Impact on the EU of SO_x, NO_x and primary $PM_{2.5}$ emissions from shipping in the Mediterranean Sea: Summary of the findings of the Euro Delta Project

Prepared by the CONCAWE Air Quality Management Group's Special Task Force on Ship Emissions (AQ/STF-67)

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Note: This report is based on work undertaken in the context of the second phase of the Euro Delta Project. CONCAWE acknowledges the work of all five modelling teams and the work of the European Commission's Joint Research Centre in Ispra in co-ordinating the input data and consolidating the results.

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ABSTRACT

This report discusses the outcome of modelling scenarios comparing the impact of emissions from ships in different areas of the Mediterranean with those from land based emissions. The modelling uses the results of a recent emission inventory for the Mediterranean Sea and the modelling structure developed for the wider "Euro Delta" project.

For the Mediterranean Sea as a whole, the emission potencies for exposure of EU populations to fine particulates are found to be significantly lower (by a factor of about five or more) than emissions from land based sources. Only for "adjacent to shore" Mediterranean Sea scenarios do the emission reduction potencies approach those of land based measures. This has important implications for the development of cost-effective abatement strategies.

These results are in good agreement with data from the RAINS/GAINS model used in the integrated assessment modelling of EU air quality. Comparison of the two sets demonstrates that the situation in the Mediterranean is very different to that of the North Sea or Baltic where emission potencies are often similar to those of land based sources (e.g. for Germany and the UK). They further confirm that for other impacts (e.g. ozone impacts on human health; acidification and eutrophication), the potency of contributing emissions from the Mediterranean Sea is also extremely low (a factor of about ten) compared to land based sources and the emissions from shipping in the North Sea and Baltic.

KEYWORDS

Air quality, particulate matter, sulphur, acidification, eutrophication, ship emissions, ozone

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SUMMARY

In both a European and Worldwide context, emissions from international shipping have become an important focus area in the development of further policies to address concerns over human health and the environment. This has been driven by the significant reductions in emissions from land based sources in many parts of the world, particularly over the past decade, and the increase in ship emissions resulting from the growth in international trade. As a consequence, at least in the European Union, ship emissions of both SO_2 and NO_x in adjacent seas are foreseen to overtake land based sources by 2020 unless further action is taken.

In response to such concerns, a revision process of IMO's MARPOL Annex VI was initiated by IMO's Marine Environmental Protection Committee in July 2005. A "Scientific Review Group" was established in July 2007 with the aim of informing the revision process which is expected to be completed during 2008.

With a view to contributing to this revision process, CONCAWE sponsored the development of an updated emission inventory for ships operating in the Mediterranean Sea. In the context of a larger project "Euro Delta Phase 2", this new inventory was used to explore a number of "Mediterranean Sea" emission reduction scenarios to be compared to the land-based scenarios already developed as part of the project. The main purpose of this work was to contribute to the further understanding of the crucial relationship between the proximity of emission sources (in this case ships) and vulnerable receptors (whether human beings or ecosystems). Such understanding is essential for designing efficient policy responses and underpinned the original drafting of Annex VI, particularly in creating the SECA (Sulphur Emission Control Area) concept.

The Euro Delta results examined in this report, clearly demonstrate the importance of the spatial proximity of emissions to sensitive receptors. "Emission potencies" (impact per mass unit of emission) generated in this work provide a clear perspective on the relative cost effectiveness of emission reductions and are seen to vary significantly with the proximity of the emitter to the sensitive receptor.

The detailed Euro Delta results indicate that for the Mediterranean Sea as a whole, the emission potencies for exposure of EU populations to fine particulates are lower by a factor of about five than emissions from land based sources. Only for "adjacent to shore" Mediterranean Sea scenarios (for example 0.1% sulphur limit alongside at berth) do the emission reduction potencies approach those of land based measures. This has important implications for the development of cost-effective abatement strategies.

The additional insight provided by the source-receptor relationships used within the RAINS/GAINS model confirms the findings of the Euro Delta project. In addition it demonstrates that the situation in the Mediterranean is very different to that of the North Sea or Baltic sea. In these latter cases emission potencies are often similar to those of land based sources (e.g. Germany and the UK).

The source-receptor functions also confirm that for other impacts (for example ozone impacts on human health; acidification and eutrophication), the potency of contributing emissions from the Mediterranean Sea is extremely low (a factor of about ten lower) compared to land based sources and the emissions from shipping in the North Sea and Baltic sea.

1. INTRODUCTION

In both a European and Worldwide context, emissions from international shipping have become an important focus in the development of further policies to address concerns over human health and the environment. This has been driven by the significant reduction in emissions from land based sources in many parts of the world, particularly over the past decade, and the increase in ship emissions resulting from the growth in international trade. As a consequence, at least in the European Union, ship emissions of both SO_2 and NO_x in adjacent seas are foreseen to overtake land based sources by 2020 unless further action is taken.

In the worldwide context, emissions from International shipping are currently regulated through the United Nations International Maritime Organisation (IMO). Annex VI (Air Pollution Annex) of the IMO's Marine Pollution Convention (MARPOL) sets a global sulphur limit for residual marine fuels of 4.5% m/m from May 2005. It also sets forth the concept of Sulphur Emission Control Areas (SECAs) which are designated sea areas where sulphur emissions from ships are limited to an equivalent maximum sulphur in the fuel of 1.5% m/m. Annex VI sets forth environmental, human health and cost-effectiveness criteria for the designation of a SECA. The Baltic and North Sea have already been designated as SECAs. The requirements for the Baltic Sea have been in force since May 2006 and the North Sea SECA status will come into force in November 2007. Annex VI also includes requirements of NO_x limits for new ships.

A revision process of Annex VI was initiated by IMO's Marine Environmental Protection Committee in July 2005. In this context, a "Scientific Review Group" was established in July 2007 with the aim of informing the revision process which is expected to be completed during 2008.

In the European context, the European Union (EU) has adopted a revision of the Sulphur Content of Liquid Fuels Directive SCLFD (see [1] for Directive numbers) which extends the 1.5% m/m sulphur limit to all ferries calling at any EU port (or the equivalent emission level via approved abatement technologies e.g. sea water scrubbers). This requirement came into effect in August 2006. The Directive also limits the sulphur content of fuel burnt while alongside at berth in EU ports to 0.1% m/m from January 2010. The Directive includes a revision clause whereby the future extension of SECAs and/or the toughening of sulphur limits within SECAs could be envisaged.

With this background, CONCAWE sponsored the development of an updated emission inventory for ships operating in the Mediterranean Sea. The results of this work have been separately reported [2]. In the context of a larger CONCAWE sponsored project "Euro Delta Phase 2", this new inventory was used to explore a number of "Mediterranean Sea" emission reduction scenarios. The main purpose of this work was to contribute to the further understanding of the crucial relationship between the spatial proximity of emission sources (in this case ships) and vulnerable receptors (whether human beings or ecosystems).

It is well understood that it is not magnitude of emissions per se that define the "size" of an environmental or human health concern, but rather the impact such emissions have on sensitive receptors. Such understanding is crucial in designing efficient policy responses and underpinned the original drafting of Annex VI, particularly in setting forth the SECA (Sulphur Emission Control Area) concept.

2. THE EURO DELTA PROJECT

2.1. PROJECT DESIGN

The Euro Delta project (ED Phase I) was initially designed as an inter-comparison exercise between five European Trans-boundary air pollution models/modelling teams iin order to explore the variability in results from the different models for the same emission scenarios and the implications for robust policy design. Included in the five models was the EMEP model[1] which, up to the present time, has been the sole model used to support policy development at both the EU and wider UN-ECE level. The more recent availability/maturing of similar "Eulerian Models" in France (the CHIMERE model[2]), Germany (the REM-3 model[3]), The Netherlands (the LOTOS model[4]) and Sweden (the MATCH model[5]) triggered such a project. The Commission's Joint Research Centre in Ispra, Italy acted as co-ordinators of this project as well as a clearing house for all the modelling results. In this context they developed a unique software application the "JRC Toolkit" to provide for ready inter-comparison, analysis and visualisation of the results.

The second phase of the project (ED Phase II) benefited from the learnings of the first phase (particularly the need for careful quality control of input data e.g. emissions) and explored a larger number of further emission reduction scenarios. The majority of these were "terrestrial" scenarios, but given the current focus within the IMO on the revision of MARPOL Annex VI, the opportunity was taken to include a number of key Mediterranean Sea emission reduction scenarios. This element of the project also benefited from the availability of the recent Mediterranean Sea emission inventory study sponsored by CONCAWE. This work is further elaborated below.

2.2. EMISSION INVENTORY

The emission inventory for terrestrial sources used in the Euro Delta study was that used by the European Commission for their work under the "Clean Air For Europe" (CAFE) programme which resulted in the publication of their Thematic Strategy on Air Pollution[6]. The policy horizon year for this work and hence the inventory was 2020, although consistent data was also available for 2010.

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[1] The EMEP model is an Eulerian trans-boundary air pollution model for the European region developed by the Norwegian Meteorological Institute

[2] The CHIMERE model is an Eulerian trans-boundary air pollution model for the European region maintained by INERIS. It is extensively used in France to forecast air pollution.

[3] The REM-3 model is an Eulerian trans-boundary air pollution model for the European region developed and maintained by the Free University of Berlin. It is regularly used in Germany to support national policy development

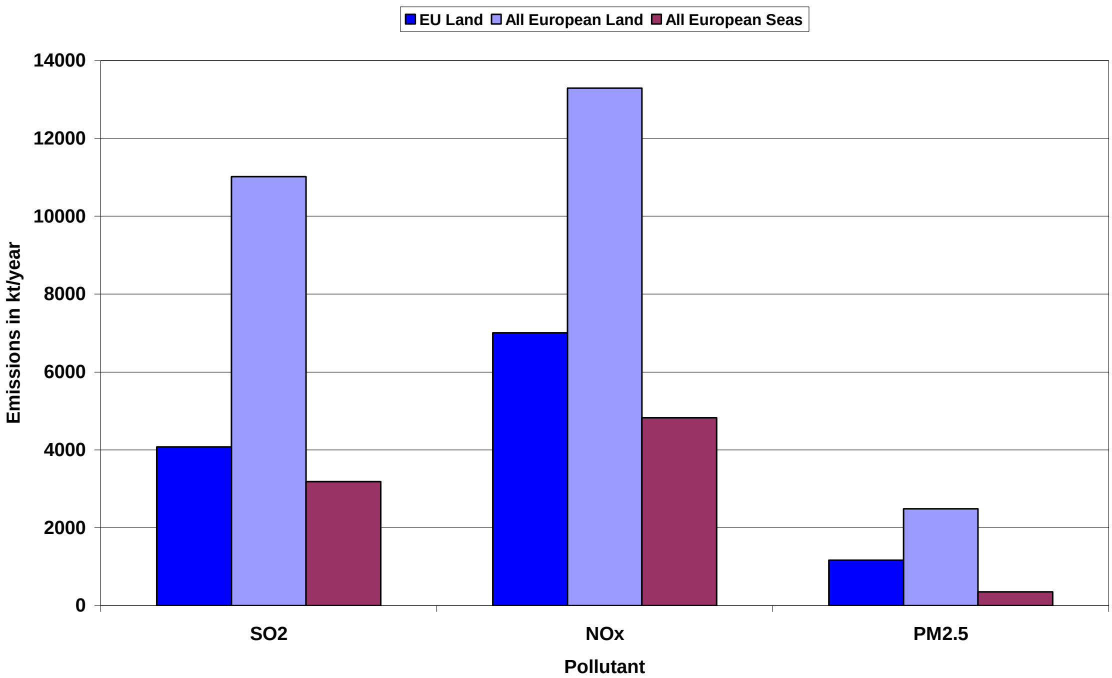
[4] The LOTOS model is an Eulerian trans-boundary air pollution model for the European region developed and maintained by the TNO in The Netherlands

[5] The MATCH model is an Eulerian trans-boundary air pollution model for the European region developed and maintained by the SMHI in Sweden. It is regularly used in Sweden and Scandinavia to support national/regional policy development

[6] The Thematic Strategy on Air Pollution (TSAP) was formally adopted by the European Commission in September 2005.

Figure 1 provides a comparison of SO_2, NO_x and primary[7] $PM_{2.5}$ emissions from European land and sea areas in the 2020 time horizon. The data shown here reflect the updated inventories currently being used for the technical analysis in support of the European Commission's planned update of the National Emission Ceilings Directive. The land areas include the non-EU European countries such as the Ukraine, Belarus and Russia (west of the Urals). The sea area emissions include the North Sea, Baltic Sea, Black Sea, Mediterranean Sea, and Atlantic Approaches.

Figure 1 Emissions In European Region In 2020



(Source: IIASA Official Data For Revision of NECD)

In order to provide an up to date ship emission inventory for the Mediterranean Sea, the study recently completed for CONCAWE by the environmental and engineering consultancy ENTEC UK Ltd was also used. ENTEC have been involved in a number of previous such studies and, in their own view, this has resulted in a more robust inventory for the Mediterranean than was the case in their earlier work.

A key objective of this study was to provide a more accurate, detailed and complete inventory than had hitherto been the case. The input data and methodology were specifically reviewed to fulfil these ambitions. The key new elements were:

[7] Primary $PM_{2.5}$ emissions refer to the mass of carbonaceous or hydrocarbon emissions generated from the incomplete combustion of the hydrocarbon fuel. It specifically excludes any sulphate aerosols generated between the "engine out" emissions and the measuring point in the exhaust e.g. the acid aerosol derived from conversion of SO_2 to SO_3 in the combustion process. The presence of such aerosols is highly dependent on the PM measuring technique used. Air quality modelling separately accounts for this sulphate formation in modelling the atmospheric chemistry.

- Use of the 2005 vessel movements and characteristics data provided by Lloyds Marine Intelligence Unit (LMIU). This latest ship movement database includes some significant improvements over the 2000 LMIU data base used by ENTEC in their previous studies, e.g. more accurate vessel arrival and departure times and vessel-specific engine power data for main and auxiliary engines. In addition, a full year of ship movements data was obtained from Lloyds rather than the "four months" of data used in previous studies.
- Manual addition of approximately 100,000 passenger vessel movements (focussing largely on Greek port callings) using detailed company timetables. This was done to overcome the limitations of the LMIU data base where multiple port calls within a single day are not recorded.
- Improved routing algorithms for individual point to point journeys based on the enhanced information in the latest LMIU data base.
- Use of a much finer "near shore" grid resolution (10x10 km) than the EMEP 50x50 km gridding used in previous studies. A key reason for using finer resolution gridding near shore was to enable emissions within "territorial waters" (12 nautical miles) to be determined accurately.
- Improved methodology for determining the time a ship spends in port based on the more detailed arrival/departure time data included in the latest LMIU database.
- Use of a more robust methodology for determining the relative percentages of gas oil and heavy fuel oil in the total fuel consumed, resulting in figures essentially in-line with studies carried out by Beicip-Franlab for the EU Commission in 2002 and 2003[8]. It has been assumed that all distillate fuel used would be Marine Gas Oil (MGO), meeting the requirements of European legislation: the gas oil sulphur level was set at 0.2% for 2005 and 0.1% for 2010 and beyond. No attempt was made to assess the amount of Marine Diesel used. As Marine Diesel has a higher S level than MGO, the SO_2 emission contribution from distillate fuel use will be underestimated in the emission inventory.

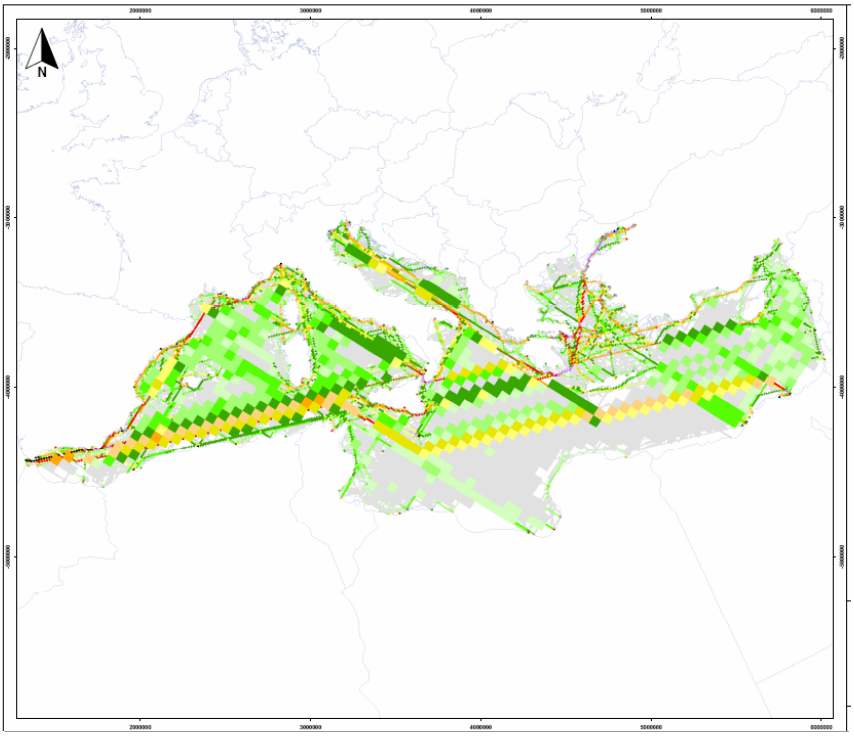
The resulting 2020 emission inventory for sulphur dioxide was found to be significantly lower than that used in the Commission's work associated with the revision of NECD; 1088 kt/a versus 1714 kt/a. For NO_x emissions the differences were found to be smaller; 1771versus 2311kt/a.

Emission intensity map

To provide an overall perspective on the spatial distribution of emissions, the resulting emission intensity map (tonnes of SO_2 emissions per km^2) for the base year of 2005 is shown in **Figure 2**. The high activity within coastal areas of the Mediterranean is readily seen in the finer near-shore grids. Also visible is the impact of the large number of "transit" ships sailing between Suez and Gibraltar.

[8] Advice on the costs to fuel producers and price premia likely to result from a reduction in the level of sulphur in marine fuels marketed in the EU (April 2002). Advice on marine fuels (October 2003). Contract EN.C1/SER/2001/0063

Figure 2 Base Case 2005 SO_2 Inventory



2.3. SCENARIOS EXPLORED

Although there has been a great deal of concern expressed over the growing relative contribution to emissions from worldwide shipping, little new quantitative work has been undertaken to inform the ongoing technical discussions on the crucial relationship between the proximity of emission to vulnerable receptors and the impact of those emissions on these receptors. That is, as a ship sails away from land into open waters, at what point do emissions have a diminishingly small impact on sensitive receptors or at what point does their control become non-cost-effective compared to other options?

Furthermore, since the development of MARPOL Annex VI, where the emphasis was on acidification, there has been growing concerns over the impact on human health from exposure to fine particulates. Both primary particulates (formed in the combustion process) and so-called secondary particulates (those particles formed from SO_2 and NO_x in subsequent chemical reactions in the atmosphere) contribute to overall levels. An understanding of the spatially disaggregated contribution of ship emissions to this "new" priority concern is an important element to inform the discussion on the revision of Annex VI as well as the upcoming review of the EU Directives related to marine fuels Directive [1].

With these aspects in mind, the following Mediterranean Sea scenarios were explored in Euro Delta Phase II:

2010 Time Horizon Scenarios: With a view to quantifying the impact of recent EU legislation targeted on shipping in the European Area (the amended SCLFD), the following three scenarios were explored:

- **Scenario 1: 2010 Baseline**: Accounting for the impact of existing EU legislation on emissions from terrestrial sources; this scenario assumes the entry into force of SECAs for both the Baltic and North Seas but with EU Ferries operating in the Mediterranean Sea at an average sulphur content of 2.7% sulphur and no specific in-port restrictions beyond current.

- **Scenario 2: 2010 Baseline + EU Ferries now at 1.5% sulphur consistent with the SCLFD.**

- **Scenario 3: 2010 Baseline+0.1% Sulphur limit in EU ports when alongside at berth:** This scenario was explored separately from the ferry requirements of the SCLFD in order to quantify the impact of this "next to shore" emission reduction compared to other "near shore" and "at sea" scenarios.

2020 Time Horizon Scenarios: This time horizon is consistent with the policy horizon of the EU's Thematic Strategy on Air Pollution. The following Mediterranean Sea Scenarios were explored:

- **Scenario 4: 2020 Baseline:** Accounting for the impact of existing EU legislation on emissions from both Terrestrial and Marine sources (including the maintenance of SECAs for the Baltic and North Seas, the 1.5% sulphur fuel for ferries and the 0.1% sulphur fuel requirement while alongside at berth) together with emission changes due to changes in energy demand (including growth in shipping) and energy supply.

- **Scenario 5:** As scenario 4 (2020 Baseline), but with a reduction in the assumption for ship emission growth from the base case level of 2.7% sulphur per year to 2% per year.

- **Scenario 6:** As scenario 4 (2020 Baseline), but assuming the Mediterranean Sea as a whole meets the requirements of a SECA under MARPOL Annex VI.

- **Scenario 7:** As scenario 4 (2020 Baseline), but assuming ships sailing within the 12 nautical miles of territorial waters of the EU comply with a maximum sulphur content in fuel of 1.5%.

- **Scenario 8:** As scenario 7, but allowing derogation from the 1.5% sulphur requirement through the Gibraltar Straits. This scenario was specifically designed to explore the environmental consequences of avoiding a fuel switch for the short journey through the straits were the 12 mile territorial waters restrictions are in force.

- **Scenario 9:** As scenario 4 but with only the Aegean Sea as a SECA under MARPOL Annex VI.

- **Scenario 10:** As scenario 4, but assuming an additional 40% reduction in NO_x emissions from ships operating in the Mediterranean. This was designed as a reasonable surrogate for the case where new build ships would be required to have SCR[9] control for NO_x i.e. penetration of new ships with SCR into the overall fleet operating in the Mediterranean by 2020 would be equivalent to an overall fleet reduction in NO_x of 40% from the Baseline Case.

[9] Selective Catalytic Reduction, a NO_x abatement technology

3. RESULTS

3.1. CONCENTRATION MAPS FOR VARIOUS SCENARIOS EXPLORED

The following series of maps derived from the EMEP model for the scenarios already described in section 2.3 above are shown as "$PM_{2.5}$ concentration change per unit of emission change (that is, per kilotonne of the component changed in the scenario at hand)". Since emission reduction costs are generally given as "cost per unit of emission reduction" (€ per kilotonne), this "emission potency" metric provides a direct link to cost-effectiveness. For ready comparison all the charts are on the same scale. For completeness, the corresponding "absolute concentration change" maps are given in **Appendix I**

Figure 3 and **4** shows, in a 2010 time horizon, the effect of meeting the requirements under the amended EU SCLFD, all ferries to use fuel with a maximum sulphur content of 1.5%and ships alongside at berth to use fuel with a maximum sulphur content of 0.1%. To appreciate the relative contribution of each of these requirements they have been separated into two separate scenarios: Figure 3 shows the impact of the ferries at 1.5% sulphur and Figure 4, the ships alongside at berth requirement of 0.1% . Comparison of the two maps shows the high effectiveness of the "adjacent to shore measure" of a maximum sulphur content in fuel of 0.1% alongside at berth.

Figure 5 shows the results, in a 2020 time horizon, of the effect of limiting all ships in EU Territorial Waters to a maximum fuel sulphur content of 1.5% (Scenario 7) compared to the 2020 Base Case (Scenario 4). **Figure 6** shows the incremental effect of moving from this case to the whole of the Mediterranean as a SECA. It is clear from these two figures, that the EU Territorial Waters only case offers a much more cost effective step than the increment to a full SECA. i.e. The reductions in $PM_{2.5}$ concentrations along coastal land areas per unit emission reduction is significantly higher in the former than the latter case.

Further, comparison of **Figure 5** with **Figure 4** (the 2010 "in port" limit of 0.1%) indicates that this already mandated measure is more cost-effective than the "Territorial Waters SECA" with significantly higher reductions in concentrations of $PM_{2.5}$ per unit of emission in the highly populated areas of northern Italy and southern France. The actual "emission potency" values in these localised areas are reaching 1-2 nanogram per m^3 per kilotonne ($ng/m^3/kt$), which, as we will see in section 3.2 below, are similar to the potencies of land measures. In the case of the Mediterranean port areas themselves, even higher potencies are apparent in **Figure 4**.

It is also worth noting from **Figures 5** and **6** that the large changes in concentrations per unit of emission reduction are achieved by the "*Territorial Waters SECA"* and the increment to *"Full Mediterranean SECA"*, but these occur over the sea and not EU land areas, thus not impacting populations.

Figure 3 Change in Annual Mean $PM_{2.5}$ Concentration ng/m^3/kt From 2010 Base (S1) to EU Ferries meeting the SCLFD (S2)

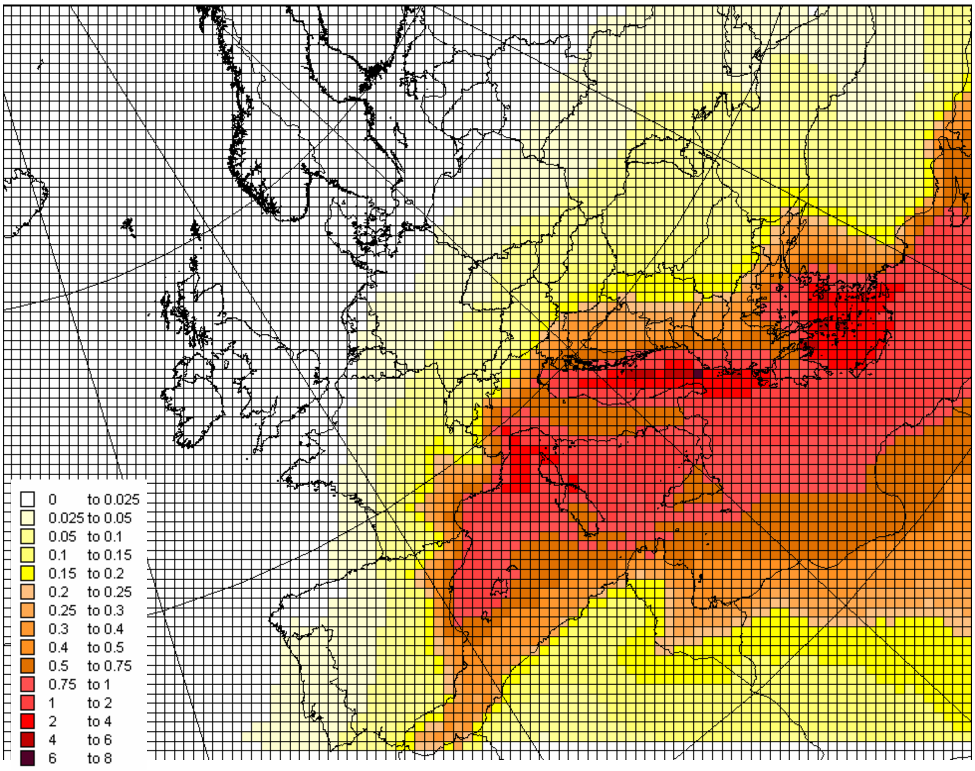


Figure 4 Change In Annual Mean $PM_{2.5}$ Concentration ng/m/kt From 2010 Base (S1) to all Ships Visiting EU Ports meeting SCLFD (S3)

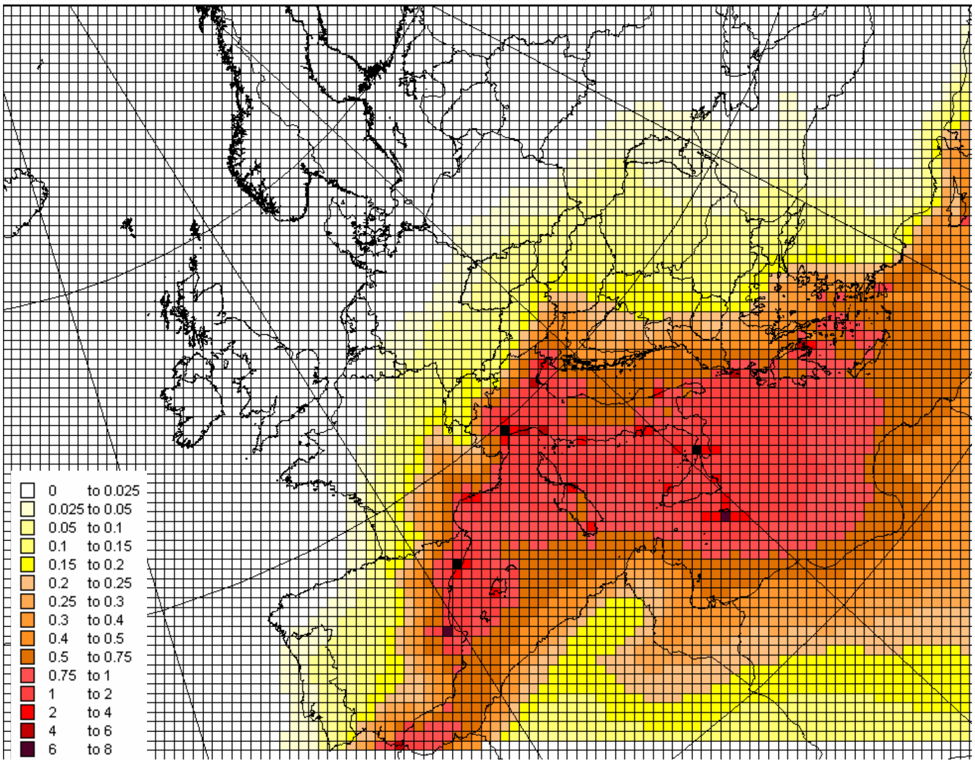


Figure 5 Change in Annual Mean $PM_{2.5}$ Concentration ng/m^3/kt From 2020 Base (S4) to EU Territorial Waters "SECA" (S7)

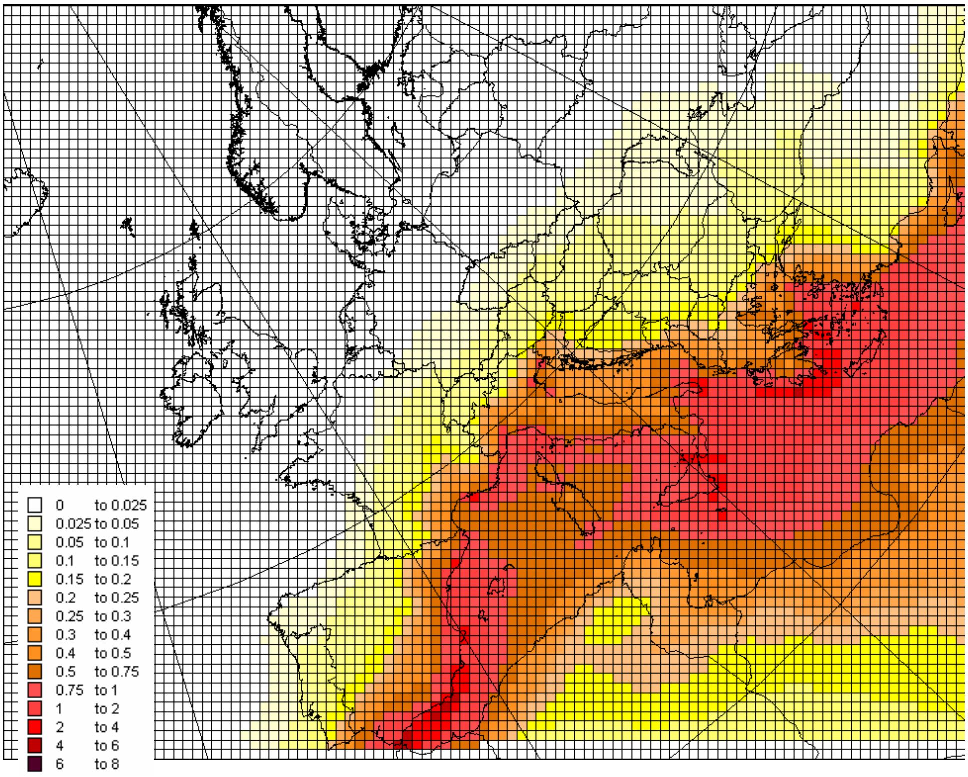
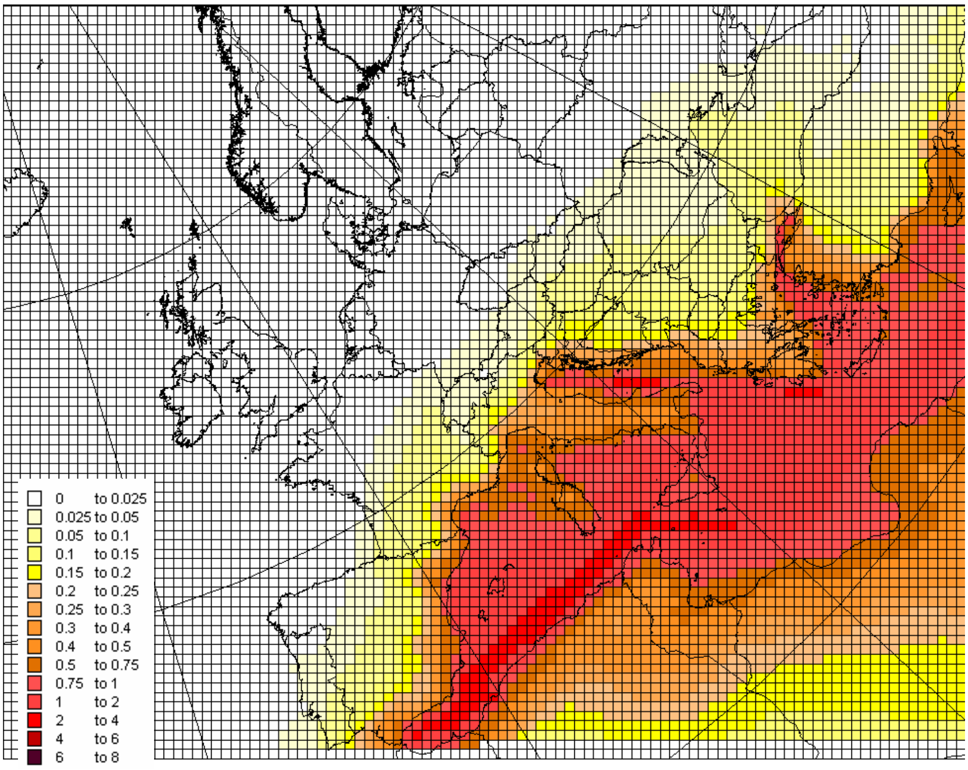


Figure 6 Change In Annual Mean $PM_{2.5}$ Concentration ng/m^3/kt From 2020 EU Territorial Waters only as "SECA" (S7) to all Med SECA (S6)



3.2. SEA VERSUS LAND BASED EMISSION REDUCTIONS

As outlined in section 2, Phase II of the Euro Delta project not only included Mediterranean Sea emission reduction scenarios but also a significant number of land based scenarios. MARPOL Annex VI, Appendix III requires an application for designation of a sea area as a SECA to include data on *"… the relative costs of reducing sulphur deposition from ships when compared with land based controls"* (Para 3.3). To provide such a comparison in the context of the Mediterranean Sea, at least on the *"effectiveness of impact reduction per unit of emission reduction"* the results of four land based SO_2 emission reduction scenarios from Euro Delta have been converted into similar maps (on the same scale) to those given for the Mediterranean Sea Scenarios in 3.1 above.

Figure 7 through 10 show the resulting maps for SO_2 emission reduction scenarios in France, Spain, Germany and the UK. The first observation to make from all four maps is that the "emission potency" (the concentration change per mass unit reduction in SO_2 emissions) is above 1 ng/m^3/kt across the whole country where the emission reduction is made. This means this level of potency will affect the majority of the populations in these countries. The only exception to this is France where such high potencies are seen only in the northern half and east side of the country. When compared to the emission potency maps of Mediterranean Sea ship emission reduction scenarios in **Figures 3** through **6**, the differences are very obvious, with such high potencies confined to the Mediterranean coastal areas.

With a focus on health impacts from exposure to fine particulates, this has significant implications for the relative cost effectiveness of ship emission reductions in Mediterranean Sea compared to alternative land based emission controls. For example, if the "emission potency" of land based SO_2 emissions in Germany are generally 5-7 times higher than the emission potency of Mediterranean Sea emissions, then, unless the cost of reducing a unit of SO_2 emissions from ships is 5-7 times lower than a unit reduction in land based sources in Germany, the ship measure would not be cost-effective compared to the alternative land based measure.

This situation becomes clearer when the results shown in the individual maps are population weighted and integrated. **Figures 11** and **12** show the resulting comparisons in emission potencies between the Mediterranean Sea scenarios and the four country land based scenarios, now for both SO_2 and NO_x emissions

Figure 11 shows the SO_2 scenarios comparison. Here all five Euro Delta modelling results are shown. While there are differences in responses between the models, the general pattern is the same and shows the significant difference in emission potency between land and Mediterranean Sea scenarios. The factor of five between potency of emissions from the Mediterranean Sea as a whole and those from land based sources in Germany as seen in the maps, are confirmed by this "integrated" view. In other words, for SO_2 abatement measures in the Mediterranean Sea as a whole (that is, its designation as a SECA) to be cost-effective in reducing exposure to fine particulates, such measures would need to be five times cheaper per tonne SO_2 removed than SO_2 reduction measures on land based sources in Germany.

Figure 7 Change in Annual Mean $PM_{2.5}$ Concentration ng/m^3/kt
2020 Base to SO2 Reduction from Land Based Sources in France

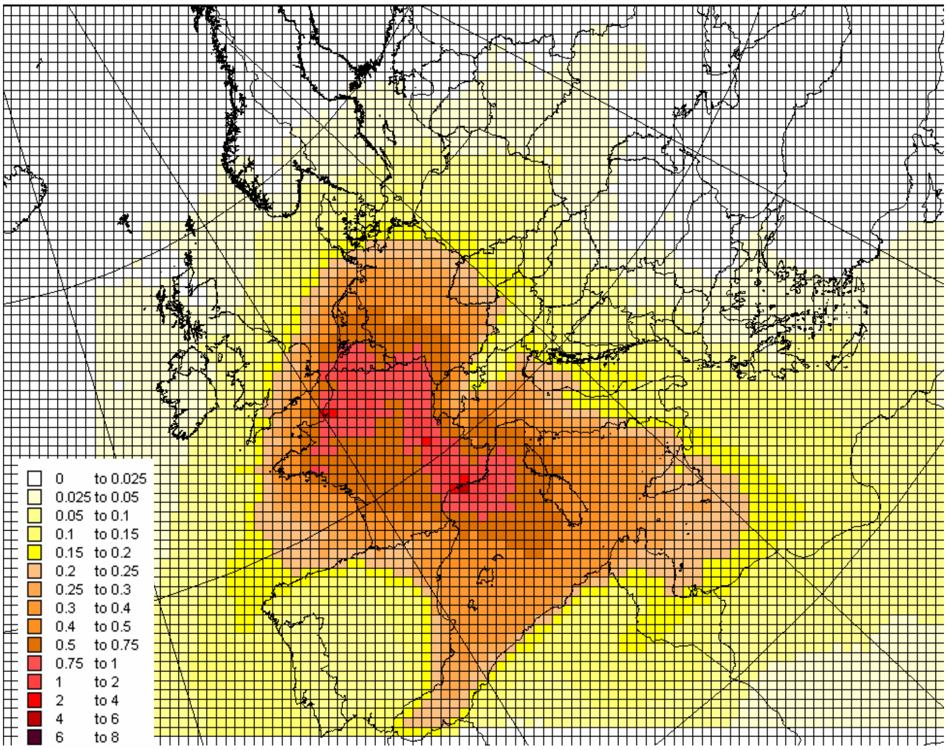


Figure 8 Change In Annual Mean $PM_{2.5}$ Concentration ng/m^3/kt
2020 Base to SO2 Reduction from Land Based Sources in Spain

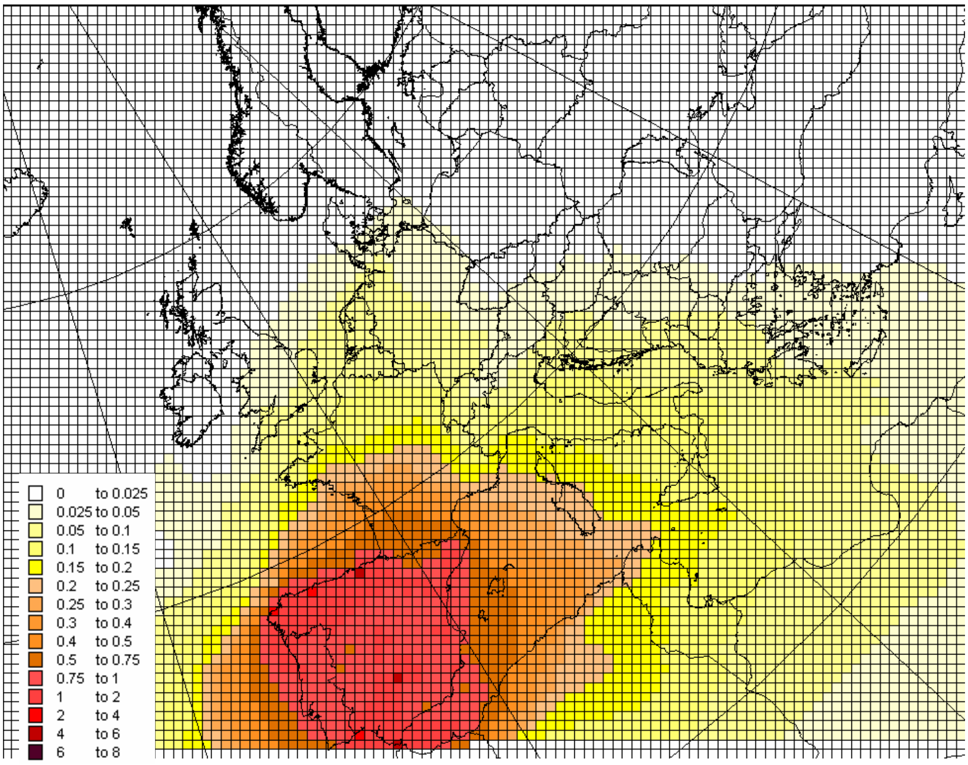


Figure 9 Change in Annual Mean $PM_{2.5}$ Concentration ng/m^3/kt
2020 Base to SO2 Reduction from Land Based Sources in Germany

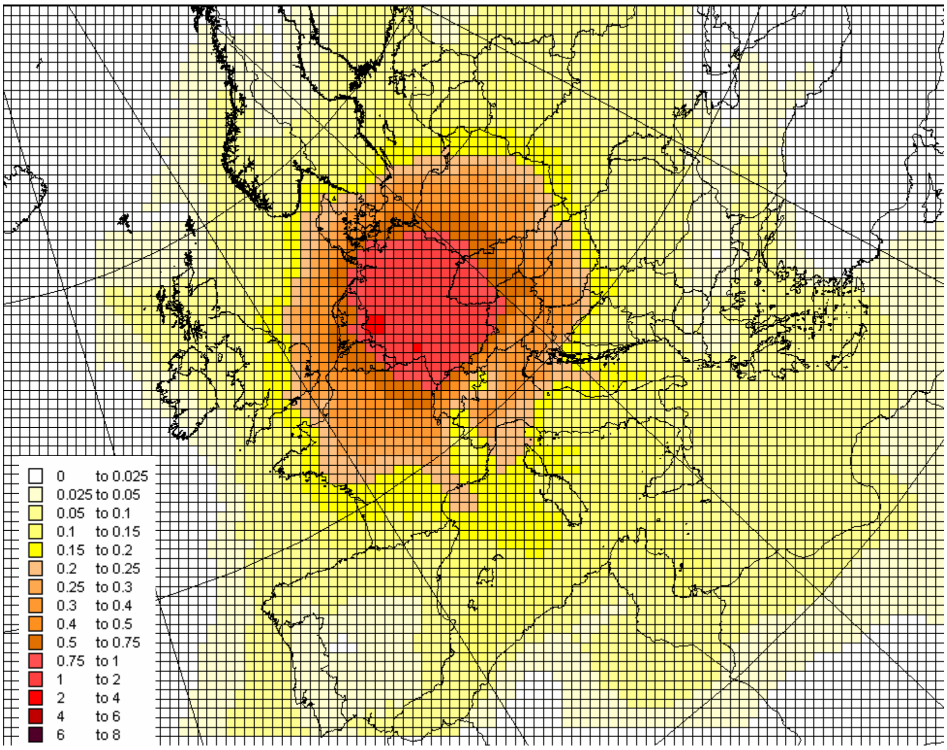


Figure 10 Change In Annual Mean $PM_{2.5}$ Concentration ng/m^3/kt
2020 Base to SO2 Reduction from Land Based Sources in The UK

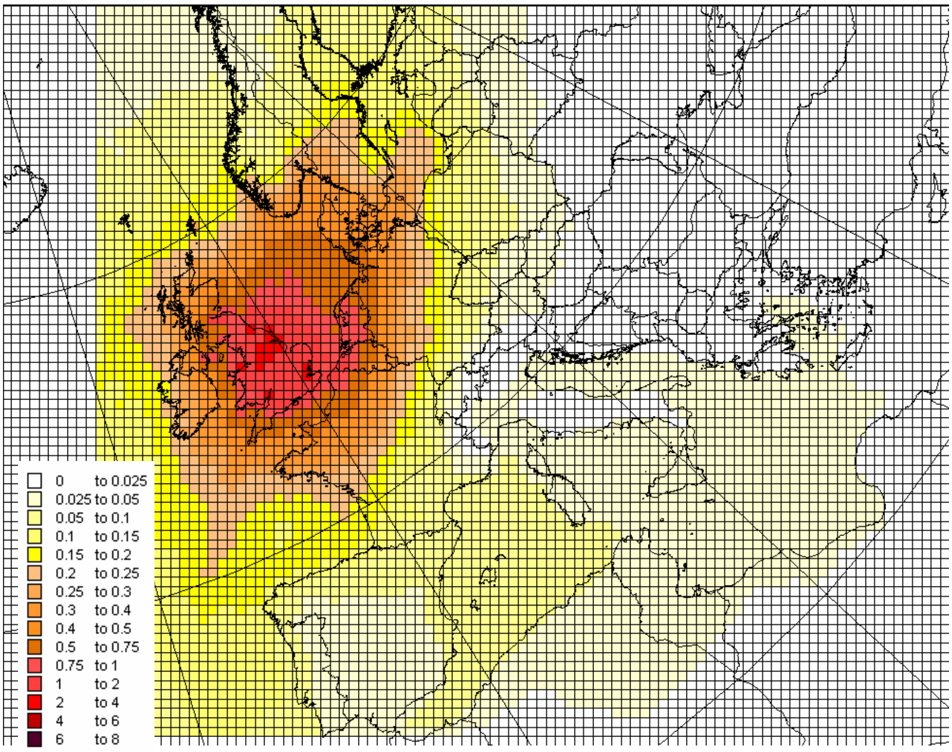


Figure 11 Population Weighted Change in Annual Mean $PM_{2.5}$ Concentration per kilotonne change in SO_2 Emissions over the EU For Various Reduction Scenarios: Results For Each Euro Delta Model (EMEP is Model 3)

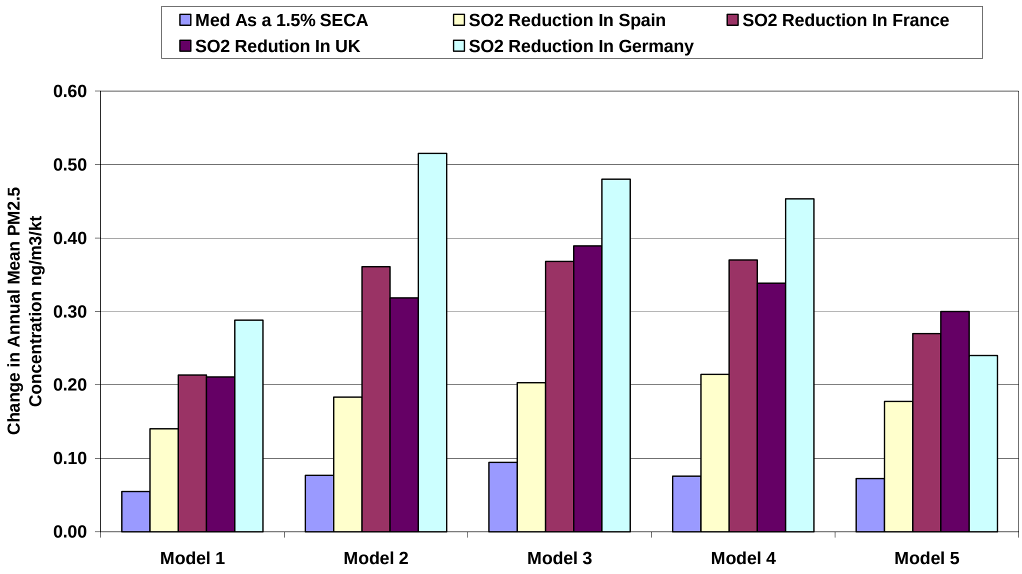


Figure 12 Population Weighted Change in Annual Mean $PM_{2.5}$ Concentration per kilotonne change in NOx Emissions For Various Reduction Scenarios For Each of the Euro Delta Models

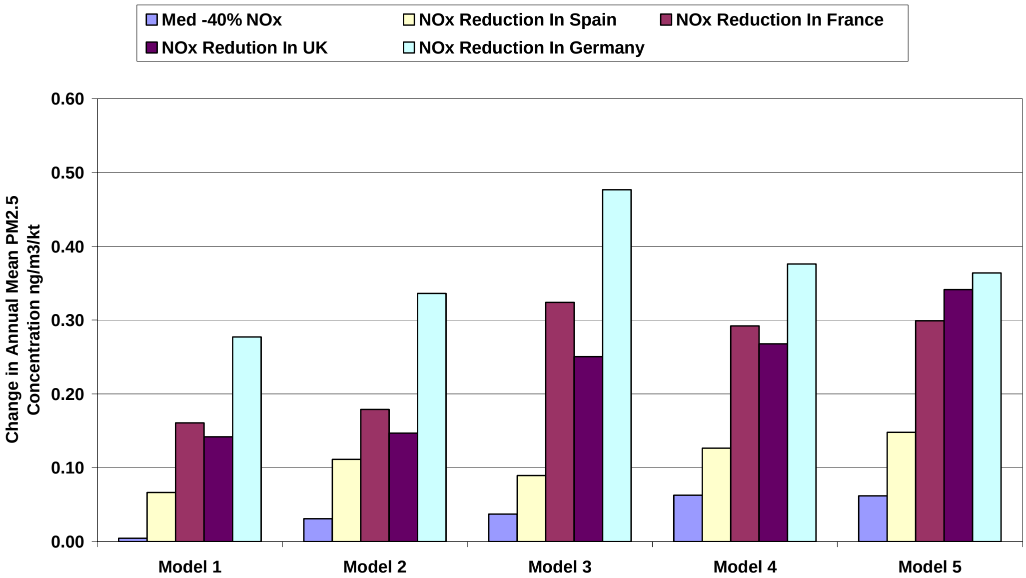


Figure 12 shows the NO_x scenarios comparison. Again while there are differences in the responses from individual models, the general pattern is very similar. Here, with a focus on human exposure to fine particulates, the NO_x emission potency derived from ship operating in the Mediterranean Sea is about 10% of those derived from land based emissions of NO_x in Germany. This implies that for to be cost effective in reducing exposure to fine particulates, NO_x emission abatement measures on Ships in the Mediterranean would need to cost ten times less per tonne of NO_x reduced than land based measures in Germany.

3.3. COMPARISON WITH SOURCE-RECEPTOR RELATIONSHIPS IN RAINS/GAINS

Within the International Institute of Applied Systems Analysis (IIASA), the Centre for Integrated Assessment Modelling (CIAM) maintains, develops and operates the RAINS or GAINS model, an important air pollution policy tool. The model is designed, among other things, to assist in the development of cost-effective strategies for attaining human health and environmental targets in relation to air quality in the EU and larger European region. This "Integrated Assessment Model" incorporates very detailed source-receptor relationships derived from the EMEP trans-boundary model; detailed impact algorithms for both human health and the environment and detailed emission control cost functions (for every country/sea area) into a common integrated framework.

CONCAWE has collaborated on a number of projects with IIASA and has access to the source-receptor functions used in RAINS/GAINS. These functions enable a complete set of "emission potencies" for each of the EU Member States/Sea Areas to be developed, not just for the impact of fine particulates on human health but also for human exposure to ozone, and acidification and eutrophication of EU ecosystems. These relationships have been used in generating **Figures 13** through **19**.

Human Exposure To Fine Particulates:
Figure 13 is a plot of the impact on the EU population as a whole from exposure to fine particulates (derived from SO_2) per kilotonne of SO_2 emissions in various EU countries or sea areas. This "emission potency" metric is very similar to the change in population weighted concentration per unit emission change used to express the results of the Euro Delta scenarios. These impacts are expressed as a percentage of the highest impacting country or sea area.

The relative "potency" of a kilotonne of SO_2 emission in Germany is here seen to be some seven times that of a kilotonne emitted in the Mediterranean which is in good agreement with the Euro Delta results discussed in 3.2 above. It is noteworthy that the relative potency of a kilotonne of SO_2 emitted in the North Sea, an already designated SECA, is some 3-4 times that of the Mediterranean Sea and about half of that of Germany.

Figures 14 and **15** show, in the same way as **Figure 13**, the relative emission potency of a kilotonne of NO_x and Primary $PM_{2.5}$. A similar picture to that for SO_2 is apparent regarding the low potency of emissions derived from the Mediterranean compared to either Germany or the North Sea.

Figure 13 Fine Particulate Impact on EU Population Per Unit of SO2 Emissions Relative To Highest Impact Country

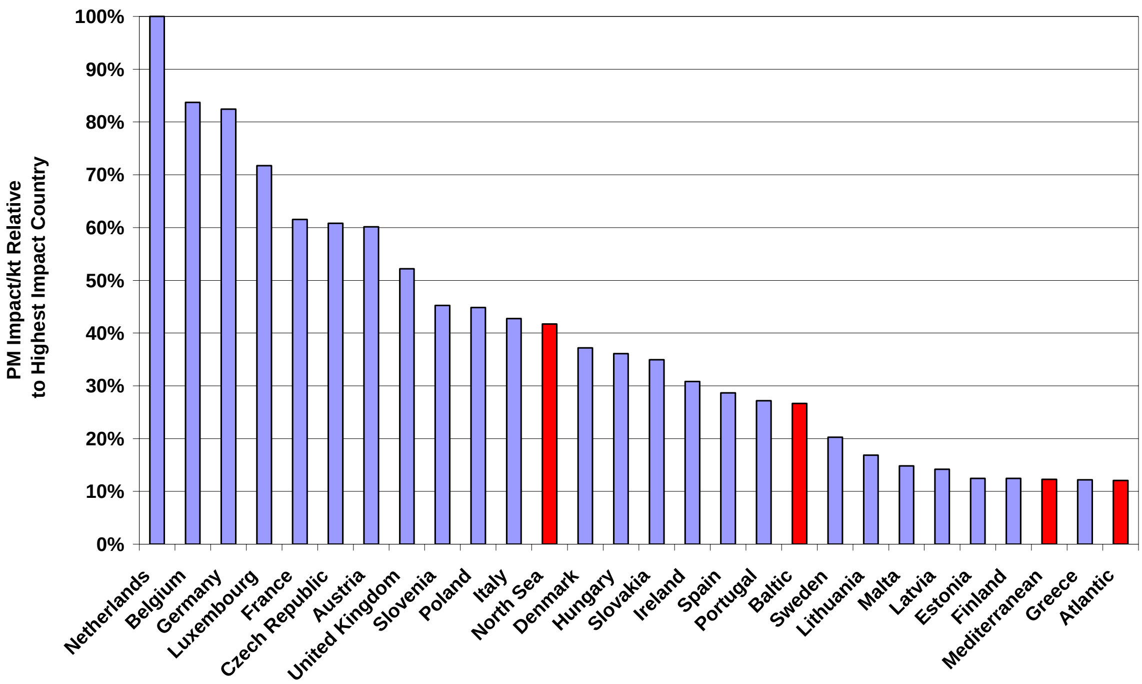


Figure 14 Fine Particulate Impact on EU Population Per Unit of NOx Emissions Relative To Highest Impact Country

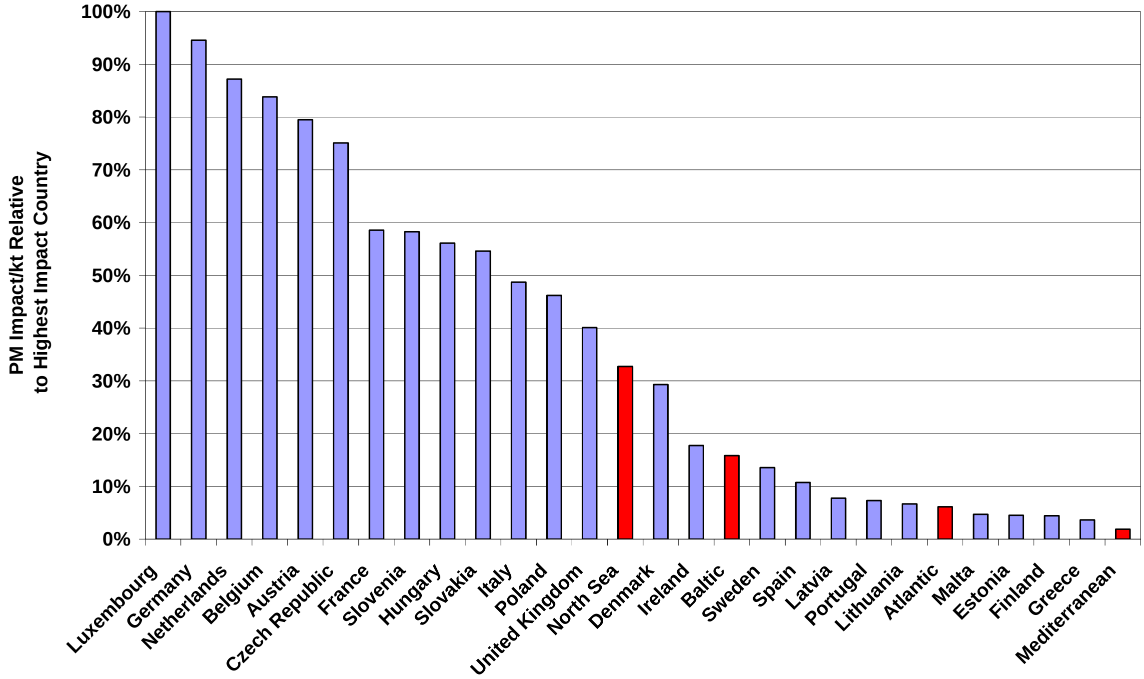
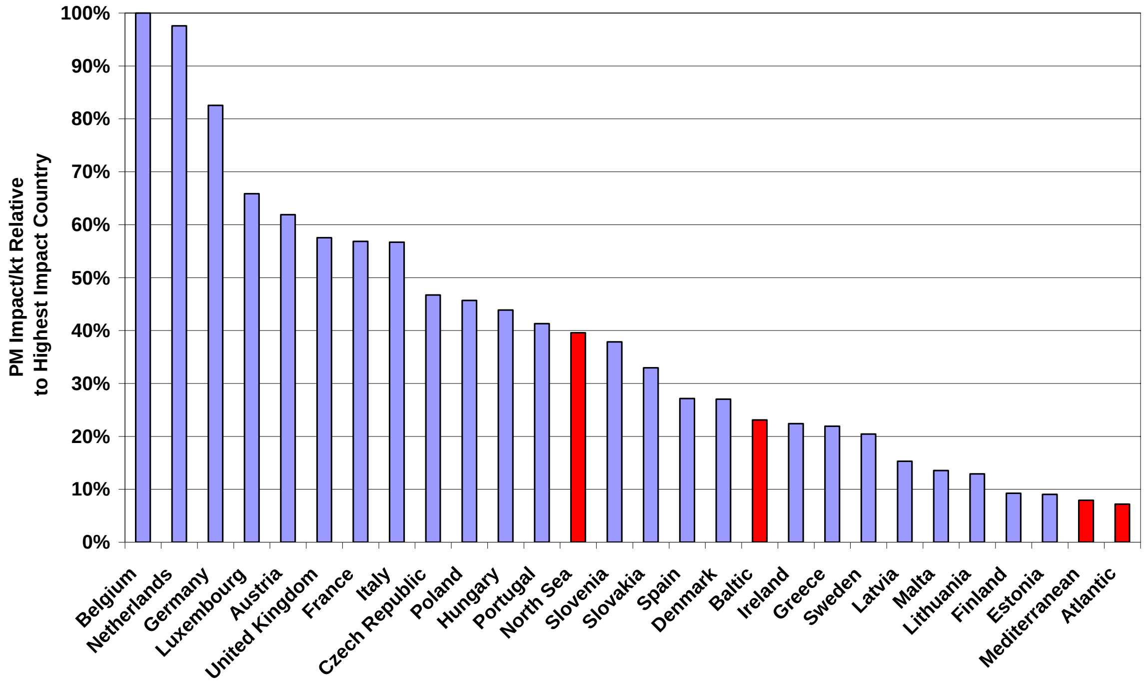


Figure 15 Fine Particulate Impact on EU Population Per Unit of Primary PM2.5 Emissions Relative To Highest Impact Country



Human Exposure To Ozone:
Figure 16 is a plot of the impact on the EU population from exposure to ozone (as generated by NO_x via atmospheric chemistry) per kilotonne of NO_x emissions from various EU countries or sea areas. This "emission potency" metric is based on the ozone metric "SOMO 35[10]". These impacts are again expressed as a percentage of the highest impacting country or sea area.

Figure 16 Ozone Impact on EU Population Per Unit of NOx Emissions Relative To Highest Impact Country

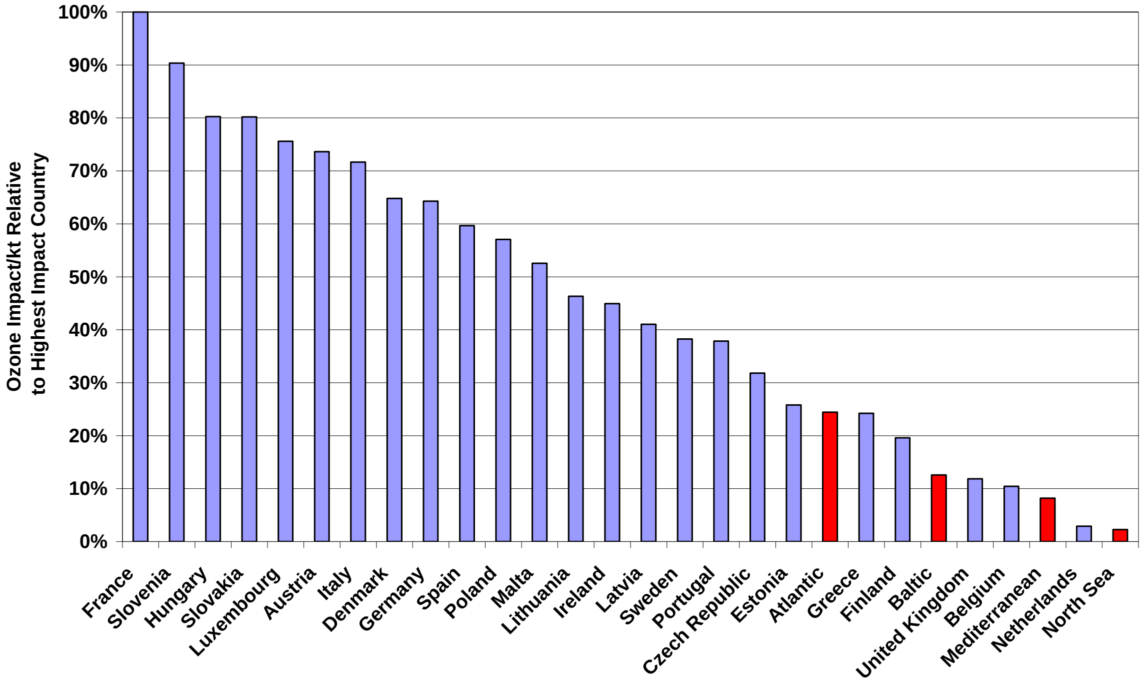
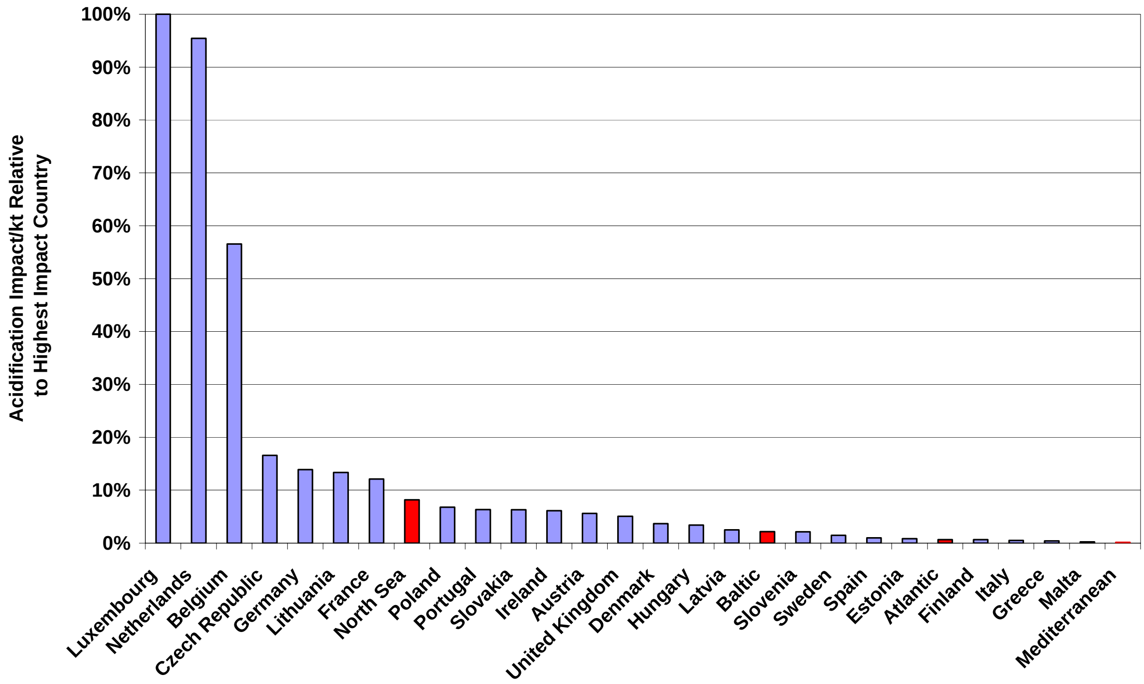


Figure 16 shows that, for the ozone health impact, the emission potency of NO_x from all sea areas is very low compared to NO_x emissions derived from most EU land based sources. For example, the potency of a kilotonne of Mediterranean NO_x emissions is more than ten times lower than a kilotonne of NO_x emitted by land based sources in France.

Most NOx is emitted as NO. When ozone is exposed to high levels of NO in the atmosphere, ozone is destroyed (known as ozone titration) by forming NO_2 and molecular oxygen. This accounts for the very low potency of NO_x emissions from the North Sea, UK, Belgium and The Netherlands. In these areas, the reduction in photochemical ozone formation brought about by reduced NOx emissions is essentially offset in by reduced ozone destruction from the lower levels of NO present in the atmosphere.

[10] SOMO 35 is the sum over the year of maximum daily 8-hour ozone levels over a threshold of 35 ppb. This is the metric used to define the impacts of ozone on human health.

Figure 17 Acidification: Contribution To Exceedances of Critical Loads In EU Per Unit of SO2 Emissions Relative To Highest Impact Country



Exceedances of Acid Critical Loads and Eutrophication Critical Loads in the EU: Figure 17, **18** and **19** show the relative potency of acidifying emissions (SO_2 and NO_x) and eutrophying emissions (NO_x). In the case of acidification, the very low potency of either a unit of SO_2 or NO_x emitted in the Mediterranean Sea relative to land based emissions is very evident. This reflects the long distance of the Mediterranean Sea from those EU land areas that are sensitive to acidification. Again, the picture is very different for acidifying emissions from the North Sea which have potencies close to those of France and Germany and higher than the UK.

In the case of eutrophication (**Figure 19**), a unit of NO_x emissions from either the Mediterranean or Atlantic Sea have the lowest potencies of any land or other sea area. A kilotonne of NO_x emitted from the Mediterranean or Atlantic has 20% of the potency compared to that of Germany and about 30% of that of the North Sea.

Figure 18 Acidification: Contribution To Exceedances of Critical Loads In EU Per Unit of NOx Emissions Relative To Highest Impact Country

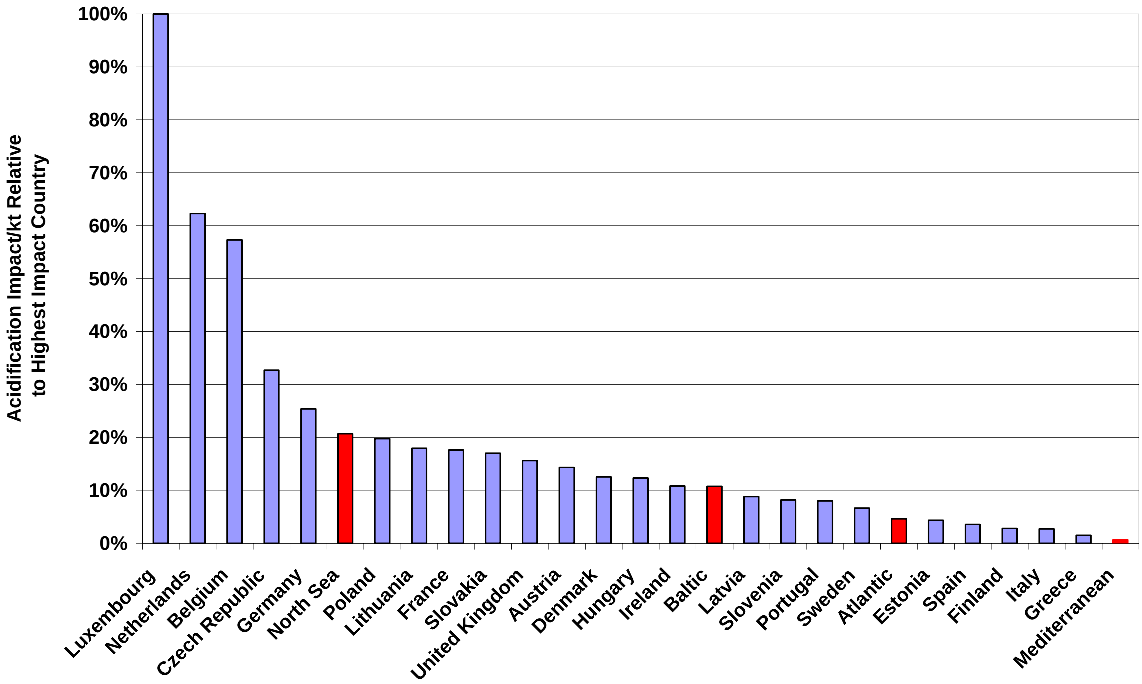
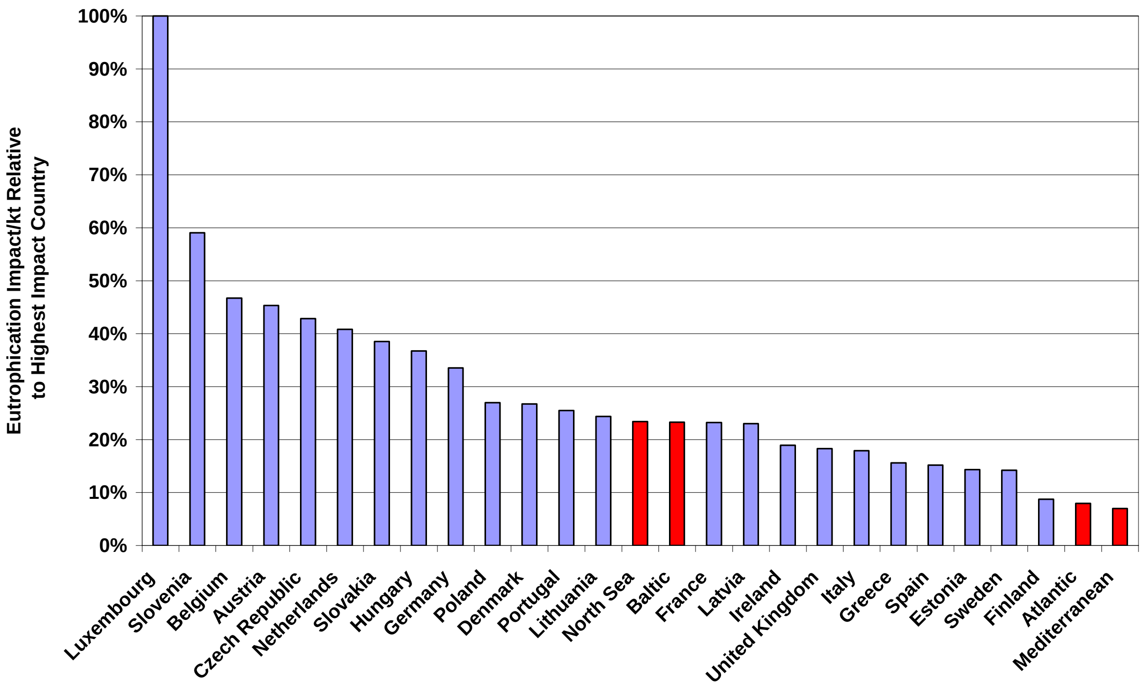


Figure 19 Eutrophication: Contribution To Exceedances of Critical Loads In EU Per Unit of NOx Emissions Relative To Highest Impact Country



4. CONCLUSIONS

The Euro Delta results, together with results derived from the source-receptor functions used in the RAINS/GAINS model clearly demonstrate the importance of the proximity of emissions to sensitive receptors. “Emission potencies” (impact per unit of emission), provide a clear perspective on the relative cost effectiveness of emission reductions and vary significantly depending on the proximity of the emitter to a sensitive receptor.

The detailed Euro Delta results from the Mediterranean and land based scenarios, , indicate that, for the Mediterranean Sea as a whole, the emission potencies for exposure of EU populations to fine particulates are significantly lower (by factors of about five) than emissions from land based sources. Only for “adjacent to shore” Mediterranean Sea scenarios (for example 0.1% sulphur limit alongside at berth) do the emission reduction potencies approach those of land based measures. This has important implications for the development of cost-effective abatement strategies.

The additional insights provided by the source-receptor relationships used within the RAINS/GAINS model confirm the findings of the Euro Delta project. In addition they demonstrate that the situation in the Mediterranean is starkly different to that of the North Sea or Baltic Sea. In these latter cases emission potencies are often similar to those of land based sources (e.g. Germany and the UK).

The source receptor functions also confirm that for other impacts (e.g. ozone impacts on human health; acidification and eutrophication), the potency of contributing emissions from the Mediterranean Sea is also very low (a factor of about ten) compared to land based sources and the emissions from shipping in the North Sea and Baltic.

5. REFERENCES

1. EU (2005) Directive 2005/33/EC of the European Parliament and of the Council of 6 July 2005 amending Directive 1999/32/EC as regards the sulphur content of marine fuels. Official Journal of the European Communities No. L191, 22.07.2005

2. Entec (2007) Database tool and ship emission inventory for CONCAWE: Ship emissions inventory – Mediterranean Sea. London: Entec UK Ltd (http://www.entecuk.com/index.html)

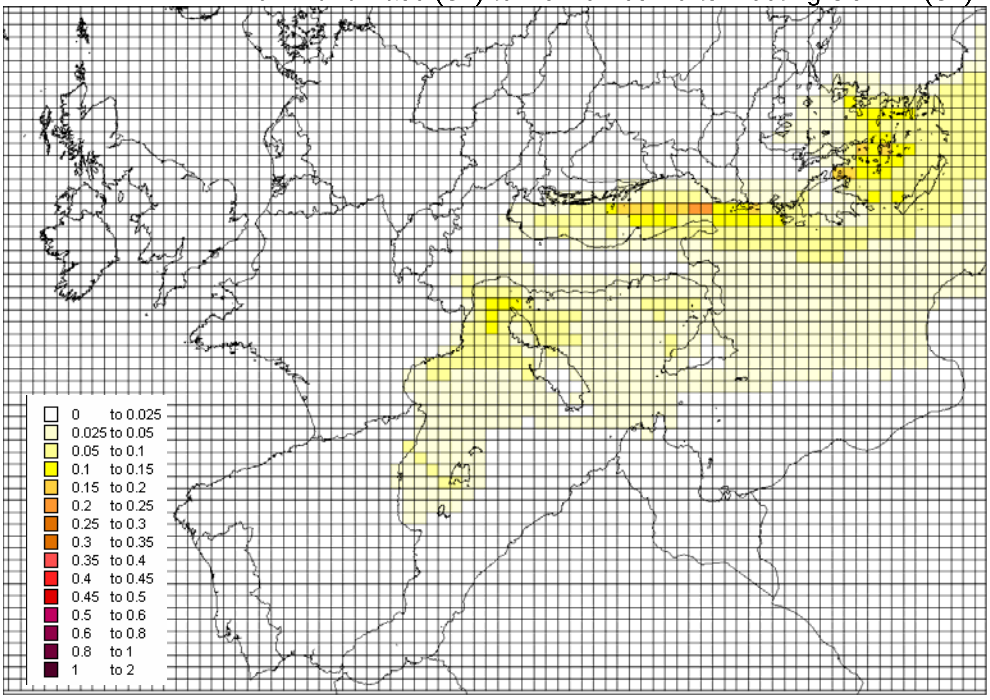
APPENDIX I: MAPS OF ABSOLUTE CHANGE IN CONCENTRATION FOR SCENARIOS EXPLORED

The following maps correspond to the series of “potency maps” discussed in section 3 but here the “absolute concentration changes” for each scenario explored are shown. For ready comparisons between the scenarios represented in each map, the same scale has been retained throughout. The absolute changes in $PM_{2.5}$ concentrations depicted in these maps should be seen in the context of the $PM_{2.5}$ annual mean limit value in the European Ambient Air Quality Directive, as proposed by the European Commission, of 25µg/m^3. For further comparison, in each case the change in SO_2 emissions for the given scenario is shown at the bottom of each map.

To illustrate, a comparison of **Figure A2** (the effect of the 2010 port requirements) with A4 (the “beyond 12 miles Mediterranean SECA” scenario) shows that the peak change in concentrations on the land grids bordering the Mediterranean Sea higher in the former case despite the much smaller emission change (44 versus 322 kt/a).

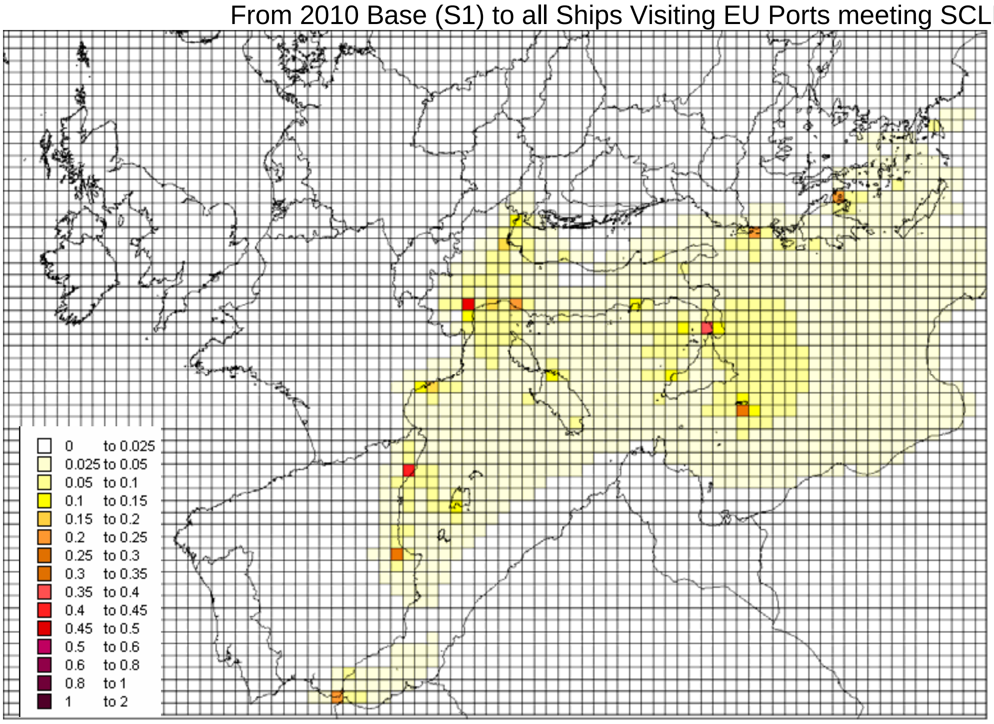
Similarly, Comparison of **Figure A3** (“12 mile Mediterranean SECA”) with A6 (Land Based SO_2 emission reduction in Spain) shows the more widespread/larger reductions in concentrations resulting from the land based reductions despite the lower SO_2 reduction involved (97 versus 126 kt/a).

Figure A1 Change in Annual Mean $PM_{2.5}$ Concentration µg/m^3
From 2010 Base (S1) to EU Ferries Ports meeting SCLFD (S2)



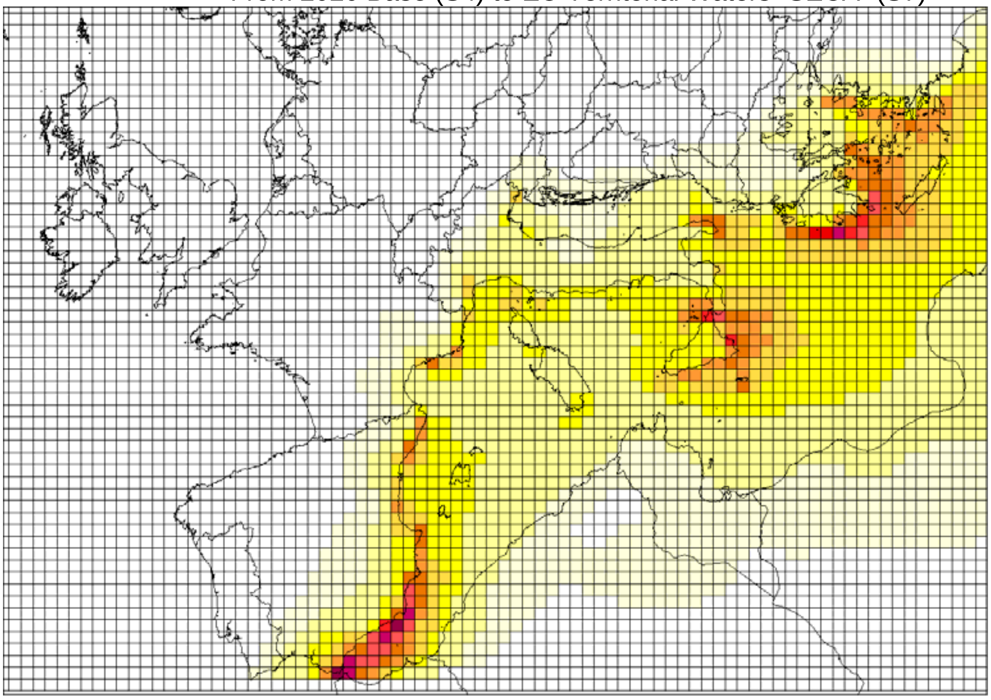
Change in SO2 Emissions: 36 kt/y

Figure A2 Change In Annual Mean $PM_{2.5}$ Concentration µg/m^3
From 2010 Base (S1) to all Ships Visiting EU Ports meeting SCLFD (S3)



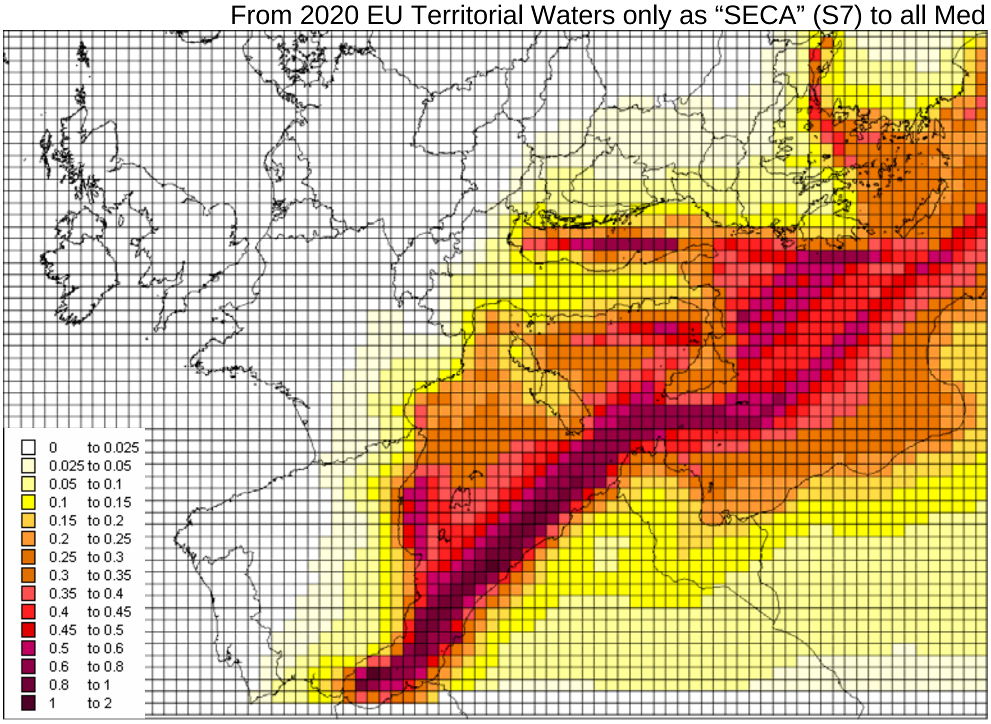
Change in SO2 Emissions: 44 kt/y

Figure A3 Change in Annual Mean $PM_{2.5}$ Concentration µg/m^3
From 2020 Base (S4) to EU Territorial Waters "SECA" (S7)



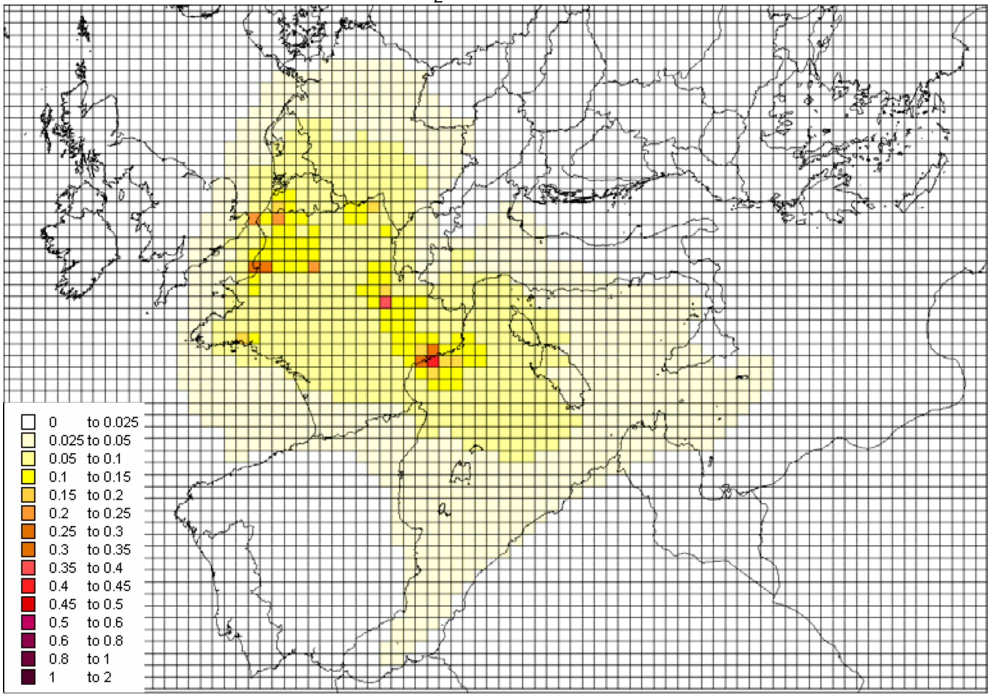
Change in SO2 Emissions: 126 kt/y

Figure A4 Change In Annual Mean $PM_{2.5}$ Concentration µg/m^3
From 2020 EU Territorial Waters only as "SECA" (S7) to all Med SECA (S6)



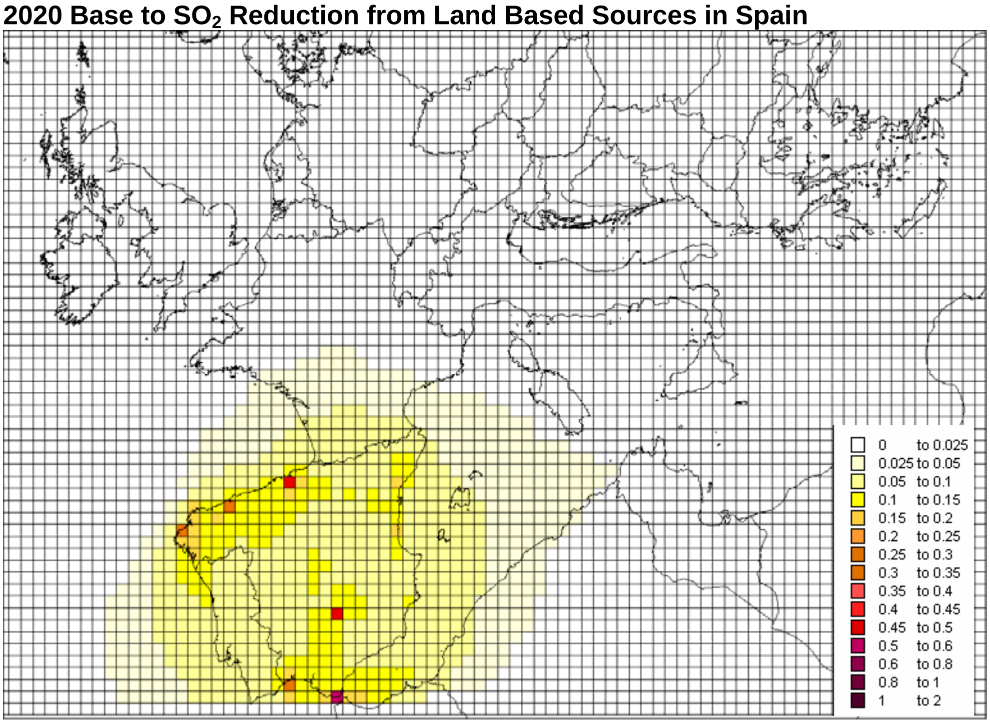
Change in SO2 Emissions: 322 kt/y

Figure A5 Change in Annual Mean $PM_{2.5}$ Concentration µg/m^3
2020 Base to SO_2 Reduction from Land Based Sources in France



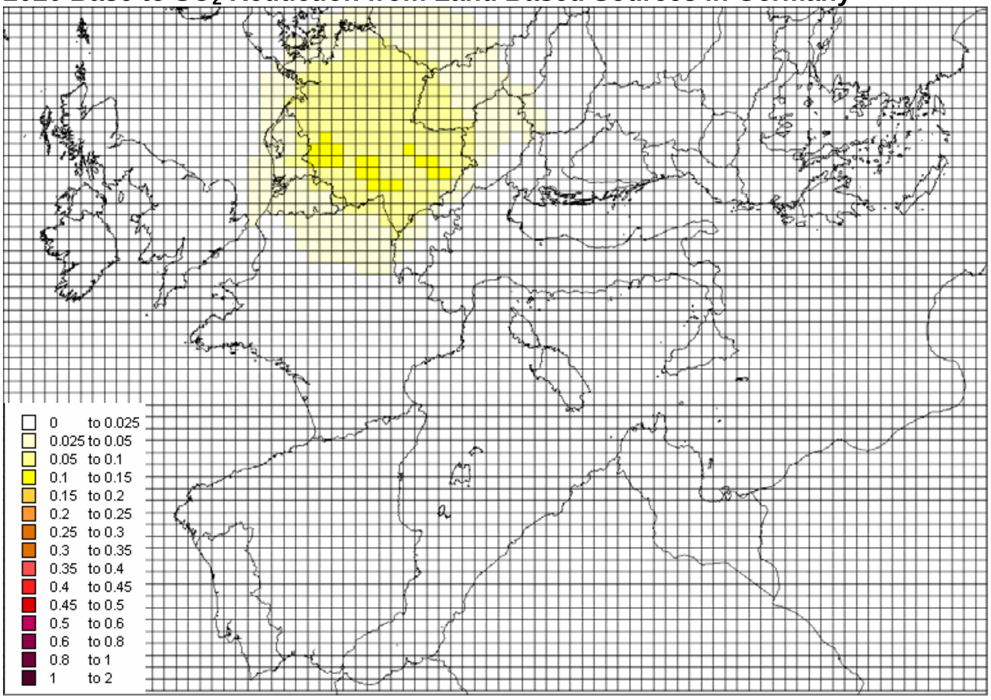
Change in SO2 Emissions: 110 kt/y

Figure A6 Change In Annual Mean $PM_{2.5}$ Concentration µg/m^3
2020 Base to SO_2 Reduction from Land Based Sources in Spain



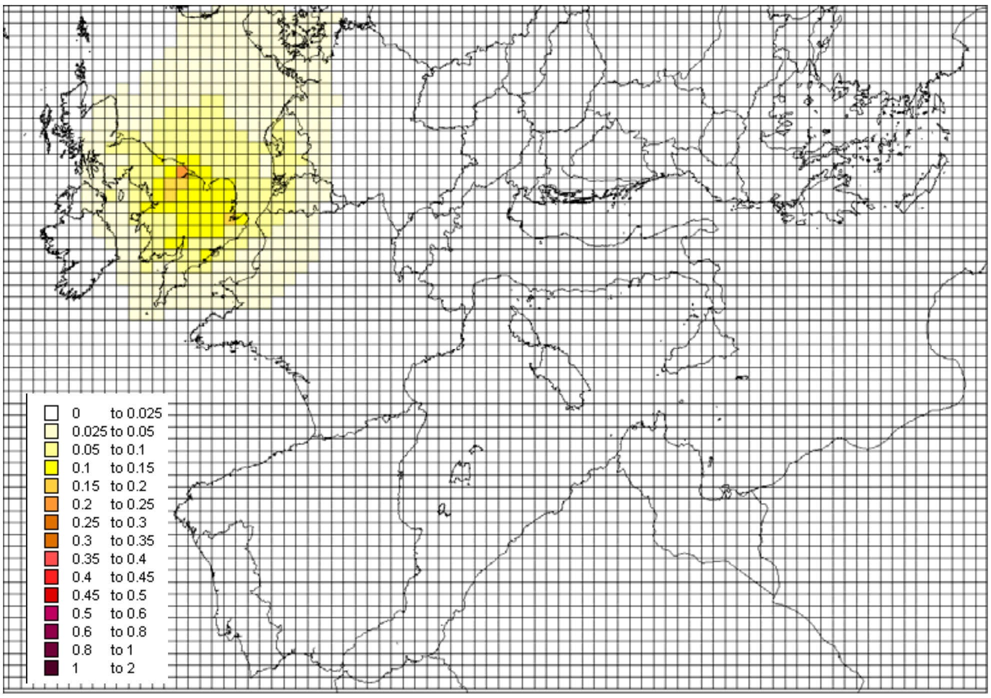
Change in SO2 Emissions: 97 kt/y

Figure A7 Change in Annual Mean $PM_{2.5}$ Concentration µg/m^3
2020 Base to SO_2 Reduction from Land Based Sources in Germany



Change in SO2 Emissions: 60 kt/y

Figure A8 Change In Annual Mean $PM_{2.5}$ Concentration µg/m^3
2020 Base to SO_2 Reduction from Land Based Sources in The UK



Change in SO2 Emissions: 65 kt/y