	2.7E+07	2.32E+09	2.82E+09	2.38E+09

Table B16: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **cough**.

		Cases						Costs		
		Children			Adults					
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	1.9E+02	3.4E+03	9.7E+02	4.3E+02	7.5E+03	2.1E+03	3.68E+04	6.47E+05	1.83E+05
DK/2	2000	1.1E+04	2.0E+03	7.6E+02	2.4E+04	4.5E+03	1.7E+03	2.02E+06	3.82E+05	1.44E+05
DK/3	2000	3.9E+02	2.3E+03	7.1E+02	8.5E+02	5.2E+03	1.6E+03	7.31E+04	4.47E+05	1.34E+05
DK/4	2000	3.9E+02	1.6E+03	4.0E+02	8.7E+02	3.6E+03	9.0E+02	7.42E+04	3.07E+05	7.66E+04
DK/5	2000	4.9E+01	1.6E+03	1.9E+02	1.1E+02	3.6E+03	4.2E+02	9.68E+03	3.09E+05	3.59E+04
DK/6	2000	0.0E+00	1.8E+03	2.0E+02	0.0E+00	4.0E+03	4.6E+02	3.72E+00	3.38E+05	3.92E+04
DK/7	2000	1.0E+04	8.3E+03	-5.5E+01	2.4E+04	1.8E+04	-9.4E+01	2.00E+06	1.55E+06	-8.81E+03
DK/8	2000	3.3E+03	2.5E+03	4.8E+02	7.3E+03	5.3E+03	1.1E+03	6.24E+05	4.62E+05	9.09E+04
DK/9	2000	1.3E+00	9.2E+01	-1.5E+00	2.8E+00	1.9E+02	-3.0E+00	2.39E+02	1.69E+04	-2.64E+02
DK/10	2000	1.1E+03	2.8E+04	5.8E+03	2.3E+03	5.9E+04	1.2E+04	2.03E+05	5.13E+06	1.06E+06
DK/all	2000	2.7E+04	3.9E+04	8.9E+03	5.9E+04	8.3E+04	1.9E+04	5.06E+06	7.23E+06	1.65E+06
All/15	2000	1.1E+04	2.6E+04	2.8E+04	2.3E+04	5.6E+04	6.1E+04	2.01E+06	4.83E+06	5.29E+06
All/15	2007	5.4E+03	2.8E+04	1.7E+04	1.2E+04	6.0E+04	3.7E+04	1.02E+06	5.23E+06	3.24E+06
All/15	2011	4.1E+03	3.0E+04	1.2E+04	9.1E+03	6.4E+04	2.7E+04	7.79E+05	5.50E+06	2.30E+06
All/15	2020	3.1E+03	3.2E+04	4.7E+03	6.7E+03	6.8E+04	1.0E+04	5.73E+05	5.91E+06	8.81E+05
BaS-NoS/15	2000	6.1E+03	2.2E+04	2.4E+04	1.3E+04	4.6E+04	5.3E+04	1.14E+06	4.01E+06	4.54E+06
BaS-NoS/15	2007	2.7E+03	2.5E+04	1.3E+04	5.9E+03	5.2E+04	2.9E+04	5.07E+05	4.54E+06	2.49E+06
BaS-NoS/15	2011	1.9E+03	2.6E+04	8.4E+03	4.1E+03	5.5E+04	1.8E+04	3.51E+05	4.80E+06	1.56E+06
BaS-NoS/15	2020	1.3E+03	2.9E+04	1.0E+03	2.7E+03	6.3E+04	2.2E+03	2.36E+05	5.41E+06	1.90E+05
All/all	2000	8.6E+04	1.8E+05	1.1E+05	1.9E+05	3.8E+05	2.4E+05	1.62E+07	3.28E+07	2.05E+07
All/all	2007	8.1E+04	1.5E+05	7.5E+04	1.8E+05	3.3E+05	1.6E+05	1.53E+07	2.87E+07	1.40E+07
All/all	2011	8.0E+04	1.6E+05	7.0E+04	1.8E+05	3.4E+05	1.5E+05	1.50E+07	2.93E+07	1.30E+07
All/all	2020	5.9E+04	1.0E+05	4.0E+04	1.3E+05	2.2E+05	8.6E+04	1.10E+07	1.92E+07	7.46E+06

Table B17: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **lower respiratory symptoms.**

		Cases						Costs		
		Children			Adults					
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	5.4E+02	1.5E+04	4.8E+03	1.0E+03	2.7E+04	8.8E+03	2.48E+04	6.20E+05	2.17E+05
DK/2	2000	1.1E+04	4.0E+03	2.7E+03	2.2E+04	7.5E+03	5.0E+03	5.32E+05	1.74E+05	1.22E+05
DK/3	2000	9.4E+02	6.4E+03	3.1E+03	1.8E+03	1.2E+04	5.7E+03	4.32E+04	2.74E+05	1.40E+05
DK/4	2000	3.6E+02	1.8E+03	1.4E+03	7.0E+02	3.5E+03	2.7E+03	1.69E+04	8.09E+04	6.58E+04
DK/5	2000	4.6E+01	1.7E+03	1.3E+03	9.0E+01	3.4E+03	2.3E+03	2.17E+03	7.89E+04	5.78E+04
DK/6	2000	1.4E+00	1.9E+03	2.1E+03	2.6E+00	3.6E+03	3.9E+03	6.40E+01	8.77E+04	9.52E+04
DK/7	2000	7.2E+03	2.7E+04	1.0E+03	1.4E+04	4.9E+04	1.9E+03	3.43E+05	1.13E+06	4.73E+04
DK/8	2000	2.8E+03	1.2E+04	7.8E+02	5.4E+03	2.2E+04	1.5E+03	1.31E+05	5.08E+05	3.58E+04
DK/9	2000	5.8E+00	1.0E+03	4.0E+00	1.1E+01	1.9E+03	7.3E+00	2.64E+02	4.41E+04	1.81E+02
DK/10	2000	1.2E+03	5.0E+04	3.6E+04	2.2E+03	9.3E+04	6.6E+04	5.33E+04	2.20E+06	1.64E+06
DK/all	2000	2.5E+04	1.0E+05	4.5E+04	4.8E+04	1.9E+05	8.3E+04	1.16E+06	4.30E+06	2.05E+06
All/15	2000	2.2E+05	7.0E+05	9.1E+05	4.0E+05	1.3E+06	1.7E+06	9.98E+06	2.78E+07	4.10E+07
All/15	2007	1.8E+05	8.1E+05	7.9E+05	3.3E+05	1.5E+06	1.4E+06	8.17E+06	3.20E+07	3.58E+07
All/15	2011	1.7E+05	8.2E+05	7.1E+05	3.0E+05	1.5E+06	1.3E+06	7.51E+06	3.24E+07	3.22E+07
All/15	2020	1.6E+05	9.8E+05	8.3E+05	2.9E+05	1.8E+06	1.5E+06	7.28E+06	3.79E+07	3.76E+07
BaS-NoS/15	2000	8.2E+04	3.0E+05	3.7E+05	1.5E+05	5.5E+05	6.8E+05	3.70E+06	1.28E+07	1.68E+07
BaS-NoS/15	2007	3.8E+04	3.7E+05	1.9E+05	6.9E+04	6.8E+05	3.5E+05	1.72E+06	1.58E+07	8.63E+06
BaS-NoS/15	2011	2.6E+04	3.8E+05	1.1E+05	4.8E+04	7.0E+05	2.0E+05	1.18E+06	1.62E+07	5.04E+06
BaS-NoS/15	2020	1.8E+04	4.6E+05	9.7E+03	3.2E+04	8.4E+05	1.8E+04	8.01E+05	1.96E+07	4.40E+05
All/all	2000	5.5E+06	9.5E+06	1.0E+07	1.0E+07	1.7E+07	1.9E+07	2.47E+08	3.71E+08	4.64E+08
All/all	2007	4.6E+06	8.7E+06	8.0E+06	8.5E+06	1.6E+07	1.5E+07	2.10E+08	3.36E+08	3.60E+08
All/all	2011	4.6E+06	8.7E+06	7.9E+06	8.4E+06	1.6E+07	1.4E+07	2.09E+08	3.36E+08	3.55E+08
All/all	2020	5.1E+06	6.2E+06	5.3E+06	9.4E+06	1.1E+07	9.6E+06	2.32E+08	2.35E+08	2.38E+08

Table B18: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **lower respiratory symptoms.**

		Cases						Costs		
		Children			Adults					
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	7.5E+01	1.3E+03	3.7E+02	1.6E+02	2.7E+03	7.7E+02	3.67E+03	6.46E+04	1.83E+04
DK/2	2000	4.1E+03	7.7E+02	3.0E+02	8.5E+03	1.6E+03	6.1E+02	2.02E+05	3.82E+04	1.44E+04
DK/3	2000	1.5E+02	9.1E+02	2.7E+02	3.1E+02	1.9E+03	5.6E+02	7.30E+03	4.47E+04	1.34E+04
DK/4	2000	1.5E+02	6.1E+02	1.5E+02	3.1E+02	1.3E+03	3.2E+02	7.41E+03	3.06E+04	7.66E+03
DK/5	2000	1.9E+01	6.2E+02	7.2E+01	4.1E+01	1.3E+03	1.5E+02	9.67E+02	3.09E+04	3.58E+03
DK/6	2000	0.0E+00	6.8E+02	7.9E+01	0.0E+00	1.4E+03	1.7E+02	3.72E-01	3.37E+04	3.92E+03
DK/7	2000	4.0E+03	3.2E+03	-2.1E+01	8.5E+03	6.5E+03	-3.4E+01	2.00E+05	1.55E+05	-8.84E+02
DK/8	2000	1.3E+03	9.6E+02	1.9E+02	2.6E+03	1.9E+03	3.8E+02	6.23E+04	4.62E+04	9.08E+03
DK/9	2000	5.0E-01	3.6E+01	-6.0E-01	1.0E+00	7.0E+01	-1.1E+00	2.39E+01	1.69E+03	-2.64E+01
DK/10	2000	4.3E+02	1.1E+04	2.2E+03	8.4E+02	2.1E+04	4.4E+03	2.03E+04	5.13E+05	1.06E+05
DK/all	2000	1.0E+04	1.5E+04	3.4E+03	2.1E+04	3.0E+04	6.9E+03	5.06E+05	7.23E+05	1.65E+05
All/15	2000	4.1E+03	1.0E+04	1.1E+04	8.4E+03	2.0E+04	2.2E+04	2.01E+05	4.83E+05	5.29E+05
All/15	2007	2.1E+03	1.1E+04	6.7E+03	4.3E+03	2.2E+04	1.4E+04	1.02E+05	5.23E+05	3.24E+05
All/15	2011	1.6E+03	1.1E+04	4.8E+03	3.3E+03	2.3E+04	9.6E+03	7.78E+04	5.50E+05	2.30E+05
All/15	2020	1.2E+03	1.2E+04	1.8E+03	2.4E+03	2.5E+04	3.7E+03	5.73E+04	5.91E+05	8.81E+04
BaS-NoS/15	2000	2.3E+03	8.4E+03	9.4E+03	4.8E+03	1.7E+04	1.9E+04	1.14E+05	4.01E+05	4.54E+05
BaS-NoS/15	2007	1.0E+03	9.5E+03	5.2E+03	2.1E+03	1.9E+04	1.0E+04	5.06E+04	4.54E+05	2.49E+05
BaS-NoS/15	2011	7.2E+02	1.0E+04	3.2E+03	1.5E+03	2.0E+04	6.5E+03	3.51E+04	4.80E+05	1.56E+05
BaS-NoS/15	2020	4.8E+02	1.1E+04	4.0E+02	9.9E+02	2.3E+04	7.9E+02	2.36E+04	5.41E+05	1.90E+04
All/all	2000	3.3E+04	6.8E+04	4.2E+04	6.8E+04	1.4E+05	8.6E+04	1.62E+06	3.27E+06	2.05E+06
All/all	2007	3.1E+04	5.9E+04	2.9E+04	6.4E+04	1.2E+05	5.9E+04	1.53E+06	2.87E+06	1.40E+06
All/all	2011	3.1E+04	6.1E+04	2.7E+04	6.3E+04	1.2E+05	5.4E+04	1.50E+06	2.93E+06	1.30E+06
All/all	2020	2.3E+04	4.0E+04	1.5E+04	4.6E+04	8.0E+04	3.1E+04	1.10E+06	1.92E+06	7.45E+05

Table B19: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **acute YOLL**.

Region/SNAP	Year	Cases			Costs		
		SO_2	O_3 more	O_3 less	SO_2	O_3 more	O_3 less
DK/1	2000	7.4E+00	8.2E+00	4.8E+00	1.56E+07	1.72E+07	1.02E+07
DK/2	2000	3.5E+00	6.4E+00	5.0E-01	7.48E+06	1.36E+07	1.02E+06
DK/3	2000	3.0E+00	3.3E+00	1.6E+00	6.43E+06	6.87E+06	3.42E+06
DK/4	2000	1.3E+00	2.7E+00	0.0E+00	2.84E+06	5.67E+06	4.15E+04
DK/5	2000	-4.0E-01	5.8E+00	0.0E+00	-7.43E+05	1.23E+07	1.64E+04
DK/6	2000	-1.1E+00	1.9E+01	0.0E+00	-2.31E+06	4.05E+07	6.46E+03
DK/7	2000	1.9E+00	2.8E+01	1.8E+01	3.93E+06	5.92E+07	3.91E+07
DK/8	2000	4.5E+00	8.2E+00	7.4E+00	9.56E+06	1.73E+07	1.57E+07
DK/9	2000	1.0E-01	1.7E+00	1.0E-01	1.69E+05	3.65E+06	2.97E+05
DK/10	2000	-2.0E-01	1.2E+00	2.9E+00	-3.96E+05	2.64E+06	6.23E+06
DK/all	2000	2.0E+01	9.4E+01	2.9E+01	4.25E+07	1.99E+08	6.19E+07
All/15	2000	9.3E+02	2.8E+03	6.2E+01	1.97E+09	5.83E+09	1.30E+08
All/15	2007	7.1E+02	2.9E+03	8.2E+01	1.49E+09	6.08E+09	1.73E+08
All/15	2011	6.0E+02	2.9E+03	8.1E+01	1.27E+09	6.09E+09	1.71E+08
All/15	2020	5.9E+02	3.9E+03	7.3E+01	1.25E+09	8.34E+09	1.55E+08
BaS-NoS/15	2000	6.2E+02	1.6E+02	2.2E+02	1.31E+09	3.32E+08	4.74E+08
BaS-NoS/15	2007	3.3E+02	1.7E+02	2.6E+02	6.88E+08	3.69E+08	5.51E+08
BaS-NoS/15	2011	2.2E+02	1.8E+02	2.6E+02	4.59E+08	3.84E+08	5.42E+08
BaS-NoS/15	2020	4.3E+01	4.0E+02	1.9E+02	9.04E+07	8.44E+08	4.04E+08
All/all	2000	1.7E+04	3.3E+04	0.0E+00	3.61E+10	6.92E+10	0.00E+00
All/all	2007	1.2E+04	3.2E+04	0.0E+00	2.59E+10	6.68E+10	0.00E+00
All/all	2011	1.2E+04	3.2E+04	0.0E+00	2.57E+10	6.66E+10	0.00E+00
All/all	2020	6.9E+03	2.9E+04	0.0E+00	1.45E+10	6.20E+10	0.00E+00

Table B20: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **acute YOLL**.

Region/SNAP	Year	Cases			Costs		
		SO_2	O_3 more	O_3 less	SO_2	O_3 more	O_3 less
DK/1	2000	2.3E+00	1.0E-01	1.1E+00	4.86E+06	2.64E+05	2.34E+06
DK/2	2000	2.8E+00	0.0E+00	3.0E-01	5.87E+06	6.63E+04	6.93E+05
DK/3	2000	1.3E+00	1.0E-01	4.0E-01	2.70E+06	1.34E+05	8.12E+05
DK/4	2000	1.3E+00	1.0E-01	0.0E+00	2.73E+06	1.19E+05	3.26E+04
DK/5	2000	0.0E+00	2.0E-01	0.0E+00	-5.84E+03	4.30E+05	2.34E+03
DK/6	2000	0.0E+00	7.0E-01	0.0E+00	-1.94E+04	1.58E+06	2.60E+02
DK/7	2000	9.0E-01	1.0E-01	1.3E+01	1.83E+06	2.45E+05	2.83E+07
DK/8	2000	3.1E+00	0.0E+00	3.5E+00	6.46E+06	6.76E+04	7.42E+06
DK/9	2000	0.0E+00	1.0E-01	0.0E+00	6.49E+03	1.45E+05	1.71E+04
DK/10	2000	0.0E+00	1.0E-01	0.0E+00	-6.03E+03	1.49E+05	3.16E+04
DK/all	2000	1.1E+01	1.6E+00	2.2E+01	2.41E+07	3.45E+06	4.55E+07
All/15	2000	2.3E+01	1.4E+01	1.5E+00	4.89E+07	2.95E+07	3.11E+06
All/15	2007	1.3E+01	1.4E+01	1.6E+00	2.67E+07	2.95E+07	3.47E+06
All/15	2011	8.1E+00	1.4E+01	1.6E+00	1.71E+07	2.96E+07	3.44E+06
All/15	2020	1.3E+00	2.0E+01	1.2E+00	2.70E+06	4.14E+07	2.53E+06
BaS-NoS/15	2000	2.4E+01	3.6E+00	5.7E+00	4.95E+07	7.58E+06	1.20E+07
BaS-NoS/15	2007	1.3E+01	3.4E+00	6.2E+00	2.69E+07	7.12E+06	1.31E+07
BaS-NoS/15	2011	8.2E+00	3.4E+00	6.2E+00	1.73E+07	7.16E+06	1.30E+07
BaS-NoS/15	2020	1.3E+00	6.4E+00	4.6E+00	2.73E+06	1.34E+07	9.73E+06
All/all	2000	5.8E+01	1.1E+02	0.0E+00	1.22E+08	2.40E+08	0.00E+00
All/all	2007	3.6E+01	1.1E+02	0.0E+00	7.68E+07	2.33E+08	0.00E+00
All/all	2011	3.2E+01	1.1E+02	0.0E+00	6.70E+07	2.32E+08	0.00E+00
All/all	2020	1.6E+01	1.1E+02	0.0E+00	3.39E+07	2.33E+08	0.00E+00

Table B21: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **chronic YOLL**.

		Cases			Costs		
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	1.6E+02	4.3E+03	1.4E+03	1.21E+07	3.30E+08	1.06E+08
DK/2	2000	3.3E+03	1.2E+03	7.7E+02	2.57E+08	8.97E+07	5.95E+07
DK/3	2000	2.7E+02	1.9E+03	8.8E+02	2.10E+07	1.43E+08	6.81E+07
DK/4	2000	1.1E+02	5.3E+02	4.2E+02	8.12E+06	4.09E+07	3.21E+07
DK/5	2000	1.4E+01	5.1E+02	3.7E+02	1.04E+06	3.96E+07	2.82E+07
DK/6	2000	4.0E-01	5.6E+02	6.0E+02	3.13E+04	4.29E+07	4.66E+07
DK/7	2000	2.1E+03	7.6E+03	3.0E+02	1.65E+08	5.88E+08	2.32E+07
DK/8	2000	8.2E+02	3.5E+03	2.2E+02	6.30E+07	2.67E+08	1.74E+07
DK/9	2000	1.7E+00	3.0E+02	1.2E+00	1.29E+05	2.28E+07	8.90E+04
DK/10	2000	3.3E+02	1.4E+04	1.0E+04	2.56E+07	1.11E+09	8.03E+08
DK/all	2000	7.2E+03	2.9E+04	1.3E+04	5.59E+08	2.22E+09	1.00E+09
All/15	2000	6.3E+04	2.0E+05	2.6E+05	4.88E+09	1.56E+10	2.00E+10
All/15	2007	5.2E+04	2.3E+05	2.3E+05	4.00E+09	1.80E+10	1.75E+10
All/15	2011	4.8E+04	2.4E+05	2.0E+05	3.67E+09	1.82E+10	1.58E+10
All/15	2020	4.6E+04	2.8E+05	2.4E+05	3.56E+09	2.17E+10	1.84E+10
BaS-NoS/15	2000	2.3E+04	8.6E+04	1.1E+05	1.81E+09	6.64E+09	8.20E+09
BaS-NoS/15	2007	1.1E+04	1.1E+05	5.5E+04	8.40E+08	8.24E+09	4.22E+09
BaS-NoS/15	2011	7.5E+03	1.1E+05	3.2E+04	5.80E+08	8.46E+09	2.47E+09
BaS-NoS/15	2020	5.1E+03	1.3E+05	2.8E+03	3.92E+08	1.02E+10	2.15E+08
All/all	2000	1.6E+06	2.7E+06	2.9E+06	1.21E+11	2.10E+11	2.27E+11
All/all	2007	1.3E+06	2.5E+06	2.3E+06	1.03E+11	1.92E+11	1.76E+11
All/all	2011	1.3E+06	2.5E+06	2.3E+06	1.02E+11	1.92E+11	1.74E+11
All/all	2020	1.5E+06	1.8E+06	1.5E+06	1.14E+11	1.38E+11	1.16E+11

Table B22: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **chronic YOLL**.

		Cases			Costs		
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	2.3E+01	4.0E+02	1.1E+02	1.74E+06	3.07E+07	8.70E+06
DK/2	2000	1.2E+03	2.4E+02	8.9E+01	9.54E+07	1.81E+07	6.84E+06
DK/3	2000	4.5E+01	2.8E+02	8.2E+01	3.45E+06	2.12E+07	6.34E+06
DK/4	2000	4.5E+01	1.9E+02	4.7E+01	3.50E+06	1.46E+07	3.62E+06
DK/5	2000	5.9E+00	1.9E+02	2.2E+01	4.54E+05	1.47E+07	1.70E+06
DK/6	2000	0.0E+00	2.1E+02	2.4E+01	1.76E+02	1.60E+07	1.86E+06
DK/7	2000	1.2E+03	9.5E+02	-5.4E+00	9.46E+07	7.35E+07	-4.17E+05
DK/8	2000	3.8E+02	2.8E+02	5.6E+01	2.94E+07	2.18E+07	4.28E+06
DK/9	2000	1.0E-01	1.0E+01	-2.0E-01	1.13E+04	7.96E+05	-1.24E+04
DK/10	2000	1.2E+02	3.1E+03	6.5E+02	9.50E+06	2.42E+08	4.99E+07
DK/all	2000	3.1E+03	4.4E+03	1.0E+03	2.39E+08	3.41E+08	7.77E+07
All/15	2000	1.2E+03	3.0E+03	3.2E+03	9.56E+07	2.29E+08	2.51E+08
All/15	2007	6.3E+02	3.2E+03	2.0E+03	4.85E+07	2.48E+08	1.53E+08
All/15	2011	4.8E+02	3.4E+03	1.4E+03	3.70E+07	2.61E+08	1.09E+08
All/15	2020	3.5E+02	3.6E+03	5.4E+02	2.72E+07	2.80E+08	4.17E+07
BaS-NoS/15	2000	7.0E+02	2.5E+03	2.8E+03	5.43E+07	1.90E+08	2.15E+08
BaS-NoS/15	2007	3.1E+02	2.8E+03	1.5E+03	2.41E+07	2.15E+08	1.18E+08
BaS-NoS/15	2011	2.2E+02	2.9E+03	9.5E+02	1.67E+07	2.27E+08	7.36E+07
BaS-NoS/15	2020	1.5E+02	3.3E+03	1.2E+02	1.12E+07	2.56E+08	9.00E+06
All/all	2000	1.0E+04	2.0E+04	1.3E+04	7.69E+08	1.55E+09	9.71E+08
All/all	2007	9.4E+03	1.8E+04	8.6E+03	7.24E+08	1.36E+09	6.66E+08
All/all	2011	9.2E+03	1.8E+04	8.0E+03	7.13E+08	1.39E+09	6.18E+08
All/all	2020	6.8E+03	1.2E+04	4.6E+03	5.23E+08	9.11E+08	3.54E+08

Table B23: Total number of cases and external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios related to **infant mortality**.

		Cases			Costs		
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	0.0E+00	4.0E-01	1.0E-01	5.02E+04	1.35E+06	4.34E+05
DK/2	2000	4.0E-01	1.0E-01	1.0E-01	1.12E+06	3.78E+05	2.46E+05
DK/3	2000	0.0E+00	2.0E-01	1.0E-01	8.76E+04	5.96E+05	2.80E+05
DK/4	2000	0.0E+00	1.0E-01	0.0E+00	3.61E+04	1.78E+05	1.32E+05
DK/5	2000	0.0E+00	1.0E-01	0.0E+00	4.60E+03	1.73E+05	1.15E+05
DK/6	2000	0.0E+00	1.0E-01	1.0E-01	1.26E+02	1.88E+05	1.89E+05
DK/7	2000	2.0E-01	8.0E-01	0.0E+00	7.54E+05	2.43E+06	9.30E+04
DK/8	2000	1.0E-01	3.0E-01	0.0E+00	2.81E+05	1.09E+06	7.38E+04
DK/9	2000	0.0E+00	0.0E+00	0.0E+00	5.29E+02	9.24E+04	3.48E+02
DK/10	2000	0.0E+00	1.5E+00	1.0E+00	1.12E+05	4.68E+06	3.28E+06
DK/all	2000	8.0E-01	2.9E+00	1.3E+00	2.47E+06	9.24E+06	4.10E+06
All/15	2000	6.2E+00	2.0E+01	2.6E+01	1.97E+07	6.30E+07	8.09E+07
All/15	2007	5.1E+00	2.3E+01	2.2E+01	1.61E+07	7.28E+07	7.07E+07
All/15	2011	4.7E+00	2.3E+01	2.0E+01	1.48E+07	7.36E+07	6.36E+07
All/15	2020	4.5E+00	2.8E+01	2.3E+01	1.44E+07	8.77E+07	7.41E+07
BaS-NoS/15	2000	2.3E+00	8.5E+00	1.0E+01	7.33E+06	2.69E+07	3.32E+07
BaS-NoS/15	2007	1.1E+00	1.0E+01	5.4E+00	3.40E+06	3.34E+07	1.71E+07
BaS-NoS/15	2011	7.0E-01	1.1E+01	3.2E+00	2.35E+06	3.42E+07	9.99E+06
BaS-NoS/15	2020	5.0E-01	1.3E+01	3.0E-01	1.59E+06	4.14E+07	8.73E+05
All/all	2000	1.5E+02	2.7E+02	2.9E+02	4.87E+08	8.45E+08	9.15E+08
All/all	2007	1.3E+02	2.4E+02	2.2E+02	4.14E+08	7.74E+08	7.10E+08
All/all	2011	1.3E+02	2.4E+02	2.2E+02	4.13E+08	7.75E+08	7.00E+08
All/all	2020	1.4E+02	1.8E+02	1.5E+02	4.58E+08	5.56E+08	4.69E+08

Table B24: Total number of cases and external costs in Euros for Denmark per chemical compounds for all the different scenarios related to **infant mortality**.

		Cases			Costs		
Region/SNAP	Year	$PM_{2.5}$	NO_3	SO_4	$PM_{2.5}$	NO_3	SO_4
DK/1	2000	0.0E+00	0.0E+00	0.0E+00	8.52E+03	1.50E+05	4.22E+04
DK/2	2000	1.0E-01	0.0E+00	0.0E+00	4.70E+05	8.96E+04	3.36E+04
DK/3	2000	0.0E+00	0.0E+00	0.0E+00	1.70E+04	1.05E+05	3.10E+04
DK/4	2000	0.0E+00	0.0E+00	0.0E+00	1.74E+04	7.24E+04	1.79E+04
DK/5	2000	0.0E+00	0.0E+00	0.0E+00	2.24E+03	7.30E+04	8.37E+03
DK/6	2000	0.0E+00	0.0E+00	0.0E+00	8.50E-01	7.97E+04	9.13E+03
DK/7	2000	1.0E-01	1.0E-01	0.0E+00	4.72E+05	3.59E+05	-1.93E+03
DK/8	2000	0.0E+00	0.0E+00	0.0E+00	1.46E+05	1.06E+05	2.11E+04
DK/9	2000	0.0E+00	0.0E+00	0.0E+00	5.53E+01	3.86E+03	-5.99E+01
DK/10	2000	0.0E+00	4.0E-01	1.0E-01	4.66E+04	1.18E+06	2.44E+05
DK/all	2000	4.0E-01	5.0E-01	1.0E-01	1.19E+06	1.66E+06	3.80E+05
All/15	2000	1.0E-01	3.0E-01	4.0E-01	4.59E+05	1.10E+06	1.21E+06
All/15	2007	1.0E-01	4.0E-01	2.0E-01	2.33E+05	1.20E+06	7.42E+05
All/15	2011	1.0E-01	4.0E-01	2.0E-01	1.78E+05	1.26E+06	5.26E+05
All/15	2020	0.0E+00	4.0E-01	1.0E-01	1.31E+05	1.35E+06	2.02E+05
BaS-NoS/15	2000	1.0E-01	3.0E-01	3.0E-01	2.61E+05	9.15E+05	1.04E+06
BaS-NoS/15	2007	0.0E+00	3.0E-01	2.0E-01	1.16E+05	1.04E+06	5.70E+05
BaS-NoS/15	2011	0.0E+00	3.0E-01	1.0E-01	8.01E+04	1.10E+06	3.56E+05
BaS-NoS/15	2020	0.0E+00	4.0E-01	0.0E+00	5.39E+04	1.24E+06	4.36E+04
All/all	2000	1.2E+00	2.4E+00	1.5E+00	3.74E+06	7.48E+06	4.69E+06
All/all	2007	1.1E+00	2.1E+00	1.0E+00	3.53E+06	6.55E+06	3.22E+06
All/all	2011	1.1E+00	2.1E+00	9.0E-01	3.48E+06	6.70E+06	2.99E+06
All/all	2020	8.0E-01	1.4E+00	5.0E-01	2.54E+06	4.39E+06	1.71E+06

Table B25: The total external costs in Euros for the whole of Europe per chemical compounds for all the different scenarios. Total S is the sum of the external cost of SO_2 and SO_4. Total N is the sum of the external costs of O_3 and NO_3.

Region/SNAP	Year	SO_2	SO_4	Total S	O_3	NO_3	Total N	$PM_{2.5}$
DK/1	2000	1.56E+07	1.33E+08	1.48E+08	7.06E+06	4.13E+08	4.20E+08	1.52E+07
DK/2	2000	7.49E+06	7.46E+07	8.21E+07	1.26E+07	1.12E+08	1.25E+08	3.24E+08
DK/3	2000	6.44E+06	8.53E+07	9.18E+07	3.45E+06	1.80E+08	1.83E+08	2.64E+07
DK/4	2000	2.84E+06	4.02E+07	4.31E+07	5.63E+06	5.14E+07	5.71E+07	1.02E+07
DK/5	2000	-7.44E+05	3.54E+07	3.46E+07	1.23E+07	4.98E+07	6.21E+07	1.31E+06
DK/6	2000	-2.32E+06	5.83E+07	5.60E+07	4.05E+07	5.40E+07	9.45E+07	3.92E+04
DK/7	2000	3.94E+06	2.90E+07	3.29E+07	2.01E+07	7.38E+08	7.58E+08	2.08E+08
DK/8	2000	9.57E+06	2.18E+07	3.14E+07	1.60E+06	3.34E+08	3.36E+08	7.95E+07
DK/9	2000	1.69E+05	1.11E+05	2.80E+05	3.35E+06	2.85E+07	3.19E+07	1.61E+05
DK/10	2000	-3.97E+05	1.00E+09	1.00E+09	-3.59E+06	1.39E+09	1.39E+09	3.22E+07
DK/all	2000	4.25E+07	1.25E+09	1.30E+09	1.37E+08	2.78E+09	2.92E+09	7.04E+08
All/15	2000	1.97E+09	2.51E+10	2.70E+10	5.70E+09	1.95E+10	2.52E+10	6.11E+09
All/15	2007	1.50E+09	2.19E+10	2.34E+10	5.91E+09	2.26E+10	2.85E+10	5.00E+09
All/15	2011	1.27E+09	1.97E+10	2.10E+10	5.92E+09	2.28E+10	2.87E+10	4.60E+09
All/15	2020	1.25E+09	2.30E+10	2.43E+10	8.18E+09	2.72E+10	3.54E+10	4.46E+09
BaS-NoS/15	2000	1.31E+09	1.03E+10	1.16E+10	-1.41E+08	8.32E+09	8.17E+09	2.27E+09
BaS-NoS/15	2007	6.89E+08	5.28E+09	5.97E+09	-1.82E+08	1.03E+10	1.01E+10	1.05E+09
BaS-NoS/15	2011	4.60E+08	3.09E+09	3.55E+09	-1.57E+08	1.06E+10	1.04E+10	7.26E+08
BaS-NoS/15	2020	9.04E+07	2.69E+08	3.60E+08	4.40E+08	1.28E+10	1.32E+10	4.90E+08
All/all	2000	3.61E+10	2.84E+11	3.20E+11	6.92E+10	2.62E+11	3.31E+11	1.51E+11
All/all	2007	2.59E+10	2.21E+11	2.47E+11	6.68E+10	2.40E+11	3.07E+11	1.28E+11
All/all	2011	2.57E+10	2.18E+11	2.43E+11	6.66E+10	2.40E+11	3.07E+11	1.28E+11
All/all	2020	1.45E+10	1.46E+11	1.60E+11	6.20E+10	1.73E+11	2.35E+11	1.42E+11

Table B26: The total external costs in Euros for Denmark per chemical compounds for all the different scenarios. Total S is the sum of the external cost of SO_2 and SO_4. Total N is the sum of the external costs of O_3 and NO_3.

Region/SNAP	Year	SO_2	SO_4	Total S	O_3	NO_3	Total N	$PM_{2.5}$
DK/1	2000	4.86E+06	1.10E+07	1.59E+07	-2.07E+06	3.90E+07	3.69E+07	2.21E+06
DK/2	2000	5.87E+06	8.68E+06	1.46E+07	-6.27E+05	2.30E+07	2.24E+07	1.21E+08
DK/3	2000	2.70E+06	8.05E+06	1.08E+07	-6.78E+05	2.70E+07	2.63E+07	4.38E+06
DK/4	2000	2.73E+06	4.61E+06	7.34E+06	8.66E+04	1.86E+07	1.86E+07	4.45E+06
DK/5	2000	-5.84E+03	2.16E+06	2.16E+06	4.27E+05	1.87E+07	1.91E+07	5.79E+05
DK/6	2000	-1.94E+04	2.36E+06	2.34E+06	1.58E+06	2.04E+07	2.20E+07	2.23E+02
DK/7	2000	1.83E+06	-5.22E+05	1.31E+06	-2.80E+07	9.32E+07	6.52E+07	1.20E+08
DK/8	2000	6.46E+06	5.44E+06	1.19E+07	-7.35E+06	2.77E+07	2.03E+07	3.74E+07
DK/9	2000	6.50E+03	-1.57E+04	-9.21E+03	1.28E+05	1.01E+06	1.14E+06	1.43E+04
DK/10	2000	-6.04E+03	6.33E+07	6.33E+07	1.18E+05	3.06E+08	3.06E+08	1.20E+07
DK/all	2000	2.41E+07	9.86E+07	1.23E+08	-4.20E+07	4.32E+08	3.90E+08	3.04E+08
All/15	2000	4.89E+07	3.18E+08	3.67E+08	2.64E+07	2.90E+08	3.17E+08	1.21E+08
All/15	2007	2.67E+07	1.95E+08	2.21E+08	2.61E+07	3.14E+08	3.40E+08	6.16E+07
All/15	2011	1.71E+07	1.38E+08	1.55E+08	2.62E+07	3.30E+08	3.57E+08	4.69E+07
All/15	2020	2.70E+06	5.29E+07	5.56E+07	3.89E+07	3.55E+08	3.94E+08	3.45E+07
BaS-NoS/15	2000	4.96E+07	2.73E+08	3.22E+08	-4.39E+06	2.41E+08	2.36E+08	6.89E+07
BaS-NoS/15	2007	2.70E+07	1.50E+08	1.77E+08	-6.00E+06	2.72E+08	2.66E+08	3.05E+07
BaS-NoS/15	2011	1.73E+07	9.34E+07	1.11E+08	-5.86E+06	2.88E+08	2.82E+08	2.12E+07
BaS-NoS/15	2020	2.74E+06	1.14E+07	1.42E+07	3.71E+06	3.25E+08	3.29E+08	1.42E+07
All/all	2000	1.22E+08	1.23E+09	1.35E+09	2.40E+08	1.97E+09	2.21E+09	9.76E+08
All/all	2007	7.69E+07	8.44E+08	9.21E+08	2.33E+08	1.73E+09	1.96E+09	9.20E+08
All/all	2011	6.70E+07	7.84E+08	8.51E+08	2.32E+08	1.76E+09	2.00E+09	9.05E+08
All/all	2020	3.39E+07	4.49E+08	4.82E+08	2.33E+08	1.16E+09	1.39E+09	6.63E+08

Appendix C: Definition of the SNAP emission sectors

In the table below, a more extensive description of the major SNAP emission sectors are given.

SNAP code	Subcategory	Emissions				
		CO	S	N	NH3	PM
1	Combustion plants	x	x	x	x	x
	Gas turbines	x		x		x
	Stationary engines	x	x	x		x
2	Small combustion installations	x	x	x	x	x
3	Boilers, gas turbines & stationary engines	x	x	x		x
	Sinter plants	x	x	x		x
	Iron foundries	x				x
	Purification of metals	x	x			x
	Cement	x	x	x		x
	Lime	x	x	x		x
	Asphalt		x			
	Glass production		x	x		x
	Bricks and tiles	x	x	x		
	Ceramics	x	x	x		
4	Coke* oven furnaces	x	x	x		
	Sinter plants	x	x	x		x
	Processes in petroleum industries	x	x	x		
	Iron processing	x	x	x		x
	Aluminium processing	x	x			
	Acid production		x	x	x	
	Paper industries	x	x	x		x
	Cement	x	x	x		x
	Glass production		x	x		x
5	Gas/energy/fuel extraction and distribution					
6	Painting					x
	Asphalt blowing	x		x		
7	Road transport	x	x	x	x	x
	Vehicle tyre and brake wear					x
8	aviation	x	x	x		x
9	outdoor toilets				x	
	incineration of domestic waste	x	x	x		x
	incineration of industrial waste	x	x	x		x
	oil refinery flaring	x	x	x		
	incineration of sludges from water treatment	x	x	x		x
	open burning of agricultural wastes (not stubble)	x	x	x	x	x
	cremation (corpses/carcasses)			x	x	
	Spreading of sewerage sludge				x	x
10	Farm animals			x	x	
	Animal housing systems					x
	Fertilisers			x	x	
	Burning stubble				x	x
	Crops			x	x	
15	shipping	x	x	x		x

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1. Reporting the CEEH integrated 'energy-environment-health' modeling framework (system) and definition of data exchange between models/modules
2. Document comparing the importance of different emissions scenarios (EDGAR, IPCC, and EMEP).
3. Description of the EVA system and validation.
4. Demonstration of the full CEEH chain – the EVA line.
5. Description of the HIA system and validation.
6. Demonstration of the full CEEH chain – the HIA line.
7. a) Description of the CEEH health effects model - selection of concentration-response functions,

   b) Laboratory tests of toxicity of combustion particles
8. Final report containing all results

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