ASSESSMENT OF THE IMPACT OF ALTERNATIVE REGULATIONS OF THE SULPHUR CONTENT IN MARITIME FUEL

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Abstract: The present study follows up on a previous study on assessment of the contribution from ships to air pollution in Denmark. According to IMO regulations the maximum allowed sulphur content in maritime fuel is reduced over time for ships sailing in the waters surrounding Denmark. The study compares the impact on air pollution for several alternative ways to proceed in the transition from the present level of maximum 1% sulphur in maritime fuel to a maximum level of 0.1% in 2020.

Keywords: Air pollution, ships, sulphur, maritime fuel, IMO regulations, projections for 2020.

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Contents

Summary

In 2009, on behalf of the Danish Environmental Protection Agency, the National Environmental Research Institute at Aarhus University carried out a study to assess the contribution from ships to air pollution in Denmark (Olesen et al., 2009). The study included an assessment of the contribution from ship traffic to the air pollution load for the three years 2007, 2011 and 2020. The computations for the year of 2007 were based on actual data, while computations for the years 2011 and 2020 were based on assumed scenarios for the future emissions from ships and land-based sources.

The current study is an extension of the previous in order to examine certain specific issues in more detail. It is based on the same data, computer models and assumptions. However, the geographical area of interest is extended to comprise Scandinavia and not just Denmark as in the previous study. The level of detail is highest for the region near Denmark.

Several variants of projections for ship emissions are considered for the years between 2011 and 2020. For landbased sources only one set of projections has been used in all calculations, which is the same as used in the previous study. Thus, for land-based sources it has been assumed that new and reduced national emissions ceilings will be adopted in EU for 2020. The negotiations concerning the new emission ceilings have been postponed, and currently it is uncertain how large the future reductions of the land-based emission will be. However, this is not critical to the objective of the current study, which is to examine the effects of certain variations in ship emissions.

The North Sea and the Baltic Sea are appointed *Sulphur Emission Control Areas* (SECA), where the maximum allowed sulphur content in fuel is reduced over time in a stepwise fashion, according to a set of requirements adopted by the International Maritime Organization, IMO. In 2011 the maximum content of sulphur in heavy fuel is 1%, while in 2020 the maximum level will be 0.1%. Ship owners have the option of implementing alternative measures (scrubbers) if they have similar effect on pollution.

The current study has been carried out on request of the Danish Shipowners Association, who requested an analysis of the impact of certain alternative temporal profiles for the regulation of sulphur content in maritime fuel. The study compares different ways to proceed in the transition from the present level of maximum 1% sulphur in maritime fuel to a maximum level of 0.1% in 2020. All profiles have the same start and end values for sulphur content in respectively 2011 and 2020, but they differ in path for the intermediate time period. The following profiles are considered:

- *The Base profile.* In 2010 the maximum sulphur content in heavy fuel oil is reduced to 1%, and in 2015 it is further reduced to 0.1%. This corresponds to the regulations currently in force.

- *Postponement profile*: As the accepted regulations until 2015, where the maximum sulphur content is reduced to 0.5%. In 2020 the maximum sulphur content is reduced further to 0.1%. Thus, the profile implies a substantial reduction to one half of the 2010 level in 2015, but postponement of the full reduction until 2020.

- *Balanced profile:* As the accepted regulations until 2012, where the maximum sulphur content is reduced to 0.5%. In 2018 the maximum sulphur content is reduced to 0.1%.

- *Mixed profile:* Certain ship routes are allowed to follow the postponement profile (0.5% sulphur after 2015), while the remaining ship traffic follows the accepted regulations (0.1% sulphur after 2015).

Based on emission inventories for the previous project, but modified to reflect the above profiles, model calculations to assess air pollution concentration levels have been carried out with the model DEHM (Danish Eulerian Hemispheric Model), which describes transport, chemical and physical processes and dispersion of air pollution. DEHM is capable of computing air pollution concentrations for a large number of substances.

The content of sulphur in maritime fuel has an effect on air pollution with sulphur dioxide (SO_2) and fine particles ($PM_{2.5}$). Accordingly, the consequences of the alternative profiles for sulphur regulation have been examined in terms of the concentration levels for sulphur dioxide and fine particles. Adverse health effects are primarily related to $PM_{2.5}$ concentrations, which are thus of particular interest.

In studies of health effects it is a widely used crude assumption that health outcomes such as the number of lost life years to a first approximation vary linearly with $PM_{2.5}$ concentrations. It is outside the scope of the current study to carry out complete calculations of the health effects of ship traffic. However, a relative estimate of the health effects of the various scenarios for a specific location can be obtained by comparing time averaged $PM_{2.5}$ concentrations for the various profiles.

In order to interpret the results it is necessary to know that a distinction is made between various types of fine particles. *Primary particles* exist as particles immediately after they have left the source; the emission of primary particles decreases somewhat if the sulphur content in fuel is reduced. On the other hand *secondary particles* were not 'born' as particles, but are created from gases, which undergo chemical transformation during transport – a process that continues for several hours or days after the pollution has left the source. Thus, sulphur dioxide which is emitted from ships will result in the formation of secondary fine particles after a while. However, the formation of secondary particles is a complicated process and many other substances than sulphur dioxide can contribute to the formation of particles. For this reason a substantial reduction in sulphur emission will not necessarily have any great impact on the formation of particles, and it is necessary with comprehensive calculations – as those presented here – to assess the effect of reduced sulphur content in fuel.

Atmospheric dispersion models are only able to describe *a part of the particles* found in the atmosphere. In order to make this clear we use here the designation $mPM_{2.5}$ (modelled $PM_{2.5}$) for the part of fine particles which *can* be modelled. $mPM_{2.5}$ includes the primary particles and the secondary inorganic particles. However, it is not possible with customary models to describe the particles which are secondarily formed from *organic* compounds, and which are, i.a., emitted from vegetation.

The results of calculations for the various profiles can be summarised as follows.

Considered as an average over the ten year period 2011-2020 the two profiles for sulphur regulations *Base profile* and *Balanced profile* result in almost identical concentrations for the substances. The main difference is the time development in the trends, were the Balanced profile gives stepwise reductions in 2012 and 2018, while the Base profile gives a single larger reduction in 2015.

The *Postponement profile* results in slightly larger ten-year average concentrations compared to the Base profile and the Balanced profile. According to the Postponement profile the sulphur content is only reduced to 0.5% in 2015, while the full reduction to 0.1% is postponed to 2020. In the Copenhagen area the effect of the Postponement profile is that the concentration level of fine particles ($mPM_{2.5}$) will be 0.04 $\mu g/m^3$ higher than for the Base profile. This difference amounts to 6% of the contribution from ships, or to 0.8% of the contribution from *all sources*. It should be noted that these values refer to the 'urban background level' in Copenhagen, i.e. at some distance from busy streets. In busy streets the relative contribution from ships will be smaller.

In the *Mixed profile* 29 specific shipping routes have been assumed to follow the postponement profile (implying 0.5% sulphur from 2015 to 2019), while the remaining fleet follows the accepted regulations. The routes in question were appointed by the Danish Shipowners Association, and are indicated in Appendix A. The average concentrations over the ten year period 2011-2020 lie between those of the Base profile and the Postponement profile. Compared to the total pollution level the differences between the Base profile and the Mixed profile are small, but locally it is possible to distinguish effects on the concentrations due to the higher sulphur content used at some of the shipping routes. For example this can be observed in the area between Rødby and Puttgarden.

In general the differences between the profiles stand out most clearly for concentration levels of SO_2, while they are less pronounced for primary $PM_{2.5}$, and smallest for $mPM_{2.5}$. This is caused by the fact that SO_2 emissions are entirely dependent on sulphur content in fuel and that the ship emissions are a major source of SO_2. Formation of primary particles does also depend on sulphur content, but to a smaller extent. The contribution to $mPM_{2.5}$ from ships is due not only to sulphur emissions, but also to NO_X emissions Therefore, changes in fuel sulphur content lead to quite modest changes in $mPM_{2.5}$.

The share of the concentrations that originate from ship traffic is generally higher for SO_2 than for particles. For instance in Copenhagen, about 19% of the total concentrations of SO_2 can be attributed to ship traffic, while this is only the case for around 13% of $mPM_{2.5}$, and only 3% of primary $PM_{2.5}$. These numbers refer to the average for the period 2011-2020.

The most pronounced difference between the profiles occurs for SO_2 in areas with much ship traffic. However, this difference should be seen in light of the low concentrations calculated for SO_2. The ten year average of the contribution from ships to SO_2 concentration in Copenhagen (about 0.1 $\mu g/m^3$) is less than 0.1% of the EU limit value for the diurnal concentration (125 $\mu g/m^3$). Although the averaging times are not comparable this illustrates that the level of concentrations calculated for SO_2 is low.

The study shows that there are large spatial variations in the impact of the different scenarios. For the cities considered the largest difference between the scenarios is seen for coastal cities where the ship traffic is dense. The largest variation in health impact due to the different scenarios will therefore be in the major cities with high density ship traffic such as Copenhagen and Gothenburg.

Sammenfatning

Rapportens titel på dansk: *Vurdering af effekten af alternative reguleringer af svovlindholdet i skibsbrændstof*

På foranledning af Miljøstyrelsen gennemførte Danmarks Miljøundersøgelser ved Aarhus Universitet i 2009 en undersøgelse, hvor skibsfartens bidrag til luftforurening i Danmark blev belyst (Olesen et al., 2009). Undersøgelsen omfattede bl.a. en vurdering af betydningen af luftforureningen fra skibe i de tre år 2007, 2011 og 2020. Beregningerne for 2007 tog udgangspunkt i aktuelle data, mens de for 2011 og 2020 var baseret på sandsynlige scenarier for udviklingen af emissioner fra skibe og fra landbaserede kilder.

Nærværende studie udbygger det forudgående hvad angår nogle specifikke problemstillinger. Det tager udgangspunkt i de samme data og beregningsforudsætninger. Dog er det betragtede område udvidet fra at omfatte Danmark og nærmeste omegn til at omfatte Skandinavien, men med størst detaljeringsgrad for området omkring Danmark.

I undersøgelsen betragtes flere varianter af emissionsudviklingen for skibe for årene mellem 2011 og 2020. Hvad angår landbaserede kilder benyttes et enkelt sæt af forudsætninger for emissionsudviklingen, nemlig det samme som i den tidligere undersøgelse. Om landbaserede kilder er det således antaget at nye og reducerede emissionslofter vil være gældende i EU i 2020. Forhandlingerne om ny emissionslofter er forsinket, og det er p.t. uvist, hvor store de fremtidige reduktioner faktisk bliver. Dette er dog ikke kritisk for formålet med nærværende studie, som er at undersøge effekten af visse variationer i emissioner fra skibe.

Nordsøen og Østersøen har status som SECA-områder (Sulphur Emission Control Area). Det indebærer at indholdet af svovl i skibsbrændstof, der benyttes i disse farvande, skal reduceres trinvis over tid i henhold til et sæt regler vedtaget i den internationale søfartsorganisation, IMO. I 2011 er den maximalt tilladte svovlprocent i tung fuel olie 1%, mens procentsatsen i 2020 er nede på 0,1%. Rederierne har dog mulighed for at gennemføre alternative tiltag (røggasrensning) i stedet for svovlreduktion i brændstoffet, såfremt de giver tilsvarende effekt.

Nærværende undersøgelse er iværksat på foranledning af Danmarks Rederiforening, der har ønsket at få belyst virkningen mht. luftforurening for forskellige tidsmæssige profiler for udviklingen af svovlprocenten i skibsbrændstof. Studiet sammenligner forskellige mulige veje i overgangen fra det nuværende niveau på maksimalt 1% svovl i tung fuel olie til maksimalt 0,1% i 2020. Alle profiler har samme start- og slutværdier for svovlindhold i henholdsvis 2011 og 2020, men de adskiller sig i den mellemliggende periode. Følgende profiler betragtes:

- *Basisprofil.* I 2010 reduceres det maksimale svovlindhold i tung fuel olie til 1%, og i 2015 reduceres det yderligere til 0,1%. Dette svarer til de vedtagne reguleringer.

- *Udsættelses-profil* (Postponement profile). Som de vedtagne reguleringer indtil 2015, hvor det maksimale svovlindhold reduceres til 0,5%. I 2020 reduceres det yderligere til 0,1%. Der er således tale om en reduktion til halvdelen af 2010-nivauet i 2015, men udsættelse af den fulde reduktion til 2020.

- *Balanceret profil*. Som de vedtagne reguleringer indtil 2012, hvor det maksimale svovlindhold reduceres til 0,5%. I 2018 reduceres det maksimale indhold til 0,1%.

- *Blandet profil* (Mixed profile). Visse skibsruter er udvalgt til at følge Udsættelses-profilen (0,5% svovl fra 2015), mens den resterende skibstrafik følger de vedtagne reguleringer.

Med udgangspunkt i emissionsopgørelser udarbejdet for det tidligere projekt, men modificeret så de afspejler de ovennævnte profiler, er der gennemført atmosfæriske spredningsberegninger med modellen DEHM, der beskriver transport, kemiske og fysiske processer og spredning af luftforurening. DEHM er i stand til at beregne koncentrationer i luften af en lang række stoffer.

Svovlindholdet i skibsbrændstof har betydning for luftforurening med svovldioxid (SO_2) og fine partikler ($PM_{2.5}$). Derfor er virkningen af de forskellige profiler for svovlregulering belyst på grundlag af værdier for koncentrationer i luften af stofferne svovldioxid (SO_2) og fine partikler ($PM_{2.5}$). Alvorlige negative helbredseffekter er især knyttet til forureningen med fine partikler, som derfor er af særlig interesse.

I studier af helbredseffekter er det en almindeligt udbredt omend grov antagelse, at effekter, såsom antallet af tabte leveår, varierer proportionalt med koncentrationen af $PM_{2.5}$. Det ligger uden for rammerne af nærværende undersøgelse at gennemføre komplette beregninger af helbredseffekten hidrørende fra skibstrafik. Derimod kan man få et relativt mål for helbredseffekten af de forskellige profiler på et bestemt geografisk sted ved at sammenligne middelværdier af $PM_{2.5}$-koncentrationer for de respektive profiler.

Som baggrund for at forstå resultaterne skal det understreges, at man sondrer mellem forskellige typer fine partikler. *Primære partikler* forefindes som partikler umiddelbart efter, at de har forladt kilden; udledningen af primære partikler mindskes noget, hvis svovlprocenten i brændstoffet nedsættes. *Sekundære partikler* er derimod partikler, der ikke er "født" som partikler, men som er dannet ved omdannelse af gasarter – typisk mange timer efter at forureningen er sendt ud i atmosfæren. Således vil det svovldioxid, der udsendes fra skibe, efter nogen tids forløb give anledning til dannelse af fine partikler. Men dannelsen af sekundære partikler er en kompliceret proces, og der er mange andre stoffer end svovldioxid, der også kan give anledning til dannelse af partikler. Derfor slår en kraftig reduktion i svovludsendelsen ikke nødvendigvis særlig kraftigt igennem på partikeldannelsen, og det er nødvendigt med ret omfattende beregninger som de foreliggende – der tager hensyn til både primære og sekundære partikler – for at vurdere effekten af nedsat svovlindhold i brændstoffet.

Modelmæssigt kan man med de nuværende modeller kun beskrive *en del* af de partikler, man finder i atmosfæren. For at tydeliggøre dette benyttes her en særskilt betegnelse for den del af de fine partikler, der *kan* modelleres, nemlig $mPM_{2.5}$. $mPM_{2.5}$ inkluderer de primære partikler og sekundære uorganiske forbindelser. Derimod kan man ikke modelmæssigt beskrive de partikler, der er sekundært dannet ud fra *organiske* forbindelse, og som f.eks. kan hidrøre fra gasarter udsendt af vegetation.

Resultaterne af beregningerne for de forskellige profiler kan sammenfattes som følger.

Vurderet på grundlag af middelværdier over ti-års perioden 2011-2020 resulterer de to profiler for svovlregulering *Basisprofilen* og den *Balancerede profil* i næsten identiske koncentrationer for alle de betragtede stoffer. Den væsentligste forskel er den tidslige udvikling, hvor den Balancerede profil medfører trinvis reduktioner af koncentrationerne i 2012 og 2018, mens Basisprofilen udløser en enkelt større reduktion i 2015.

Udsættelsesprofilen resulterer i ti-års koncentrationsmiddelværdier, der er en smule højere end værdierne fra Basisprofilen og fra den Balancerede profil. Udsættelsesprofilen indebærer at svovlindholdet bliver reduceret til 0,5% i 2015, mens den fulde reduktion til 0,1% udsættes til 2020. I København er virkningen af Udsættelsesprofilen at koncentrationsniveauet af fine partikler ($mPM_{2.5}$) er 0,04 $\mu g/m^3$ højere end for Basisprofilen. Denne forskel udgør ca. 6% af bidraget fra skibstrafik eller 0,8% af bidraget fra *alle kilder*. Det skal bemærkes at vi her betragter forureningsniveauet i den københavnske "bybaggrund", dvs. lidt væk fra trafikerede gader. I trafikerede gader er skibenes andel mindre.

Den *Blandede profil* indebærer, at 29 udvalgte skibsruter følger Udsættelsesprofilen, mens al øvrig skibsfart følger de vedtagne regler (Basisprofilen). De pågældende skibsruter er udpeget af Danmarks Rederiforening og angivet i Appendix A. Middelkoncentrationerne for perioden 2011-2020 ligger mellem værdierne fra Udsættelsesprofilen og Basisprofilen. I sammenligning med det totale forureningsniveau er forskellene mellem Basisprofilen og den Blandede profil små, men lokalt kan man skelne effekter på koncentrationerne som skyldes bestemte skibsruter. For eksempel er det tilfældet i området mellem Rødby og Puttgarden.

Generelt er forskellen mellem profilerne mest udtalt for koncentrationer af SO_2, mens den er mindre udtalt for primær $PM_{2.5}$ og mindst for $mPM_{2.5}$. Det skyldes, at SO_2 er totalt afhængig af brændstoffets svovlindhold og at skibstrafik er en af de største kilder til SO_2. Dannelsen af primære partikler afhænger også af svovlindholdet, men i mindre grad, mens skibstrafikkens bidrag til $mPM_{2.5}$ ikke alene er forårsaget af emissioner af svovlforbindelser, men også af kvælstofoxider (NO_X). Derfor medfører ændringer i brændstoffets svovlindhold kun beskedne ændringer i koncentrationerne af $mPM_{2.5}$.

Den andel af forureningsniveauet som skibe er ansvarlige for, er generelt højere for SO_2 end for partikler. Som eksempel kan tages København i perioden 2011-2020, hvor 19% af de totale koncentrationer af SO_2 kan tilskrives skibstrafik, mens det gælder omkring 13% hvad angår $mPM_{2.5}$, og kun 3% af primær $PM_{2.5}$. Disse tal gælder middelværdien over perioden 2011-2020.

Den mest udtalte forskel mellem profilerne optræder for SO_2 i områder med megen skibstrafik. Disse forskelle skal dog ses i lyset af de lave koncentrationer, der beregnes for SO_2. Således er skibsfartens bidrag til niveauet af SO_2 i København som gennemsnit for perioden 2011-2020 omkring 0,1 $\mu g/m^3$, hvilket er mindre end 0,1% af EU grænseværdien for døgnkoncentrationer (125 $\mu g/m^3$). Selv om midlingstiderne ikke er sammenlignelige, illustrerer dette at forureningsniveauet for SO_2 er ganske lavt.

Undersøgelsen viser at forskellene mellem profilernes virkning er langt mere markante for nogle lokaliteter end for andre. For de betragtede byer ses de største forskelle for kystbyer med intens skibstrafik. De største variationer med hensyn til helbredseffekter som følge af de forskellige scenarier optræder derfor i større havnebyer med høj tæthed af skibstrafik så som København og Göteborg.

1 Introduction

In 2008-2009 the National Environmental Research Institute at Aarhus University carried out a study on behalf of the Danish Environmental Agency in order to assess the contribution from ships to air pollution in Denmark.

The results of the study were published in the report *Ship emissions and air pollution in Denmark* (Olesen et al., 2009). The study included an assessment of the air pollution load for the three years 2007, 2011 and 2020, resulting from a baseline scenario with a likely development in emissions from ships and from land-based sources. There was particular focus on the contribution from ships.

This previous study is the point of departure for the present, which considers certain additional scenarios compared to the previous. The scenarios represent different developments in the regulation for sulphur in marine fuel. The present study is concerned with the evolution of air pollution load as a function of time in the period 2011-2020. The geographical area of interest is not confined strictly to Denmark as in the previous study. Results are presented for a larger geographical region, which includes a major part of Scandinavia.

The new study was prompted by the Danish Shipowners Association in order to study the impact which would result from certain alternative regulations of the sulphur content in maritime fuel.

The North Sea and the Baltic Sea are appointed *Sulphur Emission Control Areas* (SECA), where the maximum allowed sulphur content in fuel is reduced over time in a stepwise fashion according to a set of requirements adopted by IMO.

The present study considers certain alternative profiles of the stepwise reduction of the sulphur content in fuel. The following profiles are considered:

- *The Base profile.* In 2010 the maximum sulphur content in heavy fuel oil is reduced to 1%, and in 2015 it is further reduced to 0.1%. This corresponds to the regulations currently in force.

- *Postponement profile*: As the accepted regulations until 2015, where the maximum sulphur content is reduced to 0.5%. In 2020 the maximum sulphur content is reduced further to 0.1%. Thus, the profile implies a substantial reduction to one half of the 2010 level in 2015, but postponement of the full reduction until 2020.

- *Balanced profile:* As the accepted regulations until 2012, where the maximum sulphur content is reduced to 0.5%. In 2018 the maximum sulphur content is reduced to 0.1%.

- *Mixed profile:* Part of the ship traffic is allowed to follow the postponement profile (0.5% sulphur after 2015), while the remaining part follows the accepted regulations (0.1% sulphur after 2015). The Danish Shipowners Association has defined the part of the ship traffic that is allowed to follow the postponement profile.

Figure 1.1 displays the four profiles for the development of sulphur content in marine fuel.

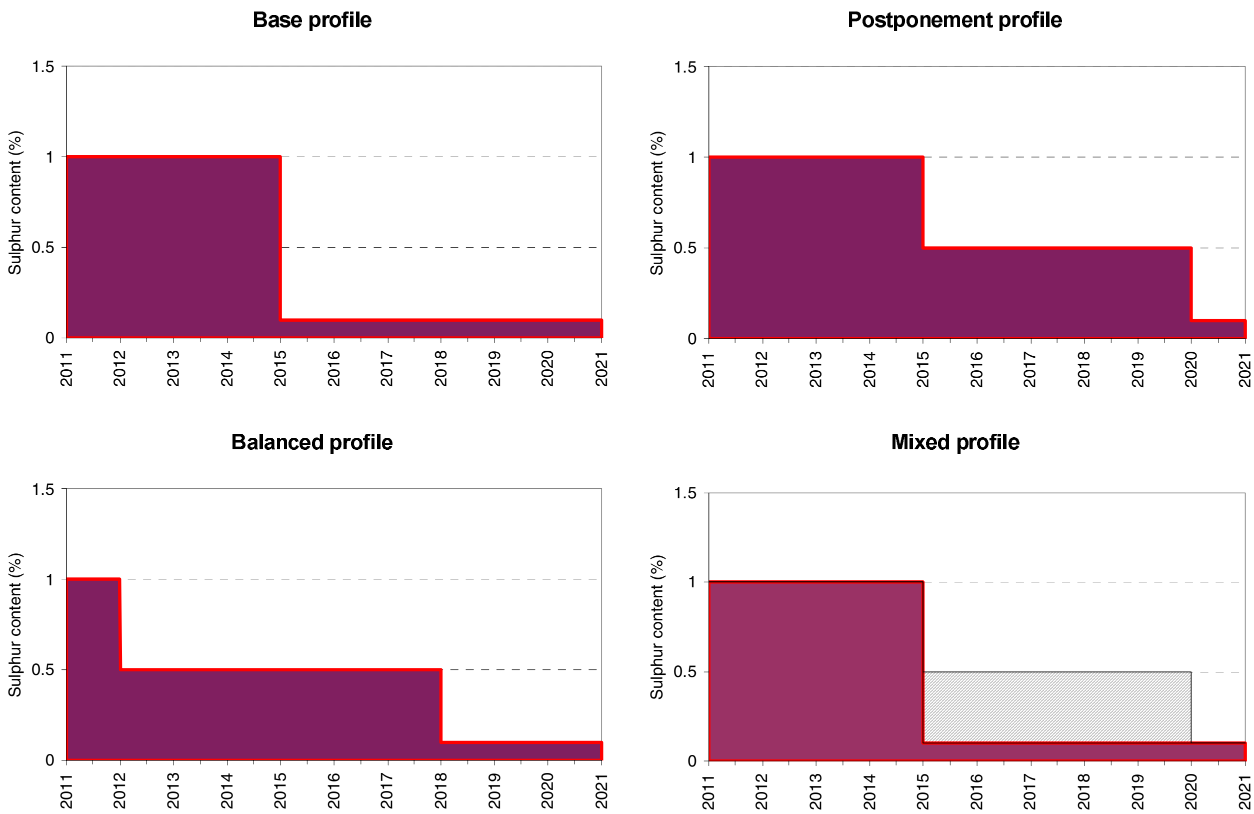

Figure 1.1. Profiles for the development of sulphur content in marine fuel in the seas around Denmark according to three scenarios. The hatched area in the Mixed profile indicates that only a part of the ship fleet are allowed to use fuel with a sulphur content of 0.5% after 2015.

The study focuses on the impact of alternative profiles in terms of concentrations of sulphur dioxide (SO_2) and fine particles ($PM_{2.5}$). It is taken into account that ships contribute to $PM_{2.5}$ in several ways – not only through the direct emission of particles, but also through so-called secondary formation of particles. Adverse health effects are primarily related to $PM_{2.5}$ concentrations. Health outcomes such as the number of lost life years can to a first approximation be regarded as proportional to $PM_{2.5}$ concentrations. A relative estimate of the health effects of the various scenarios for a specific location can be obtained by comparing time averaged $PM_{2.5}$ concentrations for that location. Such results are presented in Chapter 3.

2 Methodology and assumptions

The methodology and the assumptions underlying the computations are briefly summarised in the present chapter. However, as the study basically relies on the methods and procedures described previously in the report by Olesen et al. (2009), the reader is referred to that report for further details.

2.1 Emission inventory

As an outcome of the previous project a detailed emission inventory for national and international ship emissions in Danish marine waters was established. The inventory was based on data from the AIS system *(Automatic Identification System)*. This was combined with other ship emission inventories to provide full hemispheric coverage for ship emissions, and was further combined with emissions from land-based sources and aviation.

The inventory was prepared for the year 2007, while projections for the years 2011 and 2020 were established, using assumptions explained in Olesen et al. (2009).

The scenarios for ship emissions in the previous report were based on the assumption that the seas around Denmark were emission control areas for both sulphur (SECA) and for NO_X (NECA, with consequences for new ships from 2016).

The present study is based on inventories developed for the previous study, but with certain modifications. Thus, several variants of an inventory for ship emissions in 2015 have been compiled, based on information from the detailed 2007 inventory, complemented with various assumptions concerning the sulphur content in fuel, corresponding to the alternative profiles defined in Chapter 1.

The scenarios for the land-based European emissions have been based on the assumption that new and reduced national emissions ceilings will be adopted in EU for 2020 (Olesen et al., 2009). The negotiations concerning the new emission ceilings have been postponed, and currently it is uncertain how large the future reductions of the land-based emission will be. However, the new emission ceilings will not have impact on the concentrations of SO_2, primary $PM_{2.5}$ and $mPM_{2.5}$ originating from ship traffic.

An inventory for land-based sources for 2015 was prepared based on linear interpolation between the previously defined scenarios for 2007 and 2020. Thus, no attempt to construct any refined scenario for land-based emissions in 2015 has been made. This is considered justified for the purpose of the present study – which is focussed on studying the effect of various ship emission scenarios compared to each other.

It should be noted that the level of geographical detail in the emission inventory is high around Denmark in the area depicted in **Figure 2.1** (the AIS inventory area), while the resolution is lower outside this area. As a consequence, the results derived are more accurate for locations in Denmark and southern Sweden than elsewhere.

Chapter 1 briefly explains the profiles considered for the stepwise reduction of sulphur content in fuel, but does not go into details concerning the so-called *Mixed profile*. The *Mixed profile* is basically identical to the *Base profile*, but assumes that 39 specific ship routes are allowed to follow the *Postponement profile* (0.5% sulphur from 2015 instead of 0.1%). These ship routes were selected by the Danish Shipowners Association and are listed in Appendix A. A total of 67 ships are sailing on these routes[1]. Detailed information for these ship routes is only available in the AIS inventory area. This means that outside of the AIS inventory area there is no difference in emissions for the *Mixed profile* and the *Base profile*.

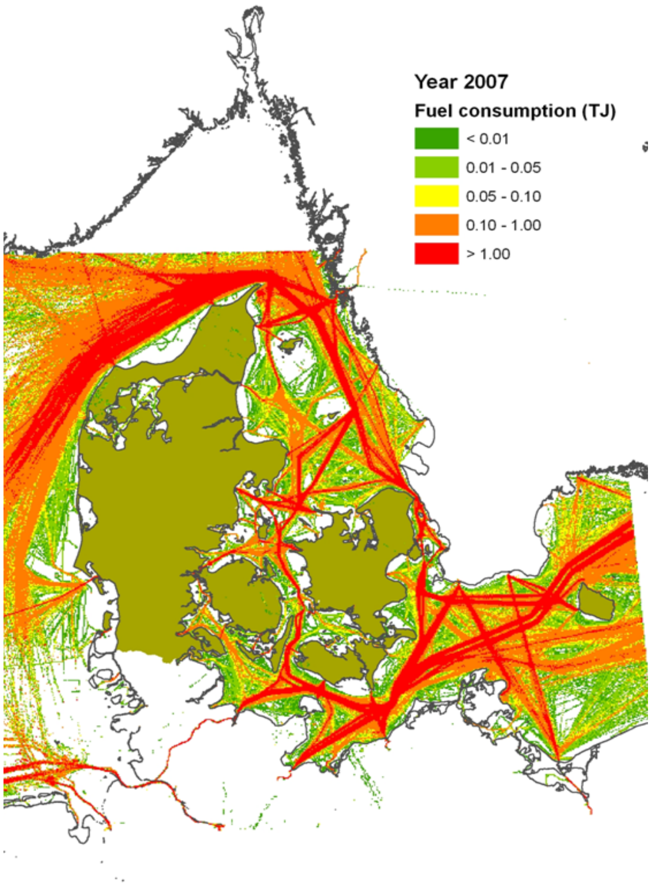

Figure 2.1. Illustration of the *AIS inventory area*. This is an area with a high degree of detail for the ship emission inventory. The map shows fuel consumption in 2007 according to AIS data. The unit is TJ/km^2.

[1] Of the 67 ships 8 were not present in the AIS-based emission inventory which forms the basis for the inventory for the scenarioes. Thus, these ships did not follow the Postponement profile.

2.2 Atmospheric transport and dispersion model

The model calculations to assess air pollution concentration levels have been carried out with the Danish Eulerian Hemispheric Model (DEHM) which was developed at NERI (Christensen, 1997). DEHM is a Eulerian model that calculates emissions, transport, chemical and physical processes and deposition of air pollution in a three dimensional grid. The DEHM model is used in a version with four nested grids, the finest of which has a geographical resolution of 6 x 6 km.

All model calculations of air pollution in this study - as well as in the previous - were carried out using meteorological data for year 2007.

The present study is based on full DEHM model runs for a limited number of years (2011, 2015 and 2020). For each of the years one or more scenarios have been considered, which represent various levels of sulphur in fuel (corresponding to the profiles described in Chapter 1). These model runs have supplied sufficient data to estimate concentrations in the intermediate years with simpler methods. The output from the model runs have been used to produce the various maps and graphs presented in chapter 3. Concentrations have been calculated for each of the years 2011-2020 in selected points, mainly representing coastal cities in Scandinavia. Furthermore, results are presented in Chapter 3 in the form of maps for the 3 years mentioned above.

3 Results

This chapter presents results for the various scenarios. There are numerous graphs in the chapter. Some introduction is required in order to put the reader in a position to interpret them and recognise their proper context.

3.1 Interpreting the results

Results are provided in terms of concentrations of SO_2 and fine particles, $PM_{2.5}$. More specifically, two fractions of $PM_{2.5}$ are considered: Primary $PM_{2.5}$ and model computed $PM_{2.5}$, designated $mPM_{2.5}$, which represents a total of primary and secondary particles (more details below). The component which deserves most attention is $mPM_{2.5}$ because adverse health effects are primarily related to concentrations of total $PM_{2.5}$. Health outcomes such as the number of lost life years can to a first approximation be regarded as proportional to $PM_{2.5}$ concentrations. A relative estimate of the health effects for the various scenarios for a specific location can be obtained by comparing time averaged $mPM_{2.5}$ concentrations for that location.

The next section explains some important aspects on particles.

3.1.1 What is the origin of $PM_{2.5}$?

Fine particles with a diameter less than 2.5 micrometer are referred to as $PM_{2.5}$. One can distinguish between *primary* particles and *secondary* particles. Primary particles exist as particles immediately after they have left the source. Secondary particles were not 'born' as particles, but are created from gases, which undergo chemical transformation during transport – a process that continues for several hours or days after the pollution has left the source. Secondary particles can be further characterised as secondary *inorganic* particles or as secondary *organic* particles.

Ship engines emit primary particles. The emission factor for primary $PM_{2.5}$ expresses the amount of primary $PM_{2.5}$ emitted per ton fuel. This emission factor depends on sulphur content in fuel, but the relationship is not linear. When considering the emission factor for primary $PM_{2.5}$ the gain in reducing sulphur content from 2.5% to 2% is larger than the gain obtained in going from 1.0% to 0.5%.

However, ship engines also emit SO_2 and NO_X which leads to the formation of *secondary* inorganic particles in the hours and days after the emission, and thus also contribute to $PM_{2.5}$ pollution. For ships the secondary contribution is larger than the primary. This can be seen from the results presented later in the chapter.

The DEHM atmospheric dispersion model takes account of the above processes. It can deliver results for the concentrations of the various components. In the following, we present results for the primary $PM_{2.5}$ as well as for the sum of primary and secondary inorganic particles. The sum is denoted $mPM_{2.5}$ - for modelled $PM_{2.5}$. However, the state of the art internationally within atmospheric dispersion modelling is such that there is not sufficient knowledge to describe the formation of secondary *organic* particles (see e.g. Yttri et al., 2009). Accordingly, DEHM does not account for these. Measured values of $PM_{2.5}$ in the ambient air will tend to be higher than $mPM_{2.5}$, because the measurements also include secondary organic particles.

3.1.2 What do the results represent?

It should be recognized that the results for concentrations represent spatial averages over an area with an extent of at least 6 by 6 km. The spatial resolution of the results is determined by the resolution of the model, as well as the resolution of the emission inventories. Both are most detailed in the area close to Denmark.

3.2 Which results are presented?

The following subsections present results from the computations for three pollution components: SO_2, total modelled $PM_{2.5}$ ($mPM_{2.5}$), and primary $PM_{2.5}$. Results are presented in the following ways:

a) Maps showing the contribution to air pollution from ships in terms of absolute concentration levels resulting from ships.

b) Maps showing the contribution to air pollution from ships in percent of the total air pollution. These maps put the contribution from ships in a context.

c) Maps focusing on the difference between the *Mixed profile* and the *Base profile* in 2015. In the Mixed profile certain ship routes are allowed to use fuel with a maximum sulphur content of 0.5% beyond the year 2015, while the general level is 0.1%. In the Base profile there is no exception for these ship routes.

d) For selected locations: Various graphs which present the pollution load over time for the different sulphur scenarios. The locations are mainly major Scandinavian cities, most of which are coastal.

The maps are well suited to give an impression of the ship contributions to the pollution load, whereas they are not good to give an impression of the difference between the scenarios. For this purpose the set of graphs (d) for specific locations are to be preferred.

Graphs have been produced for the following geographic locations:

- Copenhagen (In line with the comments above the concentrations should be interpreted as urban background concentrations - not as hot spot values. A similar interpretation applies to results for other cities).
- Anholt (of interest because it is very exposed to ship pollution)
- Rønne
- Göteborg
- Oslo

- Stockholm
- Helsinki
- Turku

The present study does not give comprehensive estimates of cumulative health effects in the region, as this is outside the scope of the study.

However, the cost of adverse health impacts for a certain location will to a first approximation be directly proportional to the average concentration of $mPM_{2.5}$ over the period considered. This fact makes it possible to compare the profiles for various sulphur regulations in a simple manner – by simply considering the results for $mPM_{2.5}$. Therefore, graphs have been produced which depict the development of $mPM_{2.5}$ over time in the period 2011-2020 according to the investigated sulphur regulations.

These graphs are a good indicator of whether one scenario (sulphur profile) is more beneficial than another in terms of health effects, and how large the relative difference is.

The subsequent results are organized in sections on SO_2, $mPM_{2.5}$ and primary $PM_{2.5}$.

The results for SO_2 reflect most clearly the effect of a change of varying regulations for sulphur contents, since SO_2 is closely linked to the sulphur content in fuel.

However, the health impact is related not so much to SO_2, but to total $PM_{2.5}$. Therefore the section on $mPM_{2.5}$ is the most elaborate and contains the largest number of graphs.

Finally, primary $PM_{2.5}$ is of some interest because it is responsible for a certain fraction of the total $PM_{2.5}$ load. In order to assess the health impact, $mPM_{2.5}$ is a better measure as it includes both primary and secondary inorganic particles.

3.3 Results for SO_2

The maps in **Figure 3.1** and **Figure 3.2** show the contribution from ships to air pollution with SO_2. The first set of maps show *absolute levels*, while the second show the *relative contribution* from ships. There are maps for the years 2007, 2011, 2020, as well as three maps representing the situation in 2015. The latter three maps differ in the assumed level of sulphur in heavy fuel, which is, respectively, 0.5 %, 0.1 %, and a mix. The mix corresponds to the Mixed profile, where certain ship routes are allowed to use 0.5% sulphur in fuel while the general level is 0.1%.

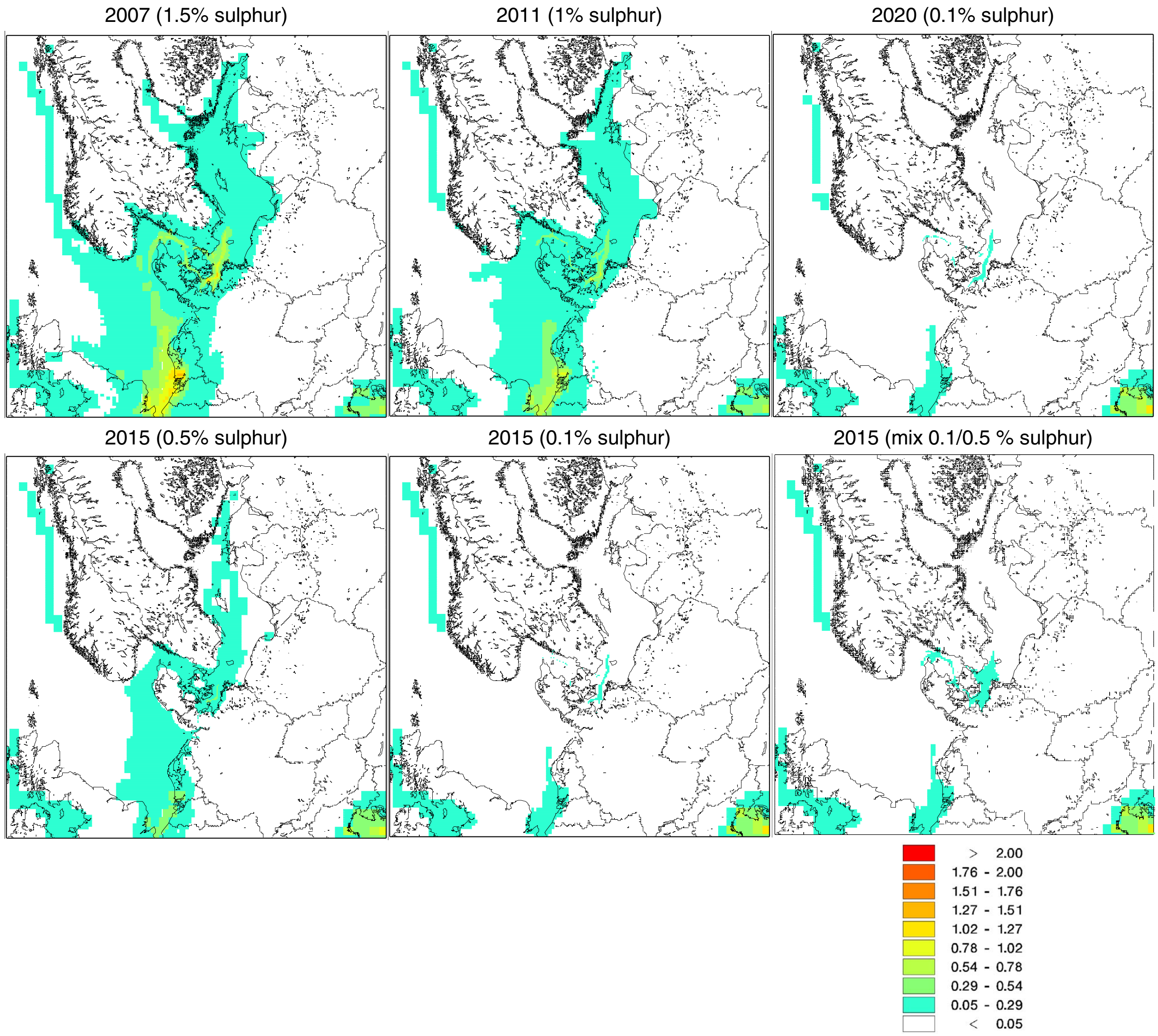

Figure 3.1. Concentration of SO_2 which can be attributed to ship emissions. Unit: $\mu g/m^3$. The upper row shows the situation in 2007, 2011 and 2020, while the lower is for 2015 with three different assumptions for sulphur level in fuel.

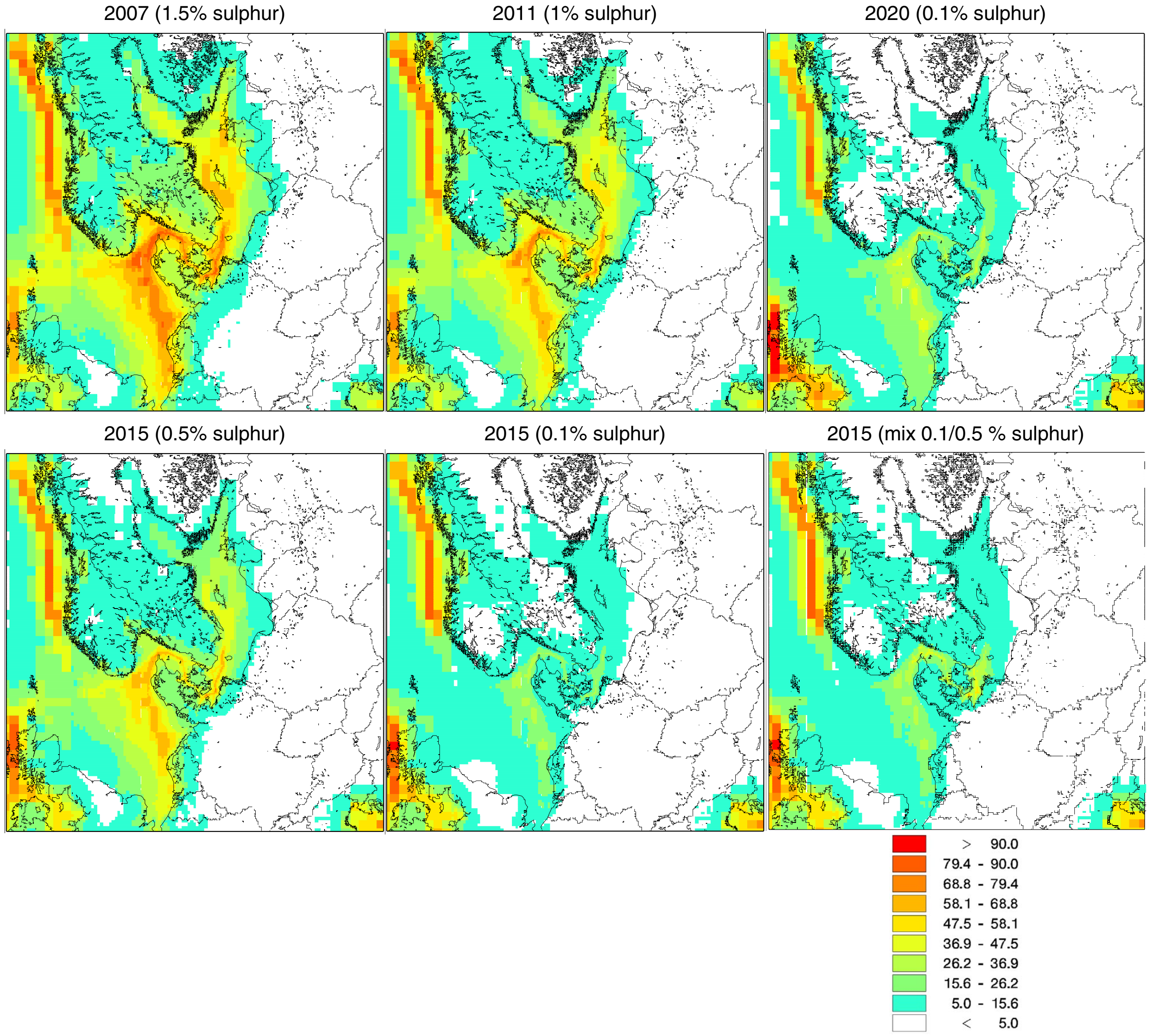

Figure 3.2. Relative contribution from ships to concentration of SO_2. This figure complements the above. Unit: percent:

In **Figure 3.3** the difference between the Base profile and the Mixed profile for 2015 is exposed. Focus is on the area close to Denmark, as this is where the emissions according to the Mixed profile and the Base profile differ. Note that the colour scales are different from those used in the previous figures.

It appears from the maps in **Figure 3.3** that locally – e.g. along the Rødby-Puttgarden route – there is a visible increase in concentrations when the Mixed profile is compared to the Base profile.

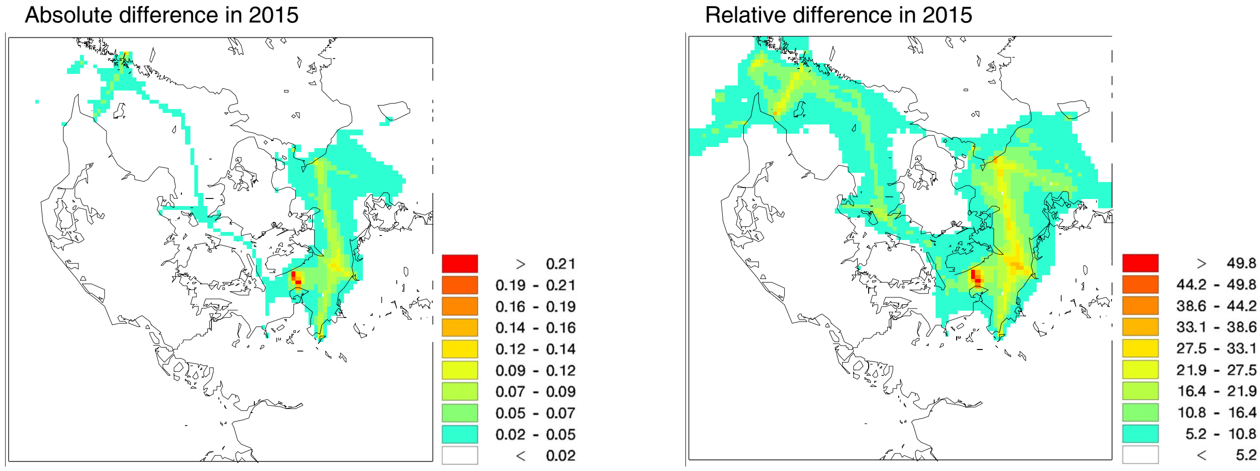

Figure 3.3. Difference between the Mixed profile and the Base profile in 2015 in terms of SO_2 concentrations. Left: concentrations in absolute numbers, i.e. $\mu g/m^3$; right: Relative difference in percent. 100% corresponds to the contribution from *all* sources according to the Base profile.

The maps above are not sufficient to give an impression of the difference between the different scenarios for sulphur in fuel between 2011 and 2020. For this purpose the graphs showing the development over time for specific locations are to be preferred.

An example of one such graph is shown as **Figure 3.4**. It shows SO_2 concentrations for the city of Göteborg, which is exposed to a relatively high influence by ship traffic. The vertical bars to the right in the graph indicate the average concentration over the period 2011-2020. It appears that the Base Profile and the Balanced Profile yield almost identical pollution loads, while the Postponement Profile results in a somewhat higher level.

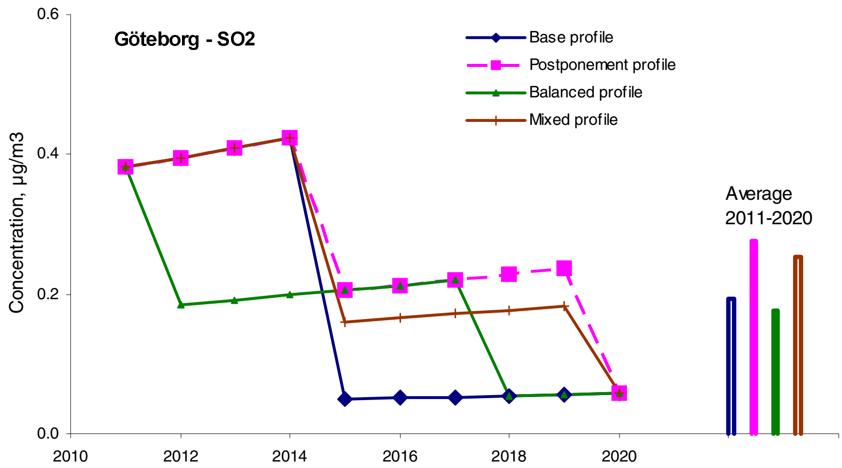

Figure 3.4. Concentration of SO_2 which can be attributed to ship emissions for Göteborg. The vertical bars indicate the average concentration over the period 2011-2020.

For the 10-year period 2011-2020 the average for the four profiles are, respectively: 0.19 µg/m³ (Base profile); 0.28 µg/m³ (Postponement profile); 0.18 µg/m³ (Balanced profile); 0.25 µg/m³ (Mixed profile).

Göteborg is a city which is very exposed to pollution from ships. A series of similar graphs are reproduced for a number of other Scandinavian cities in **Figure 3.5**. There, the contributions from ships to SO_2 concentrations are smaller than for Göteborg.

The impact that the scenarios have on SO_2 must be seen in light of the low concentrations calculated for SO_2. The ten year average of the contribution from ships to SO_2 concentration in Copenhagen is around 0.1 µg/m³, which is less than 0.1% of the EU limit value for the diurnal concentration (125 µg/m³). Although the averaging times are not comparable this illustrates that the level of concentrations calculated for SO_2 is low.

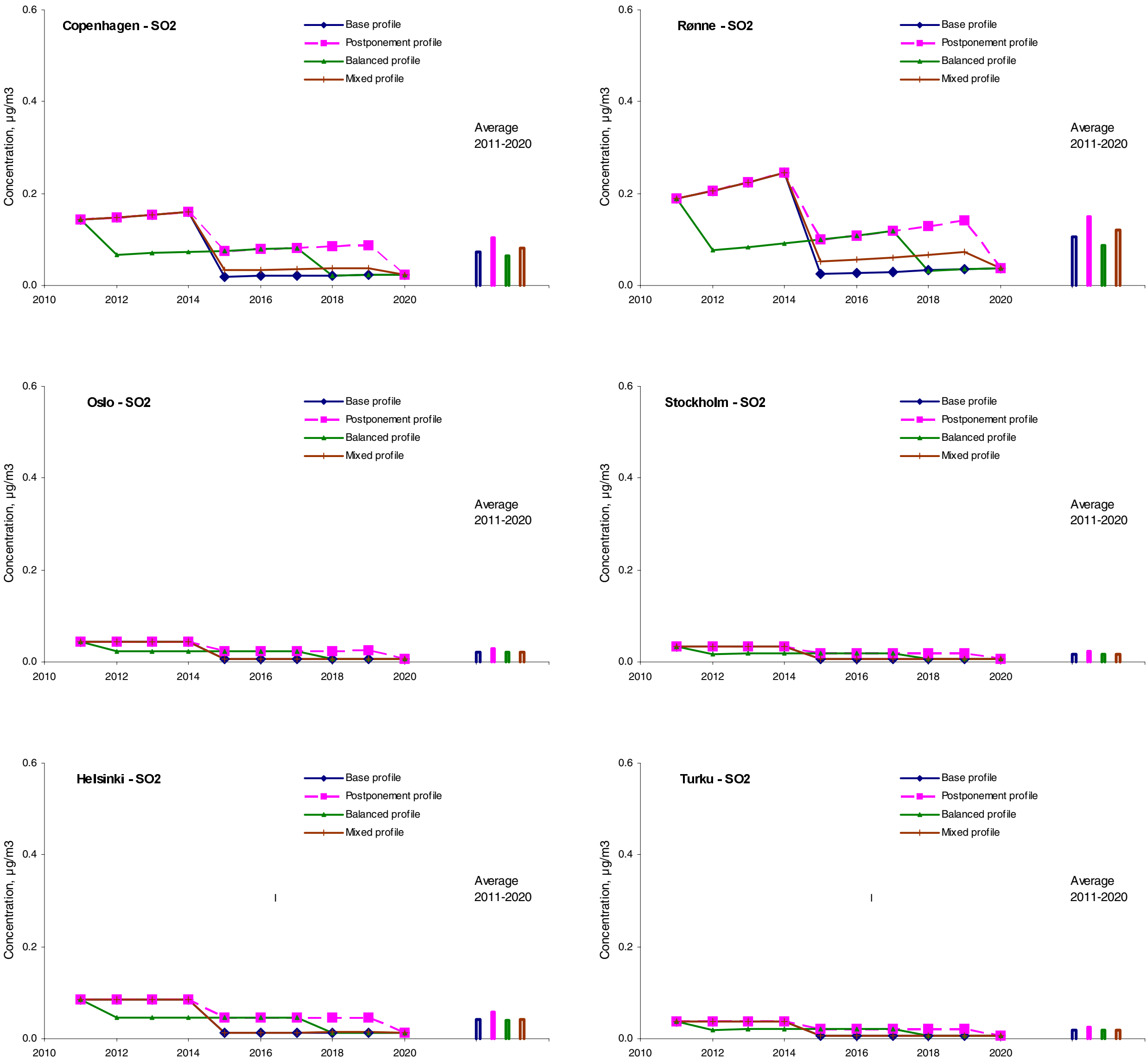

Figure 3.5. Concentration of SO_2 which can be attributed to ship emissions in a number of Scandinavian cities. The vertical bars indicate the average concentration over the period 2011-2020.

3.4 Results for modelled total $PM_{2.5}$ ($mPM_{2.5}$)

The results in this subsection are the most central in the report.

As explained in section 3.1 adverse health effects are primarily related to total $PM_{2.5}$ concentrations, and modelled $PM_{2.5}$ ($mPM_{2.5}$) is the best estimate that can be provided for total $PM_{2.5}$. An estimate of the health effects for the various scenarios for a specific location can be obtained by comparing time averaged $mPM_{2.5}$ concentrations for that location.

First, in order to set a frame of reference **Figure 3.6** displays maps for total $PM_{2.5}$ ($mPM_{2.5}$) for *all sources*, both ships and land-based sources. Elsewhere in the report focus is on the ship contribution, but it is instructive to be aware of the overall picture: there is a very pronounced pattern with large concentrations over the European continent, while concentrations gradually decrease as one moves north through Scandinavia.

The upper row in **Figure 3.6** shows results for the years 2007, 2011 and 2020. The decline in concentrations between 2011 and 2020 is to a large part due to the assumed reductions of NO_X from land-based sources, which is one of the assumptions underlying the calculations (see Chapter 2.1).

The lower row represents three scenarios for different sulphur content in fuel. The differences between these scenarios are so small that it is difficult to recognise them on the maps with the colour scale used.

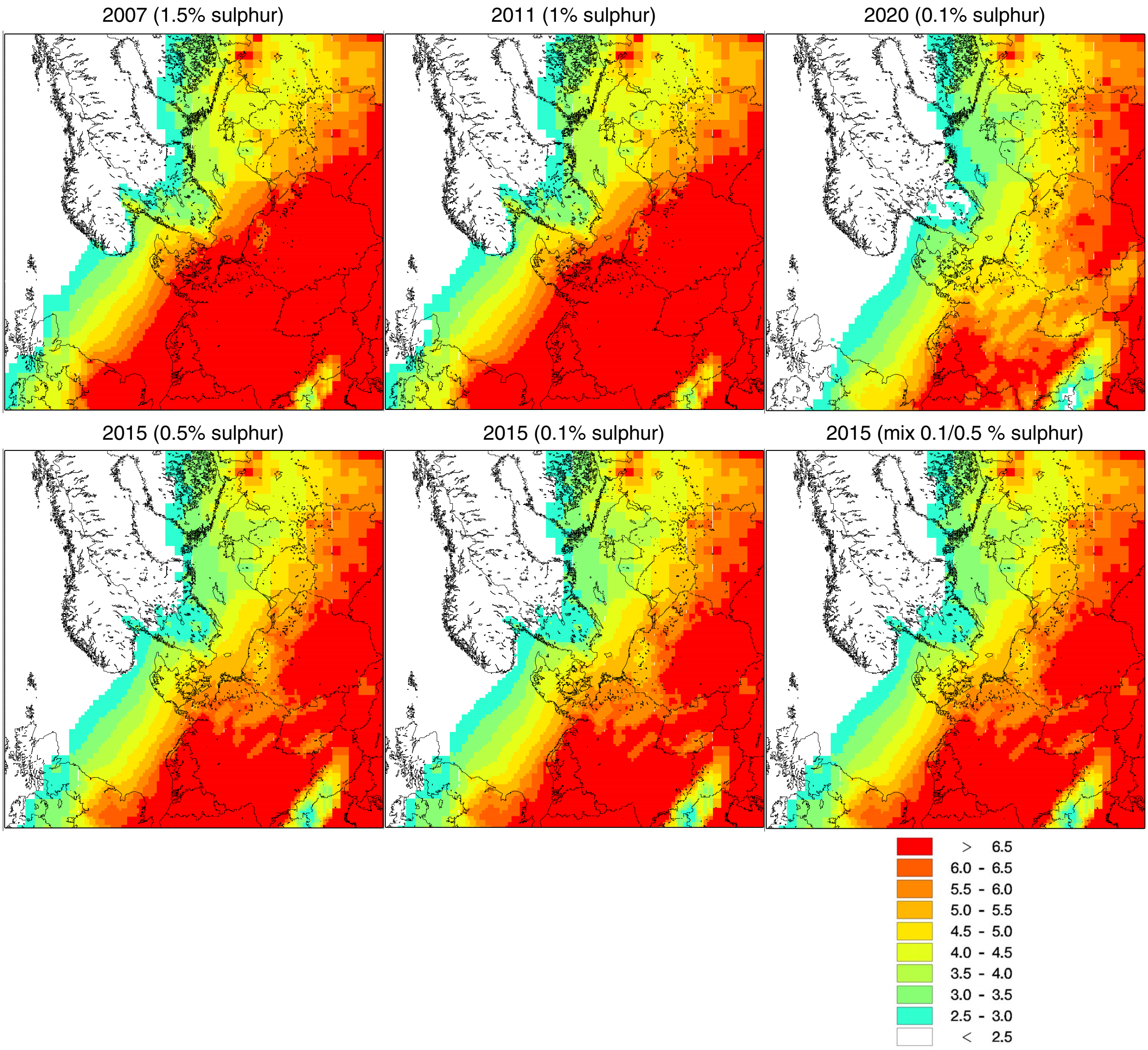

Figure 3.6. Concentration of total $PM_{2.5}$ ($mPM_{2.5}$) from all sources, both ships and land-based. Unit: µg/m^3. The upper row shows the situation in 2007, 2011 and 2020, while the lower is for 2015 with three different assumptions for sulphur level in fuel.

Two sets of maps for $mPM_{2.5}$ are shown as **Figure 3.7** and **Figure 3.8** in order to describe the geographical pattern of the *contribution from ships* to air pollution with $mPM_{2.5}$. When looking specifically at ship contribution it is possible to recognize the some small differences between three scenarios in the lower row of the figure, representing the 2015 situation with different sulphur content in fuel.

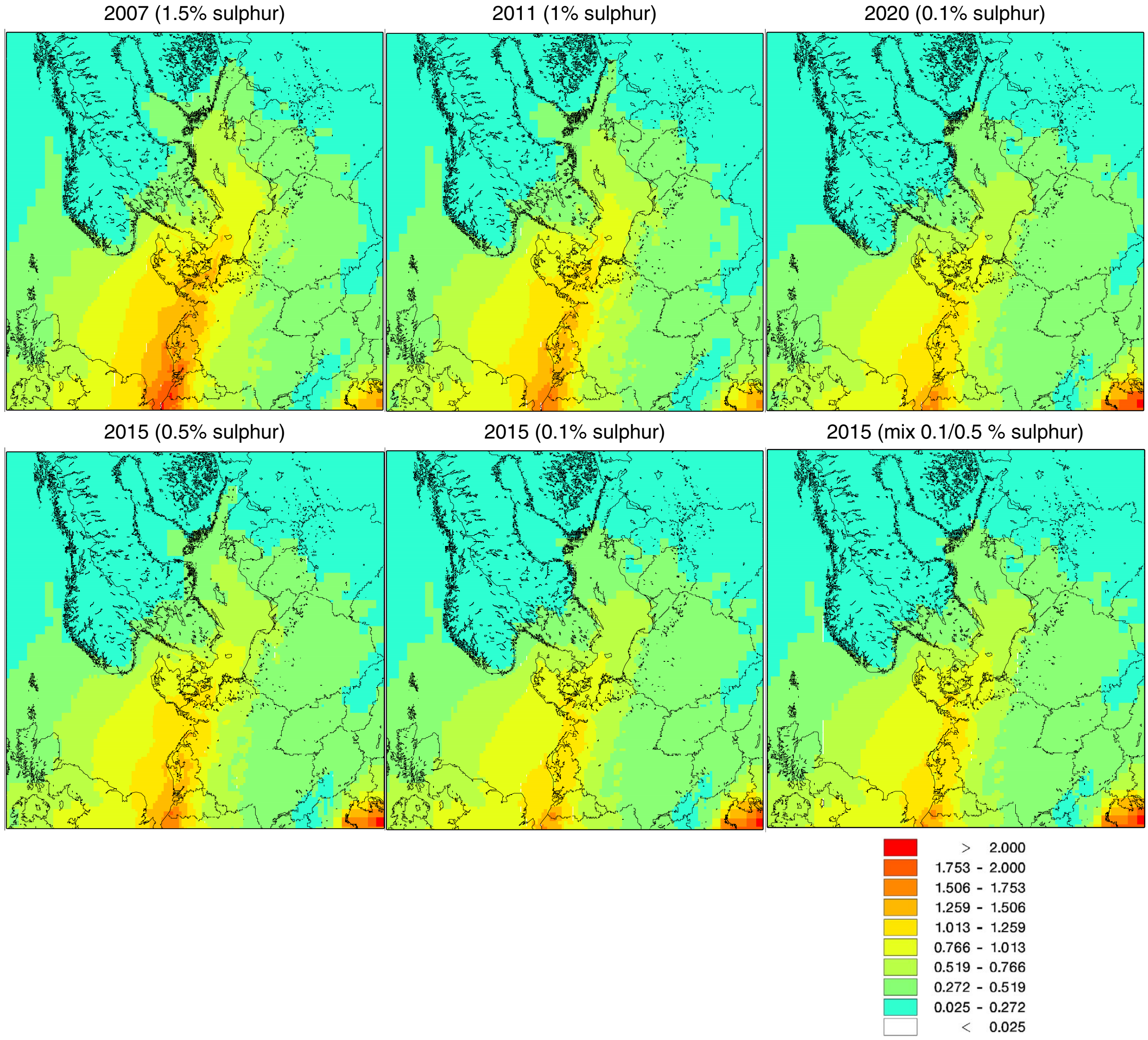

Figure 3.7. Concentration of $mPM_{2.5}$ which can be attributed to ship emissions. Unit: µg/m^3. The upper row shows the situation in 2007, 2011 and 2020, while the lower is for 2015 with three different assumptions for sulphur level in fuel.

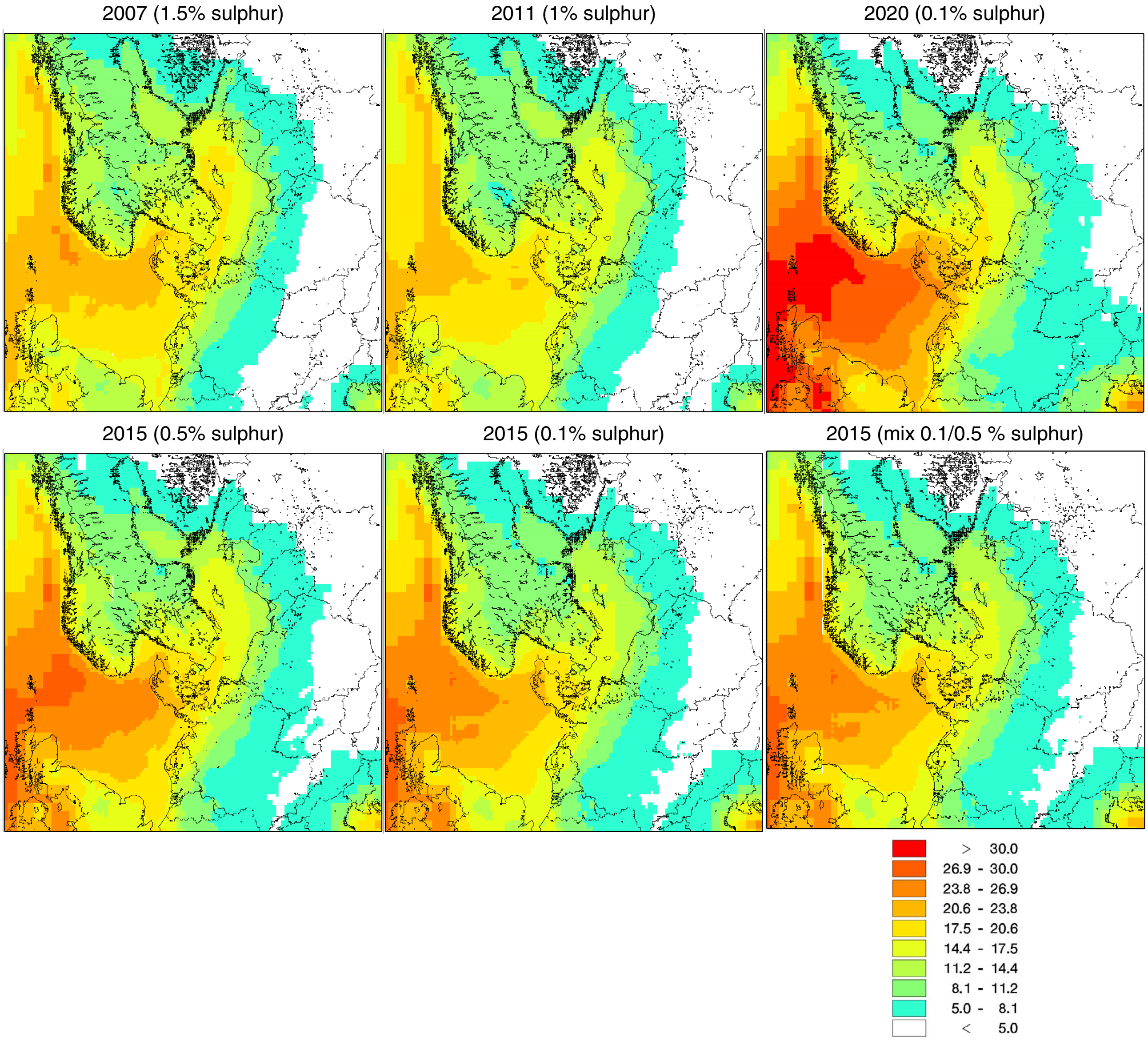

Figure 3.8. Relative contribution from ships to concentration of $mPM_{2.5}$. This figure complements the above. Unit: percent:

The differences between two of the scenarios become clearer in **Figure 3.8**. This figure exposes the difference between the Base profile and the Mixed profile for 2015. Focus is on the area close to Denmark, as this is where the emissions according to the Mixed profile and the Base profile differ. It appears from the maps in **Figure 3.8** that locally – e.g. along the Rødby-Puttgarden route – there is a visible increase in $mPM_{2.5}$ concentrations when the Mixed profile is compared to the Base profile.

Note however, that the colour scales are very different from those used in the previous figures.

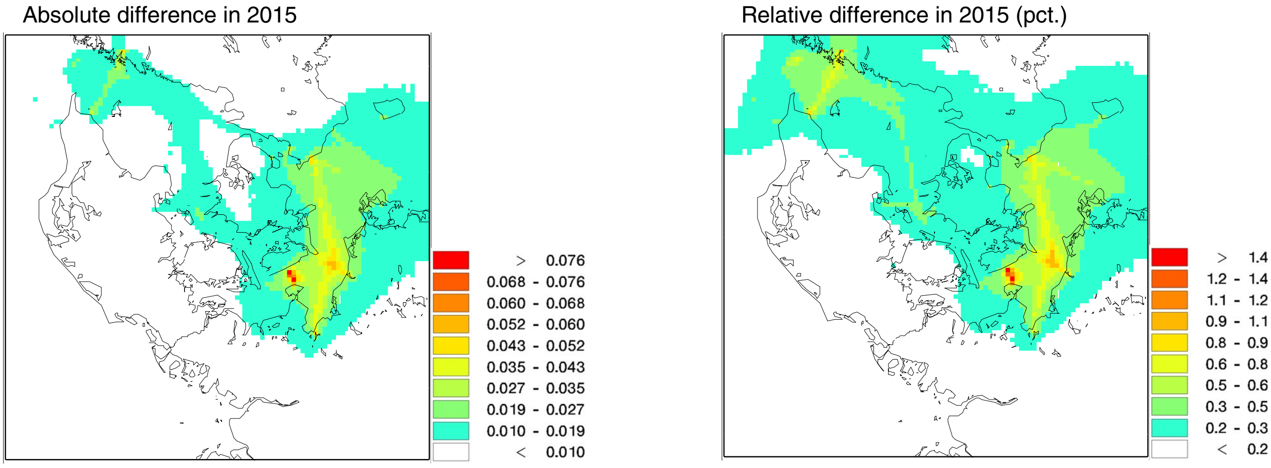

Figure 3.9. Difference between the Mixed profile and the Base profile in 2015 in terms of $mPM_{2.5}$ concentrations.
Left: concentrations in absolute numbers, i.e. $\mu g/m^3$; right: Relative difference in percent. 100% corresponds to the contribution from *all* sources according to the Base profile.

Next, graphs showing the development over time of the contribution from ships to $mPM_{2.5}$ concentrations are displayed for a number of Scandinavian cities. A graph for the isle of Anholt is also included as an example of a location highly exposed to ship traffic.

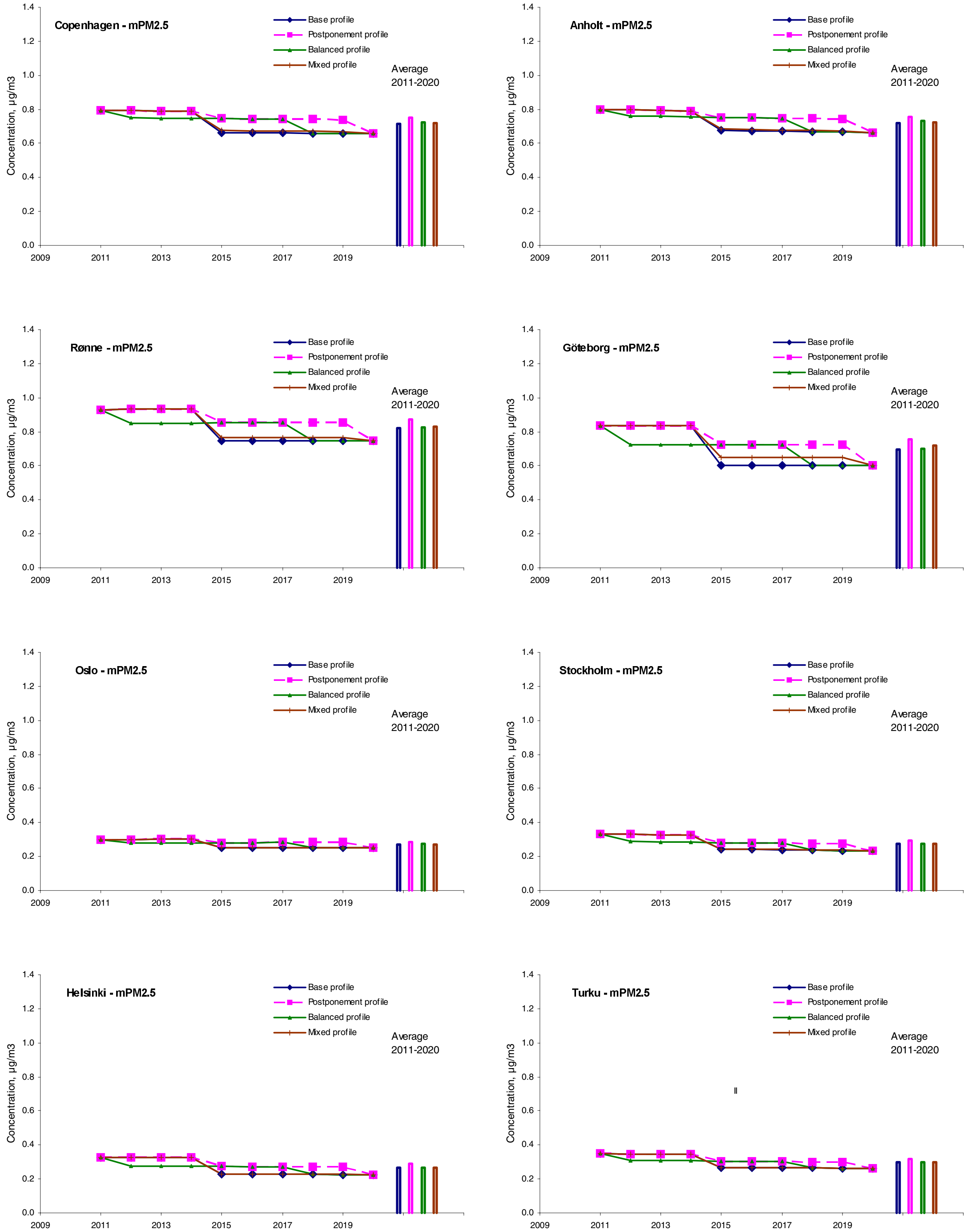

Figure 3.10. Concentration of $mPM_{2.5}$ which can be attributed to ship emissions in a number of Scandinavian cities. The vertical bars indicate the average concentration over the period 2011-2020.

The average for the period 2011-2020 is a good indicator for the health effect of the three profiles in the various cities. It is represented by a set of vertical bars in the graph for each city in **Figure 3.10**, and also indicated in **Table 3.2**. For reference, **Table 3.1** is included. It indicates the $mPM_{2.5}$ level when *all sources* are included, not only ships.

Table 3.1. Concentration of $mPM_{2.5}$ in µg/m^3 for a number of Scandinavian cities/locations. This table includes contributions from all sources, both ship emissions and other sources.

All sources	2007	2011	2015, Base profile	2020	Average 2011-2020, Base profile
Copenhagen	7.0	6.8	5.2	4.3	5.3
Anholt	5.0	4.9	3.8	3.3	3.9
Rønne	6.4	6.1	4.8	4.1	5.0
Göteborg	4.9	4.7	3.8	3.4	3.9
Oslo	4.2	4.1	2.9	2.2	3.0
Stockholm	3.6	3.5	3.2	3.1	3.3
Helsinki	4.4	4.2	3.9	3.7	3.9
Turku	3.8	3.7	3.4	3.2	3.4

Table 3.2. Contribution from ships to concentration of $mPM_{2.5}$ in µg/m^3 for a number of Scandinavian cities/locations. The data in the table correspond to the results displayed in **Figure 3.10** (and also include numbers for 2007 which are not shown in **Figure 3.10**),

				Average 2011-2020			
Ship contribution	2007	2011	2020	Base profile	Postponement profile	Balanced profile	Mixed profile
Copenhagen	0.92	0.79	0.66	0.71	0.75	0.72	0.72
Anholt	0.92	0.80	0.66	0.72	0.76	0.73	0.72
Rønne	1.09	0.93	0.75	0.82	0.87	0.83	0.83
Göteborg	1.02	0.84	0.60	0.70	0.76	0.70	0.72
Oslo	0.35	0.30	0.25	0.27	0.29	0.27	0.27
Stockholm	0.40	0.33	0.23	0.27	0.29	0.27	0.28
Helsinki	0.41	0.33	0.23	0.27	0.29	0.27	0.27
Turku	0.41	0.35	0.26	0.30	0.32	0.30	0.30

It appears from **Figure 3.10** and **Table 3.2** that the *Base profile* and *Balanced profile* result in almost identical concentrations as an average over the ten years period 2011-2020.

The *Postponement profile* apparently results in slightly larger average concentrations compared to the Base profile and the Balanced profile. For example, the contribution from ship traffic to $mPM_{2.5}$ in the Copenhagen area in the period 2011-2020 is 0.04 µg/m^3 higher than for the Base profile. This difference amounts to 6% of the contribution from ships, or to 0.8% of the contribution from *all sources*.

In the *Mixed profile* 29 specific shipping routes have been assumed to follow the postponement profile (implying 0.5% sulphur from 2015 to 2019), while the remaining fleet follows the accepted regulations. With the Mixed profile the average concentrations over the ten year period 2011-2020 lie between those of the Base profile and the Postponement profile. Compared to the total pollution level the differences between the Base profile and the Mixed profile are small, but locally it is possible to distinguish effects on the concentrations as it was illustrated in **Figure 3.9**.

3.5 Results for primary $PM_{2.5}$

The results in the previous section concerned modelled $PM_{2.5}$ which is the sum of primary $PM_{2.5}$ and secondary inorganic $PM_{2.5}$. It is interesting to identify how much is actually primary $PM_{2.5}$ (directly emitted fine particles). Results for primary $PM_{2.5}$ are presented in the following.

First, two sets of maps are reproduced, showing the absolute and the relative contribution from ships to primary $PM_{2.5}$.

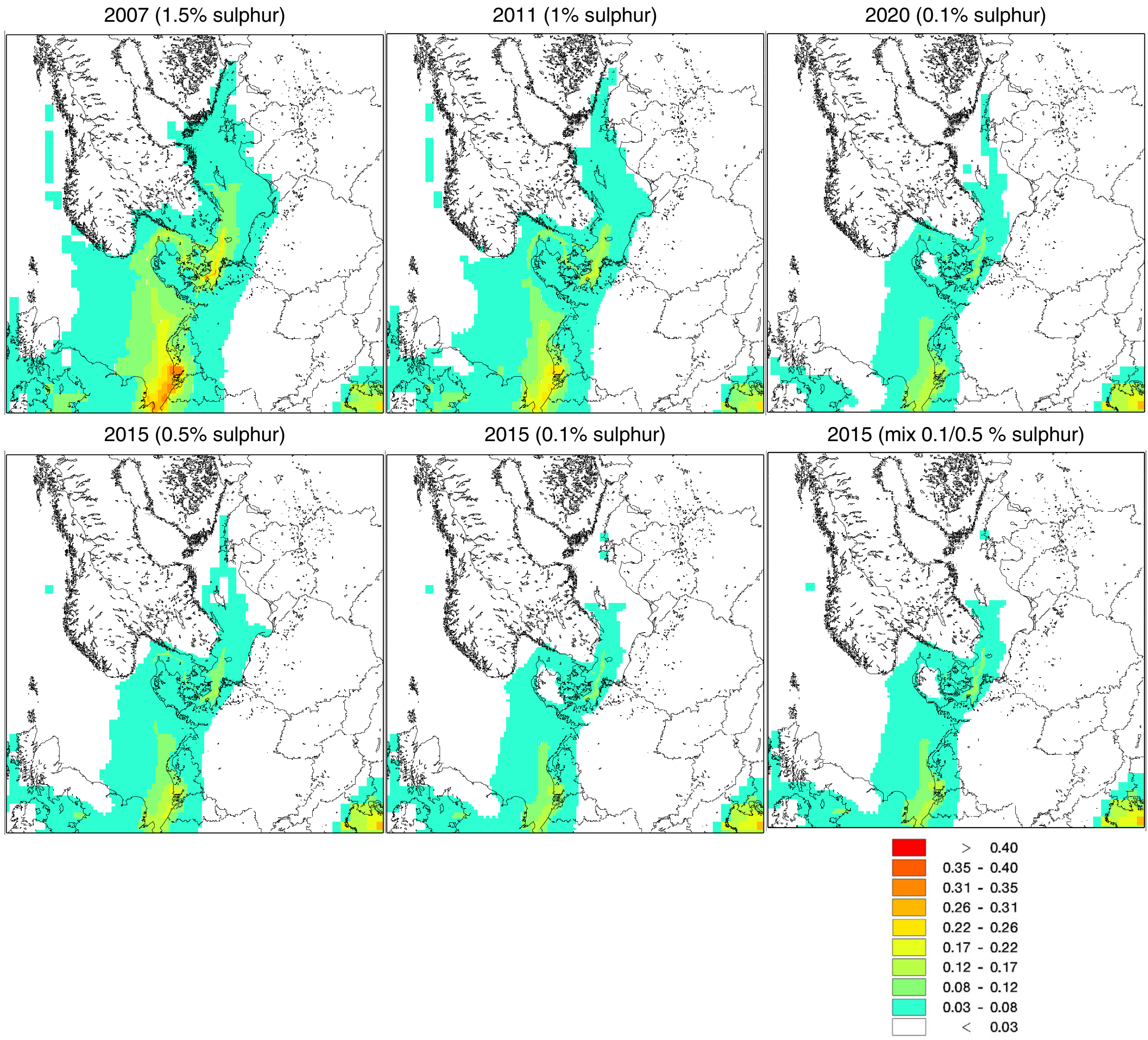

Figure 3.11. Concentration of primary $PM_{2.5}$ which can be attributed to ship emissions. Unit: $\mu g/m^3$. The upper row shows the situation in 2007, 2011 and 2020, while the lower is for 2015 with three different assumptions for sulphur level in fuel.

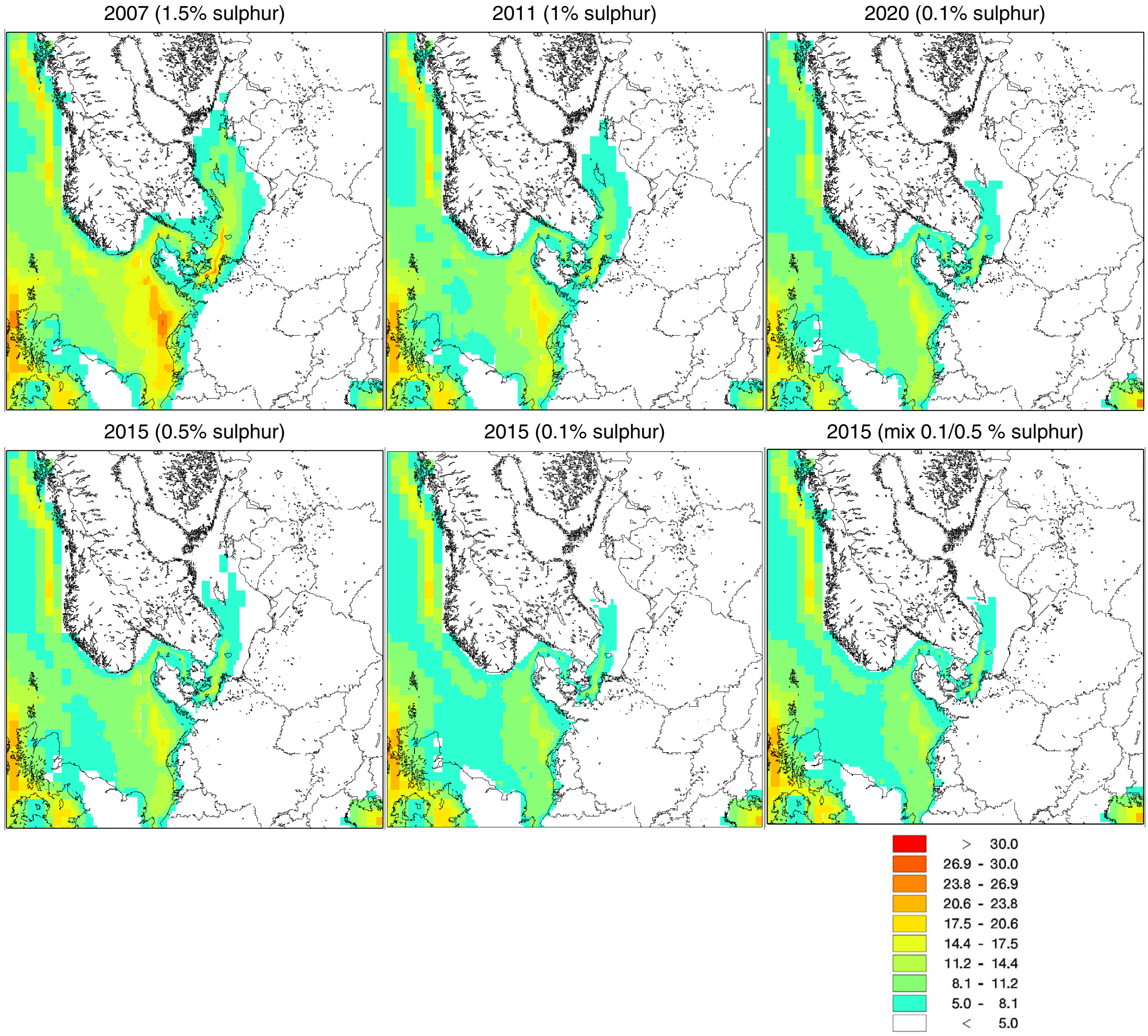

Figure 3.12. Relative contribution from ships to concentration of primary $PM_{2.5}$. This figure complements the above. Unit: percent.

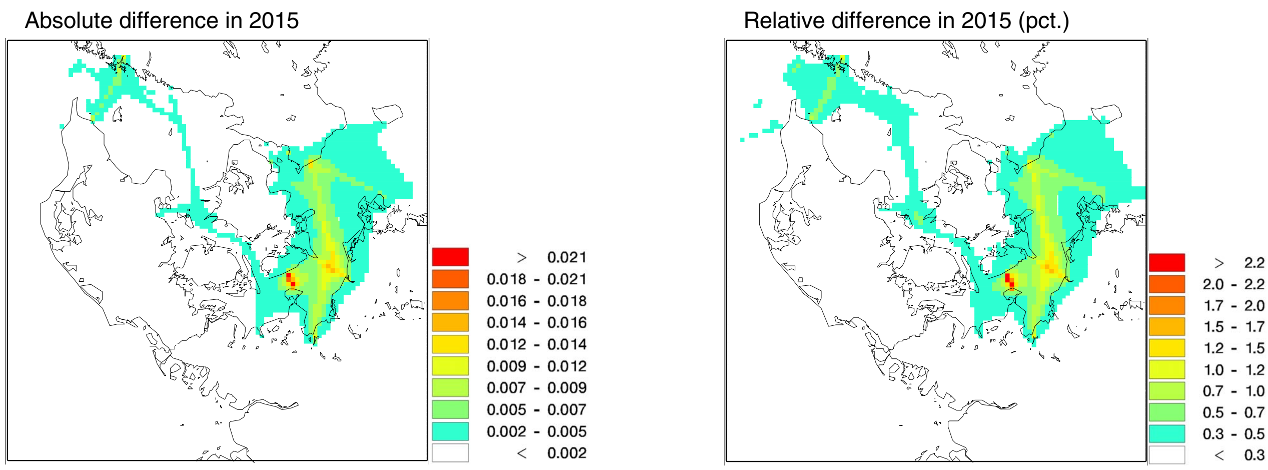

Figure 3.13. Difference between the Mixed profile and the Base profile in 2015 in terms of primary $PM_{2.5}$ concentrations. Left: concentrations in absolute numbers, i.e. $\mu g/m^3$; right: Relative difference in percent. 100% corresponds to the contribution from *all* sources according to the Base profile.

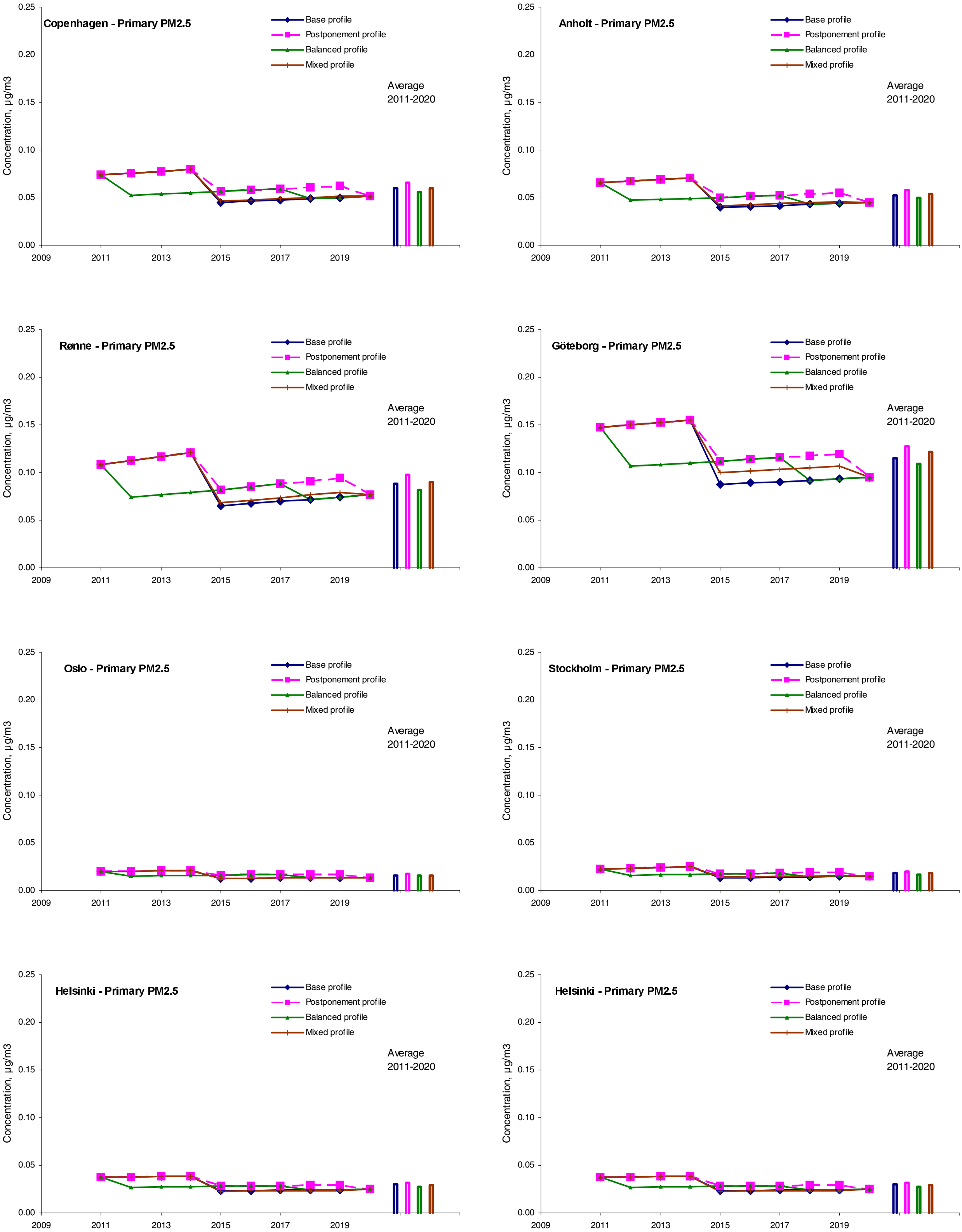

Figure 3.14. Contribution of primary $PM_{2.5}$ which can be attributed to ship emissions in a number of Scandinavian cities. The vertical bars indicate the average concentration over the period 2011-2020.

Primary $PM_{2.5}$ is a part of the total $PM_{2.5}$, which is illustrated in **Figure 3.10**. A comparison of the two figures reveals that the secondary particles constitute the major part of $mPM_{2.5}$. Note that the y axis has different scales in the two figures.

4 Conclusions

The study concerns different ways to proceed in the transition from the present level of maximum 1% sulphur in maritime fuel to a maximum level of 0.1% in 2020 in the North Sea and the Baltic Sea.

The trends in the period 2011-2020 for the concentrations of SO_2, primary $PM_{2.5}$ and $mPM_{2.5}$ (total $PM_{2.5}$ as modelled) have been calculated using NERI's air quality models for three different scenarios for a stepwise reduction of the sulphur content in fuel.

It is beyond the scope of this project to make direct calculations of the health impacts related to the future emissions for the ship traffic. Instead the concentrations of SO_2, primary $PM_{2.5}$ and $mPM_{2.5}$ originating from ship traffic have been used as an indicator for the health impact. This is based on the fact that the health impact to a good approximation is proportional to the concentrations. Most important is $mPM_{2.5}$ since the main health impact is associated with $PM_{2.5}$.

The two profiles for sulphur regulations *Base profile* and *Balanced profile* result in almost identical concentrations as an average over the ten years period 2011-2020. The main difference is the time development in the trends, were the Balanced profile gives stepwise reductions in 2012 and 2018, while the Base profile gives a single larger reduction in 2015.

The *Postponement profile* apparently results in slightly larger average concentrations compared to the Base profile and the Balanced profile. According to the Postponement profile the sulphur content is only reduced to 0.5% in 2015, while the full reduction to 0.1% is postponed to 2020. The delay in the full reductions of the emissions results in a delay in the reductions of concentrations. Thus, if we consider the contribution from ship traffic to $mPM_{2.5}$ in the Copenhagen area in the period 2011-2020 the Postponement profile leads to a concentration level which is 0.04 $\mu g/m^3$ higher than for the Base profile. This difference amounts to 6% of the contribution from ships, or to 0.8% of the contribution from *all sources*.

In the *Mixed profile* 29 specific shipping routes have been assumed to follow the postponement profile (implying 0.5% sulphur from 2015 to 2019), while the remaining fleet follows the accepted regulations. The 29 routes have been selected by the Danish Shipowners Association. The average concentrations over the ten year period 2011-2020 fall between those of the Base profile and the Postponement profile. Compared to the total pollution level the differences between the Base profile and the Mixed profile are small, but locally it is possible to distinguish effects on the concentrations due to the higher sulphur content used at some of the shipping routes. For example this can be observed in the area between Rødby and Puttgarden.

In general the differences between the scenarios stand most clearly out for concentration levels of SO_2, while they are less pronounced for primary $PM_{2.5}$, and smallest for $mPM_{2.5}$. This reflects that the share of the concentrations that originate from ship traffic is generally higher for SO_2

than for primary $PM_{2.5}$. For instance in Copenhagen, about 19% of the total concentrations of SO_2, respectively 3% of primary $PM_{2.5}$ originate from ship traffic. As to $mPM_{2.5}$, in Copenhagen around 13% of $mPM_{2.5}$ can be attributed to ship traffic. However, the fact that the contribution to $mPM_{2.5}$ from ships is due not only to sulphur emissions, but also to NO_X emissions has the effect that changes in fuel sulphur content lead to only relatively small changes to $mPM_{2.5}$.

The large impact that the scenarios have on SO_2 must be seen in light of the low concentrations calculated for SO_2. The ten year average of the contribution from ships to SO_2 concentration in Copenhagen (about 0.1 $\mu g/m^3$) is less than 0.1% of the EU limit value for the diurnal concentration (125 $\mu g/m^3$). Although the averaging times are not comparable this illustrates that the level of concentrations calculated for SO_2 is low.

The study shows that there are large spatial variations in the impact of the different scenarios. The largest difference between the scenarios is seen for cities where the ship traffic is dense and close to the coast. The largest health impact will therefore be in the main cities with high density of ship traffic (i.e. Copenhagen and Gothenburg).

The project concerns the trends for SO_2 and $PM_{2.5}$ during the period form 2010 to 2020 under different scenarios for regulation of the sulphur content in maritime fuel. Other direct or indirect effects related to change in sulphur content (i.e. other changes in the quality of maritime fuel) have not been studied during this project.

The results show a slight increase in the concentrations of SO_2, primary $PM_{2.5}$ and $mPM_{2.5}$ for periods with constant sulphur content in maritime fuel. This is due to the expected increase in ship traffic. This has been assumed to increase with 3.5% annually during the period from 2011 to 2020 (Olesen et al., 2009).

The scenarios for the land-based European emissions have been based on the assumption that new and reduced national emissions ceilings will be adopted in EU for 2020 (Olesen et al., 2009). However, the negotiations concerning the new emission ceilings have been postponed, and currently it is therefore uncertain how large the future reductions of the land-based emission will be. The new emission ceilings will not have impact on the concentrations of SO_2, primary $PM_{2.5}$ and $mPM_{2.5}$ originating from ship traffic. However, they will have impact on the relative share of air pollution originating from ship traffic compared to the total air pollution from all sources.

5 References

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Appendix A

Ship routes relevant for scenario with mixed profile

DANMARKS REDERIFORENING
(DANISH SHIPOWNERS' ASSOCIATION)

Project on assessment of the impact of alternative regulations of the sulphur content in maritime fuel
Mixed profile (Data for 2007)

Ro-ro ships and ferries on regular routes to be allowed to follow.the postponement profile

1	Frederikshavn - Læsø, Færgeselskabet Læsø I/S	
	Ane Læsø	IMO No 7909437
	Margrete Læsø	IMO No 9139438
2	Kalundborg – Århus, Mols Linien	
	Maren Mols	IMO No 9112765
	Mette Mols	IMO No 9112777
3	Køge - Rønne, Bornholmstrafikken	
	Dueodde	IMO No 9323704
	Hammerodde	IMO No 9323699
4	Rødby – Puttgarden, Scandlines	
	Deutschland	IMO No 9151541
	Holger Danske	IMO No 7432202
	Prins Richard	IMO No 9144419
	Prinsesse Benedikte	IMO No 9144421
	Schleswig-Holstein	IMO No 9151539
5	Gedser – Rostock, Scandlines	
	Kronprins Frederik	IMO No 7803205
	Prins Joachim	IMO No 7803190
6	Copenhagen – Oslo, DFDS	
	- Crown of Scandinavia	IMO No 8917613
	- Pearl of Scandinavia	IMO No 8701674
7	Frederikshavn – Larvik, Color Line	
	Peter Wessel	IMO No 7826790
8	Frederikshavn – Oslo, Color Line	
	Color Festival	IMO No 8306486
9	Hirtshals – Kristiansand, Color Line	
	Christian IV	IMO No 8020642

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E-mail: info@shipowners.dk

10	Hirtshals – Larvik, Color Line	
	Peter Wessel	IMO No 7826790
11	Hirtshals – Oslo, Color Line	
	Prinsesse Regnhild	IMO No 7904891
12	Hirtshals – Stavanger – Bergen, Color Line	
	Prinsesse Ragnhild	IMO No 7904891
13	Hanstholm – Egernsund – Haugesund – Bergen, Fjord Line	
	Atlantic Traveller	IMO No 9058985
	Lygra	IMO No 7704629
14	Hirtshals – Langesund, Kystlink	
	Fantaasia	IMO No 7807744
	Pride of Telemark	IMO No 7907257
15	Esbjerg – Tananger, Sea-Cargo AS	
	Amber	IMO No 8917871
	Lygra	IMO No 7704629
	Nordia	IMO No 5255951
16	Frederikshavn – Oslo, Stena Line	
	Stena Saga	IMO No 7911545
17	Frederikshavn – Gøteborg, Stena Line	
	Stena Danica	IMO No 7907245
	Stena Jutlandica	IMO No 9125944
	Stena Scanrail	IMO No 7305772
18	Grenå – Varberg, Stena Line	
	Stena Nautica	IMO No 8317954
19	Rønne – Ystad, Bornholmstrafikken	
	Povl Anker	IMO No 7633143
20	Kiel – Oslo, Color Line	
	Color Fantasy	IMO No 9278234
	Color Magic	IMO No 9349863
	Kronprins Harald	IMO No 8506311
21	København – Swinoujscie, Polferries	
	Pomerania	IMO No 7516761

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22 Kiel – Gøteborg/Travemünde - Gøteborg, Stena Line

Stena Germanica	IMO No 9145176
Stena Scandinavia	IMO No 7907661
Stena Carrier	IMO No 9138800
Stena Freighter	IMO No 9138795

23 Malmø – Travemünde, Finnlines NordöLink

Europalink	IMO No 9319454
Finnpartner	IMO No 9010163
Finntrader	IMO No 9017769
Lübeck Link	IMO No 7822859
Malmö Link	IMO No 7822861
Nordlink	IMO No 9336256

24 Travemünde – Trelleborg

Scandlines

Götaland	IMO No 7229514

TT-Line

Nils Dacke	IMO No 9087477
Nils Holgersson	IMO No 9217230
Peter Pan	IMO No 9217242
Robin Hood	IMO No 9087465

25 Sassnitz – Trelleborg, Scandlines

Sassnitz	IMO No 8705383
Trelleborg	IMO No 7925297

26 Rostock – Trelleborg

Scandlines

Mecklenburg/Vorpommern	IMO No 9131797
Skåne	IMO No 9133915

TT-Line

Huckleberry Finn	IMO No 8615358
Tom Sawyer	IMO No 8703232

27 Swinoujscie – Trelleborg, Unity Line

Galileusz	IMO No 9019078
Gryf IMO No 8818300	
Wolin	IMO No 8420842

28 Swinoujscie – Ystad, Unity Line

Jan Sniadecki	IMO No 8604711

	Kopernik	IMO No 7527887
	Mikolaj Kopernik	IMO No 7336721
	Polonia	IMO No 9108350
29	Sandefjord – Strömstad, Color Line	
	Bohus	IMO No 7037806
	Color Viking	IMO No 8317942

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ASSESSMENT OF THE IMPACT OF ALTERNATIVE REGULATIONS OF THE SULPHUR CONTENT IN MARITIME FUEL

The present study follows up on a previous study on assessment of the contribution from ships to air pollution in Denmark. According to IMO regulations the maximum allowed sulphur content in maritime fuel is reduced over time for ships sailing in the waters surrounding Denmark. The study compares the impact on air pollution for several alternative ways to proceed in the transition from the present level of maximum 1% sulphur in maritime fuel to a maximum level of 0.1% in 2020.

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